Rethinking Learning in the Digital Age. Making the Learning Sciences Count Volume 2

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Preface

The International Conference of the Learning Sciences (ICLS) is a major international event, organized biennially by the International Society of the Learning Sciences (ISLS): a professional society dedicated to the interdisciplinary empirical investigation of learning as it exists in real-world settings and to how learning may be facilitated both with and without technology. The international and interdisciplinary field of the Learning Sciences brings together researchers from the fields of cognitive science, educational research, psychology, computer science, artificial intelligence, information sciences, anthropology, sociology, neurosciences, and other fields to study learning in a wide variety of formal and informal contexts (see www.isls.org). The field emerged in the late 1980s and early 1990s, with the first ICLS held in 1991 at Northwestern University in Evanston, Illinois, USA. Subsequent meetings of ICLS were held again in Evanston, USA (1996), Atlanta, GA, USA (1998), Ann Arbor, MI, USA (2000), Seattle, WA, USA (2002), Santa Monica, CA, USA (2004), Bloomington, IN, USA (2006), Utrecht, the Netherlands (2008), Chicago, IL, USA (2010), Sydney, NSW, Australia (2012), and Boulder, CO, USA (2014) and National Institute of Education, Nanyang Technological University of Singapore (2016).

A bumper crop of 965 submissions for ICLS 2018 were received in December 2017 (571 were received at the last ICLS Conference ion 2016). All submissions went through a process of rigorous peer review. The acceptance rate was 32% for full papers, 27% for short papers and 33% for posters. 110 of the full papers and 61 of the short papers were accepted as posters. For symposia, the acceptance rate was also 32%. At least three reviewers were recruited for each paper and a member of the Programme Committee provided a metareview. The Programme Chairs made decisions, based on reading every review, metareview and the online discussion.

This meant that over 3000 reviews were completed by the ICLS community – many, many thanks. We are particularly indebted to the committee members and reviewers who responded to the call for volunteers to manage extra papers. We especially note those who managed at least 9 papers and those reviewers who responded so generously to calls for additional reviews: we could not have completed the selection process without you.

The UCL Institute of Education, London, is hosting the 13th International Conference of the Learning Sciences (ICLS), 2018, from June 23rd to 27th, 2018. It is a right and fitting venue to host the 13th International Conference of the Learning Sciences (ICLS). UCL Institute of Education (IOE) was founded in 1902, and is a world-leading centre for research and teaching in social science and education. For three successive years (2014, 2015, 2016 and 2017), the Institute has been ranked first for education worldwide in the QS World University Rankings, and was shortlisted for the ‘University of the Year’ title in the 2014 Times Higher Education (THE) awards. In January 2014, Ofsted judged it to be ‘outstanding’ in every category for initial teacher training across primary, secondary and further education programmes. In the most recent Research Excellence Framework, 94% of the IOE’s research was judged to be world class. In 2016, it was awarded the Queen’s Anniversary Prize for Higher and Further Education, for its innovative social research and contribution to policy and practice in education. The IOE currently has more than 8,000 students, 800 staff, and attracts students from over a hundred countries around the world. Since December 2014, it has been a school of University College London, formally called the UCL Institute of Education. University College London (UCL) was founded in 1826, and was the first English university established after Oxford and Cambridge, the first to admit students regardless of race, class, religion or gender, and the first to provide systematic teaching of law, architecture and medicine. We are among the world's top universities, as reflected by performance in a range of international rankings and tables. UCL currently has over 35,000 students from 150 countries and over 11,000 employees.

The theme for this year’s conference is Rethinking learning in the digital age: Making the Learning Sciences Count. This reflects the fact that now, more than ever, the learning sciences have a key role to play in unpacking the complexity of the teaching and learning process. AI and Automation in the workplace, including within education, will alter what we need to learn and how we need to teach it. Therefore, as scientists and educators we need to explore learning in real-world settings in an interdisciplinary manner in order to understand how learning may be facilitated both with and without technology.

For the first time this year we also welcomed Crossover paper submissions to reflect the fact that ICLS 2018 is co-located with L@S and AIED, as part of the London Festival of Learning. Ten papers were accepted (acceptance rate 30%). These papers appeal to a broad audience of researchers from across the communities of the three conferences. The London Festival of Learning is a unique opportunity to bring together world experts in artificial intelligence in education, the learning sciences and technical innovations in education. There has never been a more important time for these three disciplines to meet and overlap, uniting academics to share their research and learn from each other, as well as engaging with a wider audience of educators, businesses and
learners. The Festival of Learning also offers an opportunity to showcase the important work being done by UCL IOE’s EDUCATE programme in promoting the best in EdTech development currently taking place in the UK.

We hope you will enjoy what promises to be a week of fascinating debate, discussion and international networking.

Judy Kay, Human Centred Technology Research, University of Sydney, Australia
Rosemary Luckin, UCL Knowledge Lab, UCL Institute of Education, UK
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A New Approach to Lesson Study Practice in Japan
from the DBIR Perspective

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Abstract: We report our progress in developing continuous improvement for educational practices in a local school district in Japan. Utilizing design-based implementation research (DBIR) design principles, we started to identify a focus for joint work with a school. After three years of searching for and identifying a focus for joint work (development and evaluation of student collaboration skills), a teacher and researchers started collaborative DBIR research practice as a new lesson study using a new evaluation tool, socio-semantic network analysis of student discourse. In addition to an ordinary post-lesson colloquium, we performed a second post-lesson colloquium that combined researchers’ discourse analysis with teacher observations and evaluations to share and discuss. The second post-lesson colloquium was found to significantly facilitate comprehension of how students engaged in student learning.

Keywords: design-based implementation research, lesson study, socio-semantic network analysis, post-lesson colloquium

Background and research purpose
Design-based research (DBR) is now widely pervasive (Barab & Squire, 2004; Sandoval & Bell, 2004), but we sometimes experience communication breakdowns between practitioners and researchers in Japan. This might be due to the unique historical background of lesson study practice in Japanese teacher communities. There, lesson study is an established professional development practice in which teachers exchange ideas for improving classroom lessons, share lesson plan documents, act out lessons for their colleagues to observe, and discuss and analyze how lessons should proceed based on lesson plans across a variety of scales, from individual schools to national events (Lewis, Perry, & Murata, 2006). On the surface, lesson study practice is very similar to DBR in that it takes PDCA (plan–do–check–act) steps. However, practitioners and researchers approach educational practices from different perspectives. First, teachers are more concerned with localized how-to and know-why knowledge, whereas researchers are more interested in the transferability of practitioners’ knowledge (Bereiter, 2014). Second, teachers do not necessarily have epistemic beliefs for the knowledge society regarding their teaching (Oshima et al., 2006), most of which are not related to new perspectives of learning as knowledge creation (Paavola & Hakkarainen, 2005). To bridge the gap between practitioners and researchers in educational practice, we applied an interventionist approach (Penuel, Cole, & O’Neill, 2016) from the perspective of design-based implementation research (DBIR) (Fishman et al., 2013; Penuel et al., 2011) to design the lesson study for facilitating teachers’ comprehension of student engagement in their collaboration by using a new evaluation technology.

An interventionist approach to lesson study in Japan
DBIR studies (e.g., Fishman et al., 2013; Penuel et al., 2011) propose four design principles for the sustainable improvement of educational practices at scale. First, a DBIR team should form around a focus on persistent problems from multiple stakeholder perspectives. Our DBIR team comprised teachers, a principal, a member from the district’s educational department, and researchers like us. The team was formed at the request of the district’s educational department for school reform to bring our learning sciences expertise into classroom practices. Before starting our lesson study practice with teachers, we visited the school several times to observe and discuss their practices. Through discussions with the principal and teachers, we extracted two problems. One problem was that instructional goals were based on national curriculum guidelines. Although every school is obliged to follow these guidelines, doing so is sometimes not feasible when students have standardized scores below 40 for knowledge corresponding to their grade level. Researchers provided teachers with the concept of learner-centered approaches, and decided to start lessons by setting a level of expertise that students could build on. Another challenging problem was new assessments that appropriately evaluate improvement in students’ collaboration skills and their conceptual understanding of the study topic. Standardized tests do not capture fine improvements in student expertise during collaboration. Test scores did not correspond with teacher
assessments of their students’ understanding. To solve this problem, we proposed the use of video-based analysis and a socio-semantic network analysis of students’ discourse that we developed (Oshima, Oshima, & Matsuzawa, 2012).

Second, our team committed to iterative and collaborative design. Our collaborating school had engaged in the iterative cycle of their lesson study before we began the collaboration. We further implemented know-why (theoretical) knowledge of how to design lessons by using jigsaw instruction. More specifically, we introduced the concept of constructive interaction (Miyake, 1986) for designing expert group activities. Even when students tackle the same content, they can bring different perspectives to the materials. Differences in student perspectives constructively induce interaction. We discussed how to design study documents and worksheets so that every student could contribute new perspectives. In jigsaw activities, where students having studied different materials gather and collaboratively integrate knowledge sources, students are supposed to engage in productive interaction across multiple zones of proximal development (ZPD) depending on the knowledge sources examined (e.g., Brown & Campione, 1996). To facilitate interactions across multiple ZPDs, we examined how study materials in the expert group would interact to help students come up with ideas for forest management.

Third, we were concerned with developing theory and knowledge related to both classroom learning and implementation through systematic inquiry. To develop theoretical knowledge related to classroom learning, we decided to implement a new assessment technology, socio-semantic network analysis (SSNA) of discourse (Oshima et al., 2012). SSNA was used in this study as an assessment tool for researchers to analyze student discourses during jigsaw group activities, then provide teachers and other stakeholders with feedback on how they engaged in collective knowledge advancement. (We discuss SSNA in more detail in the “Lesson Study from the DBIR Perspective” section). Furthermore, through implementation of the new assessment tool for student discourse, we revised our lesson study practice by having another post-lesson colloquium a month after the ordinary post-lesson colloquium conducted on the research lesson day. The two post-lesson colloquia were expected to facilitate our scrutiny of research lessons from multiple stakeholders’ perspectives and to enable more systemic inquiry.

Finally, we were also concerned with developing capacity for sustaining systemic change. The education department provided funding of seven million yen (about US$60,000) to renovate infrastructure and to purchase information and communications technology such as iPads for students to use during inquiry-based learning. We discussed with teachers and the principal how they wished to renovate their learning environment, and coordinated the construction and purchase processes. The educational department asked us to additionally coordinate renovation of the learning environment at a high-performance school, to implement what they called “sandwiching” tactics. That is, they thought that if we succeeded in reforming both high- and low-performing schools, other schools might be more interested in similar reforms.

Lesson study from DBIR perspective

Purpose of the lesson study in DBIR
The lesson study practice reported in this study was a sub-component of our DBIR project with highest- and lowest-performing high schools. In both schools, we collaborated with teachers of different subjects. The high-performing school was a top-quality college preparatory school. Most graduates go on to colleges or universities after graduation. The low-performing school was an industrial high school for agriculture and forestry students with low learning skills and motivation. The educational department requested that the researchers help both schools establish new learning cultures based on the idea of 21st-century skills (Griffin, McGraw, & Care, 2012). To begin, the educational department decided to encourage schools to implement jigsaw instruction as a collaborative learning method. Our mission in lesson studies at the two high schools was to create a new style of learning activity that applies students’ prior knowledge and expertise to improve jigsaw instruction. We previously reported our progress in developing a learning culture at the prep school at CSCL 2015 and 2017 (Oshima et al., 2015, 2017). In this paper, we report on progress in our collaborative lesson study at the agricultural and forestry high school.

Research lesson
The study topic was forest management. Seven twelfth-grade students had engaged in extensive forestry studies and had managed practical forest divisions for three years. The instructional goal was understanding how to manage forests in consideration of their carbon fixation function. During 50-min class periods, expert group students were divided into three groups to study 1) determining the size of their practical forests using a digital planimeter, 2) figuring out how much carbon dioxide per hectare is fixed by trees of different ages by examining
a graph, or 3) calculating how many trees are needed to fix the amount of carbon dioxide produced by a person in Japan by examining a table of tree volumes and carbon fixation amounts. In jigsaw group activities during the next class period, students from different expert groups were grouped to exchange ideas and integrate knowledge regarding how forest divisions should be managed to maximize carbon dioxide fixation. Student activities were video recorded using 360-degree cameras and microphones, and their discourses were transcribed for SSNA.

**Figure 1.** Participatory structure of the jigsaw instruction.

**Socio-Semantic Network Analysis as a new assessment tool for teachers and researchers to share and examine student discourse**

In the computer-supported collaborative learning research (CSCL) field, there have been discussions on the advantages of using social network analysis (SNA) to investigate collective knowledge advancement (e.g., Martinez et al. 2003; Reuven et al. 2003). De Laat et al. (2007) proposed an approach to synthesizing and extending comprehension of CSCL teaching and learning processes to balance SNA, content analysis, and critical event recall. In the complementary approach, SNA was used to study interaction patterns within a learning community in the network, and to study how participants share and construct their knowledge. De Laat et al. (2007) concluded that the inclusion of SNA in any multi-method approach is advantageous, because it provides researchers and learners with tools for illustrating comprehension and cohesion of group activities, as well as providing researchers a method for selecting appropriate groups to study. For instance, to analyze student collective knowledge-building in Knowledge Forum, Zhang et al. (2009) implemented a complementary approach that used SNA to visualize and compare classroom collaboration among fourth-grade elementary school students over three years. An analysis of online participatory patterns and knowledge advancement indicated that this learning process effectively facilitated knowledge advancement through critical changes in organizations within the classroom, from fixed small groups in the first year of the study to appropriate collaboration through the dynamic formation of small teams based on emergent goals.

Based on those preceding studies, we extended the potential of SNA by developing a different type of network, the socio-semantic network. Ordinary SNA illustrates the social patterns of learners. As de Laat et al. (2007) suggested, this approach is thus informative when examining developments or changes in the participatory structure of a community. However, several studies have argued that existing social network models cannot examine how collective knowledge advances through learner collaboration (Oshima et al., 2012; Schaffer et al., 2009). Instead, we proposed a procedure similar to ordinary SNA but with a different type of social network, one based on the words learners use in their discourses. Figure 2 shows the interface of a SSNA tool called Knowledge Building Discourse Explorer (KBDeX) (Oshima et al., 2012). Discourse datasets in CSV
format can be input into KBDeX and analyzed by visualizing a socio-semantic network of vocabulary of researcher concern. In addition to visualization of the socio-semantic network, KBDeX also provides researchers with several metrics of network structures, such as centralities. The visualization of student discourse, a socio-semantic network of vocabulary in particular would help practitioners to examine how students collaborate from the perspective of collective knowledge advancement.

In their ordinary post-lesson colloquium after the research lesson, practitioners discuss how the lesson unfolded by relying only on observation notes. They also sometimes use video data, but such use is not systematic and shows certain points of discourse or activities that they consider as important for reflection. Computational analysis tools like KBDeX would further extend practitioners’ reflections in post-lesson colloquia as follows. First, they can easily view and compare total processes of student discourse between groups. When practitioners examine the discourse process of a given group, they can stop the visualization and freely review what happened during collaboration, rewinding to the original discourse and conducting brief conversation analysis. After examining all groups, they can be categorized into cohorts representing specific interaction patterns. Practitioners can also examine student contributions to collective knowledge advancement through discourse by discarding exchanges from the discourse datasets to reveal changes in the vocabulary network structure. Significant structural changes are characteristic of significant student contributions.

In ordinary lesson study, teachers conduct a post-lesson colloquium on the same day as the research lesson. In our DBIR lesson study, we added a second post-lesson colloquium in which researchers used SSNA to analyze student discourse in the jigsaw group and to give teachers feedback regarding researcher findings for comparison with teacher reflections in the first post-lesson colloquium. Colloquia were video recorded and transcribed. Here, we report on researchers’ SSNA analysis of student discourse and how findings compared with teachers’ reflections in the first post-lesson colloquium to develop new ideas for improving lesson plans for the next year.

**SSNA of student discourse in jigsaw group activities**
To examine how students in the jigsaw group activities engaged in collective knowledge advancement, we selected a list of vocabulary related to the materials studied in the expert groups and visualized the selected vocabulary network of their discourse (Figures 3 and 4). Each visualization shows how a student contributed to collective knowledge advancement. Red nodes in the visualization represent vocabulary terms used by the student.

In both groups, student discourses were visualized as well-structured vocabulary network. Most words representing three expert-group documents were used in the discourses and interconnected. However, when we
examined how many words each student used and which expert documents the words came from, differences in student contributions between the groups were revealed. Our analysis suggested that jigsaw group 1 better advanced collective knowledge than did group 2. This finding contradicted teacher reflections in the first post-lesson colloquium. In jigsaw group 1, students used many words from all the three expert group documents in their discourse. This revealed that student contributions to collective knowledge advancement were distributed and overlapped among students, who attempted to link their ideas with others from their expert perspective. In contrast, one student (2c) in jigsaw group 2 took the lead in integrating different pieces of knowledge, followed by two other students (2a and 2b). The fourth student (2d) used a single word related to his expert group document but did not contribute at all. The teacher evaluated student 1a and 2a as unmotivated ones based on his classroom practices (“They do not like to pay attention to the study topic, instead playing games on their smartphones during class.”), but our SSNA found that they played important roles in integrating different pieces of knowledge from expert documents. The results of our SSNA suggested that these learners did not meet teacher expectations. Rather, they contributed to collective knowledge advancement by making utterances that linked different ideas or helped others to do so.

Figure 3. Socio-semantic network of vocabulary in a jigsaw activity by group 1.

Figure 4. Socio-semantic network of vocabulary in a jigsaw activity by group 2.

Teacher reflections on student learning based on observations and SSNA at post-lesson colloquia
We conducted the second post-lesson colloquium one month after the research lesson. At the second post-lesson colloquium, researchers first explained their analysis of student discourse in jigsaw group activities, then accepted questions from practitioners. We as researchers demonstrated visualization of student discourse from beginning to end. We then summarized our SSNA results as described in the previous section. When the research lesson teacher saw the vocabulary network visualized for jigsaw group 2 compared with group 1, he recognized that advancement by group 1 exceeded that of group 2. This awareness led him to ask the researchers to demonstrate in detail how group 1 engaged in their discourse. Researchers ran KBDEx to visualize time-serial changes in vocabulary network structure, stopping at times of critical change. We discussed how each student in group 1 contributed to collective knowledge advancement by looking back at the original transcript and video.

During the second post-lesson colloquium, teachers and researchers could come up with issues for further research lessons. First, we need to redesign the lesson plan so that student contributions during group activities might be more democratized. The remarkable difference in student contributions to their collective discourse in KBDx demonstrated that the jigsaw participatory structure was insufficient for supporting students in productive collaboration for knowledge creation. Further instructional intervention (namely, scaffolding) should be implemented. We decided to further modify the expert group documents and the jigsaw group activity worksheet in order to democratize student contributions. Second, teachers realized that student motivation was not innate, but rather resulted from interaction with the environment. SSNA clearly showed that typically “unmotivated” students productively engaged in collaboration though discourse. The research lesson teacher was highly interested in what motivated students to work on the study topic in the research lesson. The researchers were asked to provide a detailed analysis of discourse to allow specification of possible factors for motivation and lesson plan redesign based on the analysis.

Discussion
We started our DBIR by searching for and deciding on a focus for joint work with teachers and the school. We spent three years identifying the focus for joint work, development of collaboration skills as an instructional goal, and implementation of a tool (SSNA) for evaluating changes in student discourse at finer granularity. In this paper, we reported on how we designed a new lesson study practice using DBIR as an extension of teachers’ original practices. Here, we discuss how our interventionist approach would make our collaboration sustainable in the future.

First, we did not have to introduce completely new ideas for lesson plans. Teachers at the school had already started lesson study for jigsaw instruction. What we attempted was to help them to examine their instruction and lesson plans from a perspective of learning as knowledge creation, that is, how students engage in collective knowledge advancement during discourse. Many teachers are resistant to theory, which they consider unhelpful for creating lesson plans and conducting them in the classroom. During our joint three-year endeavor to search for a focus for our work, we successfully developed a trust relationship by sharing lesson study practices many times. After the three years, teachers requested that we implement something from our theoretical perspective. We felt that it was time for more rigorous lesson research by intimately collaborating with teachers as reflective practitioners.

Second, to more rigorously examine student discourse, we proposed that the school implement SSNA as an assessment tool. We recommended this because we considered the tool as needed for evaluating student discourse. Before starting our research lesson in the year, we introduced SSNA at another meeting and requested that they use it for the evaluation. The school was interested in implementing this new assessment tool. Implementation of the new tool consequentially led to the second post-lesson colloquia, which were found to be productive for several reasons. One reason was that time (a month) had passed since the research lesson. The research lesson teacher and researcher could step back a bit and discuss how the lesson went on based on a variety of evidence. Doing so might facilitate us to “reflect on our action rather than reflection in action” (Schön, 1983). In his seminal book on reflective practitioners, Schön defined two types of reflection that practitioners engage in. Reflection in action is a process by which practitioners reflect on their present action.

When someone reflects-in-action, he becomes a researcher in the practice context. He is not dependent on the categories or established theory and technique, but constructs a new theory of the unique case. (Schön, 1983, p. 68)

In our research lesson practice, the first post-lesson colloquium was an opportunity for the teacher to engage in reflection-in-action since the lesson was in the middle of a curriculum of the study unit. As Schön described, the teacher realized “new” incidents that were unexpected before the lesson and attempted to explain why they
happened. In his attempt, there was no space for us to introduce theories to his reflections, because he dealt with several incidents case-by-case. Over the three years of our experiences with teachers, this phenomenon was typically seen in post-lesson colloquia right after the research lesson. At the second post-lesson colloquium, we succeeded in implementing reflection on action.

We reflect on action, thinking back on what we have done in order to discover how our knowing-in-action may have contributed to an unexpected outcome. (Schön, 1983, p. 26).

At our second post-lesson colloquium, we brought a variety of evidence on research lessons from multiple stakeholders’ perspectives. Although evidence from different perspectives suggested different conclusions, the contradictory relation among different pieces of evidence stimulated our boundary-crossing effort (Engeström, 1999, 2011) to develop more comprehensive understanding of learners.

In this way, our interventionist approach to lesson study practice promoted a new style of lesson study through partnerships among teachers, the school, the district education department, and researchers. In future research, we will further examine whether this change represents just another proof of concept or continuous improvement. The following studies are further necessary and promising. First, we have to conduct more rigorous qualitative analyses of how our designed post-lesson colloquium has influence on the critical change in teachers’ epistemic beliefs and comprehension of students’ performance. We can examine how we as a group of practitioners and researchers constructed our shared understanding of student performance based on the results of SSNA by conducting the conversation analysis. Second, our report here is only the result in the first year of our endeavor. Through the iterative lesson studies in the DBIR framework, we can further examine our hypothetical design principles of the post-lesson colloquium.

References


Acknowledgments
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Evaluating Innovative Collaborative Learning Practice: An ‘Innovative’ Delphi Approach

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Teachers need to know what aspects of any proposed innovative practice are supported by evidence and are likely to be effective. However, when there is insufficient time or money to conduct a detailed trial of each proposed innovation, are there other less resource intensive methods that can be used? Here, we present a study conducted with thirty-six learning sciences experts and practitioners who were asked to judge the potential effectiveness of eighty collaborative learning activities using an adaptive comparative judgment (ACJ) approach. The results of the ACJ process show that the most innovative and effective collaborative learning activities are those that are monitored but not formally assessed. In addition, the use of technology and explicit support of students’ social and problem-solving skills are identified as important features of innovative collaborative learning activities that are likely to be effective. The contribution of this paper is twofold. First, it presents features of innovative collaborative learning practice that are considered to be important for effectiveness by experts. Second, it provides an ‘innovative’ research approach to assess educational practice when teaching is considered as a design science rather than a theoretical science.

Introduction
Collaborative learning is a teaching approach in which small groups of students work actively to achieve their common goals. It provides students with opportunities to augment each other’s learning experience through meaningful interactions. The meta-analyses and best evidence syntheses demonstrate that, when implemented appropriately, collaborative learning approaches do produce positive effects on pupil learning, motivation and attitudes. Meta-analyses show that classroom-based studies of collaborative learning consistently show advantages for collaborative group-based learning in classrooms, especially in comparison to ‘control’ classes where the pupils study the same curriculum topics but under ‘traditional, teacher-directed’ or individual learning practices (See for instance Johnson & Johnson, 2002; Kyndt et al., 2013). Indeed, the Education Endowment Foundation in the UK equates the impact of collaborative learning approaches on attainment to an additional five months of schooling (EEF, 2017).

In addition to evidence about the positive impact of collaborative learning on achievement and attitude, there is also evidence that collaborative learning approaches lead to higher motivation than other traditional approaches to instruction (Johnson, Johnson, Roseth, & Seob Shin, 2014), and to encourage students to be active participants in their own learning (Webb, Troper, & Fall, 1995). However, although this evidence of effectiveness exists, there appears to be highly variable practice in the nature and quality of the implementation of collaborative learning (Abrami, Poulsen, & Chambers, 2004). Very few teachers have appropriate training to implement collaborative learning activities and most teachers have virtually no time to design effective collaborative learning activities and support the learners as they would like. This was true, even among the trained teachers studied by Antil, Jenkins, Wayne, and Vadasy (1998), estimates of the long-term effective use of collaborative learning vary broadly from 10% to 93%. Collaborative learning is an effective way of learning when it is implemented well. However, much of what happens as group learning is not effective as collaborative learning. As observed by researchers in the UK, (Galton et al., 1999), in the majority of classrooms, students sit in groups, but very rarely work as groups to complete collaborative learning activities. This begs the question as to why practitioners do not implement collaborative learning activities in their classrooms, even though there is good evidence about their effectiveness.

Implementation of an educational innovation is very often challenging and meets with limited success. It is therefore not very surprising that practitioners do not often implement this approach. Nonetheless, it is important to boost the application of innovative practices, such as this, that have been shown to be effective in Education. The extent to which practitioners implement an educational innovation is a complex topic with factors from multiple levels influencing the teachers’ decisions. Prior studies have investigated some of these aspects. For example, Briscoe (1991) identified the association between the innovation and the teachers’ philosophy of education as an important factor; Olhhausen, Meyerson, and Sexton (1992) identified the importance of teachers’ self-efficacy in the adoption of educational innovations, whereas Fullan (1997)
discussed the significance of the school culture and the influence of principals. In addition, to these practical constraints including the availability of materials, time and space requirements are identified as significant factors (Sleeter, 1992). With the purpose of studying these factors in their study Abrami et al. (2004) devised a questionnaire with the aspects of value (how highly a teacher values an innovation), effectiveness (how successful a teacher expects an innovation to be), and the cost (how high a teacher perceives the costs of an innovation implementation to be). This research identified that the expectancy of success was the most important factor in differentiating teachers who implement the educational innovation and those who do not. In order to increase the likelihood of widespread implementation of an educational innovation, including those involving collaborative learning, what features of existing practice meets the teachers’ and experts’ expectations of success should be addressed. Therefore, in this study, the main research question we are investigating is: what are the common features of innovative collaborative learning practice that is likely to be effective for learning from experts and practitioners’ perspectives?

A working definition of educational innovation

In this paper, we refer to the collaborative learning activities that we investigated as educational innovations. Innovation is defined as “a new method or idea or product” in dictionaries as a term. However, innovation as a fundamental cognitive schema underpinning various ideas that relate to this newness is notoriously hard to define. In their review of the literature Edison, Bin Ali, and Torkar (2013) found 41 different definitions of innovation as a concept. The authors identify certain key aspects of innovation including those relate to the impact of innovation, types of innovation, degree of novelty, innovation activities and the nature of the process of innovation. The key message given regarding innovation is that innovation is not only about the generation of new ideas but, as importantly, about the effective implementation of new ideas. Innovation does not necessarily refer to the change of the things that we do and in the ways we do them, yet it explicitly refers to improving the things that we do and the ways we do them. Hence, for a practice to be innovative it is not enough for it to be new and exciting, in addition it has to be promising for successful implementation. While a novel device is often described as an innovation, in economics, management science, and other fields of practice and analysis, innovation is generally considered to be the result of a process that brings together various novel ideas in a way that they affect society (Luckin et al., 2012). In this paper, all collaborative learning practice examples we have investigated were considered as promising to be successful in terms of its implementation in actual classrooms. Therefore, they are defined as educational innovations.

Literature review on the common features of effective collaborative learning

It is extremely difficult to isolate the precise nature of the key factors that in general impact on the effectiveness of collaborative learning. Of course, it is possible to identify factors within particular individual studies for which there is evidence of their impact on the collaborative learning process and output, but once one looks beyond individual studies, the situation is far more complicated. However, it is still important to briefly mention the emerging features from discussions regarding the evidence of effective collaborative learning. Looking at the existing literature on collaborative learning, we find that researchers have examined a wide range of characteristics that may make collaboration more likely to take place (Blatchford, Kutnick, Baines, & Galton, 2003). These include elements that concern the:

- Environment in which collaborative learning takes place;
- Composition, stability and size of the group;
- Knowledge, attributes, skills and attitudes of group members;
- Social, communicative and group based skills of members;
- Nature and structure of the task and how it relates to what has come before;
- Educational systems and framework in force;
- Role of adults in strategically planning for and setting up collaborative activities and how they engage with and facilitate groups aiming to collaborate.
Early research by Deutsch (1949) highlights positive interdependence and promotive interaction as central aspects for successful collaborative learning. Over the years, additional elements have been suggested to form a set of 5 features considered as essential for successful collaborative learning (Luckin et al., 2017). All of these features are studied in the literature and have been shown to have impact on the effectiveness of the collaborative learning activities. Similarly, most of these features are also studied at meta-review levels.

1. Group members must be positively interdependent. This means that the task cannot be successfully completed by one person alone, but all group members must recognise that they all need to synchronise their efforts;
2. Group members must engage in promotive interaction and show a willingness to support each other in their joint efforts to complete the task and achieve the goal;
3. Group members must be individually accountable – they must make sure that they undertake their share of the work and feel personally responsible for the group’s success in completing the task.
4. Interpersonal and group skills need to be developed. We cannot assume that people, children in particular, naturally have the skills to participate in collaborative learning and promotive interaction – thus these skills need to be developed such that they are of a high quality.
5. Groups participate in group processing. This involves members reflecting on the quality of their working relationship and seeking to improve this through personal and joint effort.

**Effective collaborative learning when considering teaching as a design science**

In the theoretical sciences, evidence regarding the effectiveness of interventions, including educational innovations, often comes from meta-analyses of research. However, these meta-analyses present what is a rather simplistic view that we can isolate particular variables and thus, potentially discover the ‘key’ factors that work or serve to enhance achievement. However, more recent views about teaching stresses on the value of considering teaching practices as part of a design science similar to engineering, computer science, or architecture rather than considering it a theoretical science such as natural sciences (Laurillard, 2013). Considering teaching practices such as collaborative learning activities as a design science highlights the importance of a multidimensional and complex view of teaching, and in our case the practice of orchestrating students’ learning together (Blatchford et al., 2003). Most factors that have an impact on the effectiveness of an educational innovation are interconnected and need to be considered in a strategic manner by teachers to identify the most relevant combination for the particular persons and circumstances at that time.

Similarly, the success of working together also depends on how teachers and other adults strategically organize these activities, how they set up the tasks, and how they engage with and support groups engaged in collaborative learning. If a teacher adopts an approach that is directive or that undermines the value of the group work, then the group is less likely to function in the desired way. This emphasizes on the value of considering teaching as a design science rather than a theoretical science. As argued by Laurillard (2013, p.1) “Teaching is not a theoretical science that describes and explains some aspect of the natural or social world. (It’s)... imperative is to make the world a better place: a design science.” Clearly as other design sciences, teaching leverages and contributes to theoretical science. However, when research has particular focus on supporting practitioners, considering teaching practice as a design science might generate more meaningful results. One of the main reasons behind this improvement in value for practitioners is that in design sciences process evaluations are often strongly emphasized. This does not mean that the outcome assessment is not appreciated, however, the more holistic evaluation of the design process regardless of the outcome produced is equally appreciated. Similar to the arguments relate to assessment of and for learning (Stiggins, 2005), the approach of process evaluation is often argued to be more meritorious in design sciences (Simon, 1969). This is mainly due to the arguments that the value of design activities is in autonomy, the context, the synthesis of relevant...
multidisciplinary knowledge with social and cognitive skills (Seery, Canty, & Phelan, 2012). However, measuring such a complex and iterative process is very challenging with rigid assessments and abstract criteria. Rather, it requires a flexible model of assessment that relies on holistic judgement and professional experience.

In the context of judging students’ design work, Kimbell (2012) outlines a new approach based on the Law of Comparative Judgement (Pollitt, 2012). The approach uses an adaptive comparative judgement (ACJ) model of assessment where comparisons of students design work with overarching criteria and professional judgement of assessors. In this paper, we use ACJ to assess collaborative learning practice examples with the purpose of identifying the most common features of those teaching practices that are considered effective collaborative learning innovations by experienced academics and practitioners. These ‘judges’ are considered to have an understanding of what is better or worse in terms of the required capability to implement an effective collaborative learning practice based on their expert knowledge and experience.

### Preparation of the collaborative learning practice examples for ACJ

In order to help us describe and classify different types and examples of collaborative learning in a systematic level, we used a taxonomy approach to the concept (Cukurova, Luckin, Baines, 2017). This taxonomy was created for collaborative problem-solving and is informed by research and practice reviews of collaborative learning. The taxonomy has six non-hierarchical, inter-connected domains Technology, Characteristics of the collaborative problem-solving, Abilities of the participants, Group Features, Problem Features, The contextual factors. Further information about the taxonomy and its each taxonomic unit can be found in Cukurova, Luckin, & Baines, (2017). Here, we used the taxonomy to describe our 80 practice examples of collaborative learning. The taxonomy was broad enough to accommodate all the examples we have identified. Each practice example was described by a brief narrative and an ID card that summarised the example with reference to the taxonomy (illustrated in table 1). Then, these examples were used as in the adaptive comparative judgement process (ACJ).

### Collaborative learning activity ID1:

Students in pairs attempt to solve what a fictitious animal species would look like after evolution had occurred using a computer simulation. Students are assigned random features of the alien planet that could put evolutionary pressure on the alien. Then, they are asked to draw what they think the animal would look like. Students work in mixed age groups, and are not provided specific instructions on how to collaborate, or how to problem-solve.

| Characteristics of CL | • One-off activity  
|• Development of participants’ skills are not explicitly targeted |
| Group composition | • Pairs of mixed aged  
|• Mixed gender groups  
|• Participants act synchronously in medium acquaintance groups |
| Problem characteristics | • STEM domain  
|• Medium complexity, authenticity, and outcome of the problem  
|• Low social interdependence of participants |
| Contextual characteristics | • Tertiary education  
|• School laboratories  
|• Participants in the same physical space and taking actions in a digital environment  
|• Participants are monitored individually |
| Use of technology | • Computer simulation |

Table 1: Collaborative learning practice example and its taxonomic representation adaptive comparative judgment of collaborative problem-solving practice

Table 2 illustrates that most examples used in the study were one-off activities and only 1 of the examples could be identified as being part of a programme of collaborative learning (CL) activities. In almost half of the examples the CL process itself was not evaluated, although it was monitored. There was more evidence of CL being evaluated with the group as the unit of analysis (37.5%) than with the individual learner as the unit of analysis (15%), and more evidence of skills in the social domain being the focus of development could be
identified (26.25%) than examples where the problem solving itself was the focus for development (13.75%). The teacher was identified as the leader of reflection in 31.25% of examples and the group was identified as the leader of reflection in only 10% of examples, illustrating the significant role that teachers play in CL practice.

Table 2: Frequency of innovative CL practice examples’ taxonomic characteristics

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Practice Example Total</th>
<th>Practice Example in this Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-off activity</td>
<td>79</td>
<td>98.75</td>
</tr>
<tr>
<td>CL not evaluated but monitored</td>
<td>39</td>
<td>48.75</td>
</tr>
<tr>
<td>CL evaluated as a group</td>
<td>30</td>
<td>37.5</td>
</tr>
<tr>
<td>Teacher-led reflection</td>
<td>25</td>
<td>31.25</td>
</tr>
<tr>
<td>Development of skills explicitly targeted in social domain</td>
<td>21</td>
<td>26.25</td>
</tr>
<tr>
<td>Technology is employed for CL</td>
<td>19</td>
<td>23.75</td>
</tr>
<tr>
<td>Development of skills explicitly targeted in both social and problem-solving domain</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Cross curricular CL activity</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Group roles are allocated</td>
<td>14</td>
<td>17.5</td>
</tr>
<tr>
<td>CL evaluated individually</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Development of skills explicitly targeted in problem solving domain</td>
<td>11</td>
<td>13.75</td>
</tr>
<tr>
<td>Group-led reflection</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Single gender grouping</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Programme of activities of CL</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Group ethos addressed part of the CL activity</td>
<td>1</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Adaptive Comparative Judgment of collaborative learning practice examples

The narrative descriptions and ID cards for all 80 collaborative learning practice examples were used for the ACJ process with members of our expert panel. The software used for the process was online and it presented two practice examples simultaneously and asked experts to pick one of them. The aggregation of these judgements across collaborative learning activities produced an order of the activities from what was judged as the most likely to be effective innovative practice example to the least likely. The precise instructions given to the experts were:

“Please read the examples and compare each of the two examples of collaborative learning activity that are presented to you and decide which of them is the best example of innovative practice that is likely to be effective for learning.”

Thirty-six experts completed the online ACJ task. The first five rounds of the comparisons were non-adaptive “Swiss Tournament” rounds to create a rough sort. After the fifth round, the algorithm of the online software becomes adaptive and starts presenting those examples, which are closely ranked at the previous round in order to increase the reliability coefficient.
Results of the ACJ

The ACJ process was completed by 36 members of our expert panel (11 experienced teachers and 25 experienced academics from the learning sciences). The top 3 examples along with associated expert comments are illustrated in Table 3 and one can see that all three explicitly targeted the development of social skills. Two of the top three examples were from secondary schools and the other one was from a primary school. All three took place in classrooms and involved mixed gender groups of mixed ability.

Using the parameter values of each practice example of CL in the ranking list emerged as the result of ACJ process, we created the table 3 below. It shows the relative importance size of the categories of practice examples based on parameter values of the practice examples. These values were calculated by adding the parameter values of the practice examples’ taxonomic unit features. As can be seen, the most important features of innovative and likely to be effective for learning CL practice examples for expert opinion were: monitoring of the CL practice rather than evaluation of it, technology used in the practice activity, whether the activity targets to develop skills in both social and problem solving space and whether the activity provides opportunity for reflection (see table 3).

Table 3: The Importance of Particular Categories of Example for Experts' Evaluation

<table>
<thead>
<tr>
<th>Categories relative importance order</th>
<th>Relative importance size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CL activity is monitored not evaluated</td>
<td>56.4</td>
</tr>
<tr>
<td>2 Technology is used to facilitate CL</td>
<td>32.7</td>
</tr>
<tr>
<td>3 Development of skills targeted in both social and PS space</td>
<td>28</td>
</tr>
<tr>
<td>4 Teacher-led reflection</td>
<td>25.5</td>
</tr>
<tr>
<td>5 Group-led reflection</td>
<td>23.7</td>
</tr>
<tr>
<td>6 CL is evaluated individually</td>
<td>19.3</td>
</tr>
<tr>
<td>7 Group ethos are addressed</td>
<td>7</td>
</tr>
<tr>
<td>8 Development of skills targeted in social domain</td>
<td>3.5</td>
</tr>
<tr>
<td>9 Programme of activities</td>
<td>2.7</td>
</tr>
<tr>
<td>10 Single gender grouping</td>
<td>1.4</td>
</tr>
<tr>
<td>11 Development of skills targeted in problem-solving domain</td>
<td>-0.6</td>
</tr>
<tr>
<td>12 Group roles are allocated</td>
<td>-2.7</td>
</tr>
<tr>
<td>13 CL evaluated as a group</td>
<td>-2.8</td>
</tr>
<tr>
<td>14 Cross curricular activity used in CL</td>
<td>-19.9</td>
</tr>
</tbody>
</table>

Table 3 was created using the sum of parameter values of each CL practice example. On the other hand, Table 4 illustrates the importance of key categories in the ACJ process and it provides information about the language that most frequently graced expert feedback. The feedback from experts indicates the aspects of the CL examples that experts focused upon in making their judgements. Although there is no particular mention of the evaluation aspect of in experts’ qualitative feedback, the other characteristics of CL practice and their relative importance rankings show great amount of overlap.

Table 4: Experts' Most Frequent Feedback

<table>
<thead>
<tr>
<th>The most frequently mentioned aspects in feedback</th>
<th>Number of mentions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>16</td>
</tr>
<tr>
<td>Contribution to students’ discussion</td>
<td>16</td>
</tr>
<tr>
<td>Contribution to students’ reflection</td>
<td>15</td>
</tr>
<tr>
<td>Authenticity of Problem or Task</td>
<td>14</td>
</tr>
<tr>
<td>Interdependence of Participants</td>
<td>12</td>
</tr>
<tr>
<td>Appropriate feedback provided for students</td>
<td>11</td>
</tr>
<tr>
<td>Contribution to CL skill development</td>
<td>11</td>
</tr>
</tbody>
</table>

The last three activities in rankings of the CL practice were all STEM activities in secondary or tertiary education. In contrast to the positive feedback from experts, the reasons experts gave for deciding these practice examples as neither being innovative nor effective were often about the lack of interdependence of students, lack of support provided to students for their development of social and problem solving skills, and the type of the problem tasks provided to students not being appropriate for providing opportunities for interactions among students and discussions.
Discussion and conclusions

The expectancy of success is an important factor in differentiating between those practitioners who do implement an educational innovation and those who do not (Abrami et al., 2004). Therefore, all educational innovations must justify their existence with some type of evidence of their effectiveness. As presented in the introduction and literature review sections, there is substantial evidence on the positive impact of collaborative learning on achievement and attitude, and that it can be more motivating than more traditional approaches to instruction. However, there is also evidence that collaborative learning is often poorly implemented. This may be because neither collaborative learning is something that students are naturally familiar with and good at completing, nor teachers are appropriately equipped to implement it. Research literature provides practitioners with some elements that are found to be present when effective collaborative learning happens, yet inevitably such reviews of meta-analyses present a rather simplistic view which encourages practitioners to think that particular variables can always be isolated and implemented. This approach to effectiveness is highly appropriate for theoretical sciences, yet their value for design sciences, in which implementations are considered as dynamic and flexible rather than as ready-made solutions, may not be equally pertinent.

There is no question that collaborative learning is anything other than complex, with multiple factors interacting and impacting upon the manner in which the collaborative process takes place. Therefore, adoption and implementation of collaborative learning approaches in teaching practice may be better supported if teaching is regarded as a design science (Laurillard, 2013) through which teachers paid attention to the design of the collaborative learning process in a systematic manner. This is not to say that evidence generated regarding the effectiveness of educational innovations from different methodologies is not valuable. However, the suitability of the proposed evaluation methods and the types of evidence should be the focus of attention on innovation evaluations (Cukurova, & Luckin, 2018). If judged by the criterion of usefulness to the practitioners, considering teaching as a design science may have greater advantages.

In this paper, we discuss a research-informed taxonomy of collaborative learning (Cukurova, Luckin, Baines, 2017). This taxonomy was used to categorize eighty proposed innovations in collaborative learning. These eighty innovations were then judged by a panel of thirty-six learning sciences experts drawn from academia and educational practice. A software, which is designed to adjust presented examples based on judges’ responses, was used to present each judge with a selection of innovations each of which had to be judged against another. The experts were asked to select from each pair, the innovation that they thought most likely to be effective. Most examples judged were one-off activities and only one of the examples could be identified as being part of a programme of collaborative learning activities. In almost half of the cases, the collaborative learning process was not evaluated, and when a potential innovation has been evaluated there is a tendency for this to have been conducted at the group level, rather than interns of each individual learner. As we have completed our crowdsourcing of the practices broadly in the UK and included some from other English-speaking countries (USA, Australia, and Canada), we expect that this landscape reflects the general practice.

The results of the ACJ process show that the most innovative and expected to be effective collaborative learning activities are those that are monitored but not formally assessed. The use of technology was a feature that was often present within innovations that are judged to be potentially effective. Moreover, the extent to which an innovation included an activity that was targeted at developing both problem-solving and social skills of students, was also considered as a significant feature for innovative collaborative learning activities that are likely to be effective. An analysis of the feedback provided from members of our expert panel revealed a consistency. Experts valued innovations that require students to discuss and reflect upon authentic problems and tasks, and to receive appropriate feedback about their progress.

This paper presents the ACJ process combined with a taxonomy to categorize across a range of potential collaborative learning innovations, as an alternative way to evaluate the common features of educational innovations that are expected to be effective. Although, we address collaborative learning innovations here, we hope that the approach exemplifies an alternative for evaluating educational innovations more broadly. We argue that the approach might be particularly appropriate when it is not practical to conduct empirical evaluations of the innovations under consideration.

References


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Combining Gaze, Dialogue, and Action from a Collaborative Intelligent Tutoring System to Inform Student Learning Processes

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Abstract: In a computer supported collaborative learning environment, students have both interactions with each other as well as the technology that is guiding their learning, which can influence how the students construct their knowledge. Often in technology enhanced learning situations, information from the system provides discrete data points that can be used to infer learning without providing much information on the knowledge construction. On the other hand, analysis of student dialogues can be time consuming and subjective. In this paper, we propose combining log data, student dialogue, and gaze analysis to provide a clearer picture of how students construct knowledge collaboratively while working with an intelligent tutoring system. We found that students’ gaze similarity is negatively correlated with levels of abstraction in speech and that students have higher gaze similarity surrounding feedback provided by the tutor. These results show that the gaze data can be used as a proxy for dialogue in a collaborative learning context.

Keywords: Dual eye-tracking, DUET, Intelligent tutoring systems, ITS, gaze analysis, eye-tracking

Introduction

To develop a better understanding of how students construct their knowledge, it is important to be able to efficiently analyze the process that the students go through as they solve them problem. When students are working collaboratively, this process involves both their interactions with the other students in the group as well as the students’ interactions with the learning materials. To fully understand how students construct their knowledge, it is important to understand both of these interactions, which cannot always be captured through a single type of process data. When using technology enhanced learning, the data about the student processes is limited to discrete moments of time that can be captured within the logs of the technology. On the other hand, within computer supported collaborative learning, we often have a continuous stream of process data from student dialogues. By combining these multiple data streams, we can develop a better understanding of the student’s knowledge construction and how the students’ interactions unfold between one another and in relation to the educational material with which they are interacting. Intelligent tutoring systems (ITSs) provide an ideal environment for investigating the relation between these multiple data streams. However, dialogue data can be complicated to analyze and the findings are often very subjective and depend upon the coding scheme that is used.

On the other hand, research shows eye gaze is tied to communication, making eye-tracking a promising method to use as a proxy for dialogue (Meyer, Sleiderink, & Levelt, 1998). Previous research has shown a link between speech and eye gaze that goes in both directions: eye gaze can precede the mention of an object or follow it (Griffin & Bock, 2000; Meyer, Sleiderink, & Levelt, 1998). This same pattern occurs when people work on a task together. There is a coupling of the collaborators’ eye gaze around a reference (Richardson, Dale, & Kirkham, 2007), meaning that the collaborators’ gaze may fixate, at approximately the same point in time, at the object referenced in the dialogue, for example just before mentioning it and just after hearing about it. The eye gaze has a closer coupling when each of the collaborators has the same initial information and when collaborators can visually share important objects that they are referencing in speech (Jermann & Nüssli, 2012; Richardson, Dale, & Kirkham, 2007), suggesting that concrete references may have more of an impact on eye gaze compared to abstract references.

Over the past few years, eye-tracking has become a key source of process data in educational research. Research using eye-tracking covers a wide range of educational ecosystems. Eye-tracking has multi-faceted use case examples: From online (Sharma et. al., 2015a) to face to face classes (Raca & Dillenbourg, 2013), from co-located (Schneider et. al., 2017) to remote collaborative learning (Sharma et. al., 2015b), and to understand teachers’ classroom orchestration processes (Prieto et. al., 2015). Eye-tracking has not only been used to...
understand the learning processes in various contexts, but it also has been used to provide students appropriate, real-time, and adaptive feedback on their learning processes (Sharma et al., 2016, D’Angelo et al., 2017).

In terms of collaborative learning scenarios, eye-tracking has most often been used with collaborating partners’ dialogues. Griffin & Bock (2000) showed that there is a time lag of about 800 milliseconds between looking at an object and referring to the same object (eye-voice span). Allopenna et al. (1998) showed that there is a time lag (about 400 milliseconds) between a speaker’s reference and a listener's gaze on the referred object (voice-eye span). In a dual-eye-tracking study, Richardson & Dale (2005) gave the notion of eye-eye (speaker’s eye listener’s eye) span as the time difference between the moment a speaker looks at an object and the moment the listener looks at the same object. Richardson & Dale (2005) found this lag to be about 1.2 seconds. Most of the dual eye-tracking studies have shown that the amount of time that the collaborating partners spend while looking at the same objects at the same time (cross-recurrence) is predictive of several collaborative constructs (e.g., collaboration quality Jermann & Nussli, 2012; misunderstandings Cherubini et al., 2007; learning gains Sangin et al., 2007). These studies consider the dialogue as basic utterances (Sangin et al., 2007), referencing words (Jermann & Nussli, 2012), or in a few cases, as a collaboration quality category (Schneider et al., 2013).

In this paper, we present a new dialogue coding scheme, which captures the abstraction in the dialogue; that is, how much context dependency (low abstraction) or domain knowledge (high abstraction) is reflected in the speech. Moreover, we present the relation between the similarity of the gaze patterns and the level of abstraction in the problem-solving processes.

ITSs have been very successful in supporting students’ learning as they work individually to solve problems (Murray, 2003), particularly within the domain of mathematics (Ritter, Anderson, Koedinger, & Corbett, 2007). ITSs are beneficial to students by providing them with cognitive support as they solve a problem (VanLehn, 2011). ITSs provide step-by-step guidance for students both through the use of immediate feedback on steps and through on demand hints. That is, students will know right away when an error occurs and they can decide to request help from the system to figure out how to do any problem-solving step correctly. Although the majority of ITSs have been developed for individual learning, there has been some work combining ITSs and collaboration successfully (Baghaei, Mitrovic, & Irwin, 2007; Walker et al., 2009; Diziol, Walker, Rummel, & Koedinger, 2010). By combining collaboration, which supports learning through processes such as co-construction and explanation-giving (Chi & Wylie, 2014), with the cognitive support provided in the ITS, students may be able to more effectively construct knowledge to both avoid errors, overcome errors when they occur, and to effectively use the support provided through hints. However, it is still an open question about how the events that occur within the ITS impacts the collaboration. By combining gaze data with tutor log data and student dialogues, we can construct a more complete picture as to how students are constructing knowledge while working on the tutor.

Eye-tracking in ITSs has been previously used to better understand student processes during the learning process but has primarily been used to investigate students working independently. The use of eye-tracking as an analysis tool in ITSs has spanned investigating both affective and cognitive states of students (Jaques, Conati, Harley, and Azevedo, 2014; Rau, Michaelis, & Fay, 2015). Within the affective states, eye tracking can be used to gauge student states around boredom, curiosity, and attention that can influence the student learning (Jaques et al., 2014). By identifying these states, interventions can be put in place. In addition to tracking the affective state of the student, the eye gaze can also be related to the cognitive state of the student. Rau et al. (2015) found that the gaze patterns of students were correlated with the types of self-explanations that students provided. However, the majority of this research does not extend the analysis of eye-tracking to students working collaboratively (Belenky, Ringenberg, Olsen, Alevin, & Rummel, 2014). When students work collaboratively, they can influence each other’s thought processes that can be expressed through both speech and gaze patterns.

In this paper, we aim to answer two main research questions: what is the relation between collaborative gaze patterns and the level of abstraction in student speech and what is the relation between tutor events and gaze patterns? To answers these questions, we analyzed multiple data streams from elementary school students working with a collaborative fractions ITS including gaze data, tutor log data, and transcript data. We hypothesized that dyads with a higher similarity of gaze data would have a lower level of abstraction in their speech (H1), as students that are talking about specific features within the problem would more likely be looking at the same thing. Second, we hypothesized that gaze similarity would be greater around correct actions, as students would be working together to solve the problem (H2). In the following sections, we will present our three data sources as well as the results from triangulating this data. This paper provides a deeper understanding of how system information can influence and interact with students’ collaborations.

Methods
**Experimental design and procedure**

Our data set involves 144 4th and 145 5th grade dyads from a larger study that tested the hypothesis about differential benefits of collaborative versus individual learning (Olsen, Belenky, Alevén, & Rummel, 2014). Each teacher paired the students participating in the study based on students who would work well together and had similar, but not equivalent, math abilities. The dyads were engaged in a problem-solving activity using a networked collaborative ITS, which allowed them to synchronously work in a shared problem space where they could see each other’s actions while sitting at their own computers. The students were able to communicate verbally through a Skype connection. Each dyad worked with the tutor for 45 minutes in a pull-out study design at their school. The morning before working with the tutor and the morning after working with the tutor, students were given 25 minutes to complete a pretest or posttest individually on the computer to assess their learning. During the experiment, dual eye tracking data, dialogue data, and tutor log data in addition to the pretest and posttest measures were collected. We collected eye-tracking data using two SMI Red 250 Hz infrared eye-tracking cameras.

**Intelligent tutoring system**

During the study, the dyads engaged with an ITS oriented towards supporting the acquisition of knowledge about fraction equivalence. Within each problem, the tutor provided standard ITS support, such as prompts for steps (i.e., revealing steps sequentially), next-step hints, and step-level feedback (i.e., correct or incorrect feedback) that allows the problem to adapt to the student’s problem-solving strategy (VanLehn, 2011). Each of these different supports were displayed as actions on the screen that could guide the students’ actions and gaze.

**Equivalent Fractions**

![Figure 1](691.png)

**Figure 1.** Example of a fractions interface showing incremental step reveals, step feedback, and hint requests.

For the collaboration, the ITS support mentioned above was combined with embedded collaboration scripts, which allowed students to take slightly different actions and see different information (see Figure 1). The embedded collaboration scripts included three theoretically proven types of collaboration support: roles, cognitive group awareness, and individual accountability. First, for many steps, the students were assigned roles (King, 1999). In the tutors, on steps with roles, one student was responsible for entering the answer and the other was responsible for asking questions of their partner and providing help with the answer. The tutor indicated the current role for the students through the use of icons on the screen. A second way in collaboration was supported was by providing students with information their partner did not have that they were responsible for sharing for the problem to be completed causing individual accountability (Slavin, 1996). The final feature was cognitive group awareness, where knowledge that each student has in the group is made known to the group (Janssen & Bodemer, 2013). On steps where this feature was implemented, each student was given an opportunity to answer a question individually before the students were shown each other’s answers and asked to provide a consensus answer.

**Dependent measures**

For our analysis, we collected data from three different data streams that were used for analysis: log data, student dialogue, and gaze data. Although the log data recorded each transaction that the student took within the tutor, we were interested in the transactions that ended in additional changes to the tutor interface besides the students own actions. These fell into three categories of hint requests, incorrect feedback, and correct feedback. On each step, the students could request hints from the tutor related to the current step that they were working on. When submitting an answer to the tutor, the students would get either correct or incorrect feedback for each
step and would need to have the step be marked as correct before being able to continue with the problem. The log data captured each of these transactions along with a time-stamp.

Each of the student dialogues were transcribed and coded for abstraction levels. Abstraction is how grounded within the concrete aspects of the problem solving and communication the student’s utterance is. The level of abstraction is fully dependent on what occurs in the dialogue and is not intended to infer all mental processes. Within our transcripts, we coded for abstraction at the utterance level. This allowed us to have a finer-grained coding for each second of the dialogue without losing the context of the words. The abstraction codes consisted of six different levels: acknowledgement, read out loud, interface, problem solving, concepts, and metacognitive (See Table 1). The levels of abstraction followed an ordering with acknowledgments being the least abstract and metacognitive being the most abstract (with the other codes following the ordering in Table 1). For the coding, all statements that were off-task or were with a researcher were marked as “not applicable” and were discarded from the analysis. An inter-rater reliability analysis was performed to determine consistency among raters (Kappa= 0.78).

Table 1: Abstraction feature coding of student utterances in increasing order of level of abstraction

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Applicable</td>
<td>The student engages in off-task behavior, converses with the experimenter, or vocalizations without any context.</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>The student acknowledges their partner, or they request acknowledgment or a repeat of what the partner has said.</td>
</tr>
<tr>
<td>Read Out Loud</td>
<td>The student is reading information provided within the problem and presented on the screen.</td>
</tr>
<tr>
<td>Interface</td>
<td>The student discusses actions that can be taken in the interface or engage in work coordination.</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>The student is providing an answer to the problem or showing evidence of think aloud as they solve the problem.</td>
</tr>
<tr>
<td>Concepts</td>
<td>The student is adding information from outside of the problem or providing an explanation that goes beyond the required answer.</td>
</tr>
<tr>
<td>Metacognitive</td>
<td>The student verbally expressing their understanding of their current knowledge/problem solving state.</td>
</tr>
</tbody>
</table>

To compute the entropy, we divided the screen in 50-by-50 pixels grid. We also divided the whole problem-solving session into 10 seconds time windows. We then computed the proportion of the time spent in each block in the spatial grid for each 10-second time window. This resulted in a series of 2-dimensional proportionality vectors. Finally, we computed the Shannon Entropy for each of the vectors. A low entropy value (the minimum possible value is zero) depicts that the student was looking at only a few elements on the screen, which we called focused gaze. On the other hand, a high value of entropy indicates more elements being looked at in a given time window, which we called unfocused gaze. Although focus and attention are related concepts, focus, as we defined here, does not contain the idea of processing the stimulus, as is required in the definition of attention. Focused gaze simply indicates a small number of elements looked over a fixed time period.

In order to compute the similarity between the gaze patterns of the collaborating students, we divided the screen space and the interaction time in the same manner as we did for entropy computation. We computed the similarity between the two proportionality vectors by using the reverse function (1/(1+x)) of the correlation matrix of the two vectors. A similarity value of one will show no similarity between the two gaze patterns during a given time window. On the other hand, a higher value of similarity will show that the two participants spent time looking at the similar set of object on the screen during the same time window.

Results
**Gaze and tutor response**

We compared gaze similarity across time (± 5 seconds) for different types of tutor responses. For this comparison, we fit a hierarchical linear model with time and tutor response as random effects and gaze similarity as the dependent measure. We observe a significant effect showing that similarity values are different among the three types of tutor responses, $F(2, 16.96) = 47.80, p < .001$, while there was no significant main effect of time, $F(1, 15.41) = 2.60, p = .12$ or interaction between time and tutor response, $F(2, 18.09) = 0.38, p = .68$ (see figure 2). A post-hoc pairwise comparison shows that the similarity is the highest for the correct feedback and the lowest for the hint requests (see Table 3).

<table>
<thead>
<tr>
<th>Tutor Response</th>
<th>Correct Feedback</th>
<th>Incorrect Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hint Request</td>
<td>$F(1, 16.41) = 85.96, p &lt; .001$</td>
<td>$F(1, 16.77) = 23.75, p &lt; .001$</td>
</tr>
<tr>
<td></td>
<td>Correct feedback &gt; Hint request</td>
<td>Incorrect feedback &gt; Hint request</td>
</tr>
<tr>
<td>Correct Feedback</td>
<td>$F(1, 15.17) = 48.88, p &lt; .001$</td>
<td>Incorrect feedback &lt; Correct feedback</td>
</tr>
</tbody>
</table>

**Figure 2.** Gaze similarity across time for hints (left), correct responses (center), and incorrect responses (right).

Further, we compared the gaze similarity values across different types of tutor responses and the probability of both students being focused. Again, we fit a hierarchical linear model. We observed a significant effect that as the probability of the students being focused increases, the similarity values increase, $F(1, 19) = 29.37, p < .001$ (see Figure 3). Additionally, we observed a significant interaction between the student focus and tutor response type, $F(3, 18) = 6.71, p < .05$, with the correlation being greatest for incorrect responses and lowest for correct responses and a marginal significant effect of tutor response on similarity, $F(2, 17) = 2.86, p = .06$.

**Figure 3.** Correlation of gaze similarity with probability of dual dyad focus by tutor response type.

**Gaze and abstraction**

For the abstraction categories, we observed that the concept category was coded for less than half of the dyads (ten out of 28) and that for these dyads, the concept category was less than 5% of the utterances. Given this low
rate, we determined that the concept category would not be a reliable category. Therefore, we merged the concept and problem solving categories for this analysis.

Table 3: Model parameters for correlation of focus and tutor response with gaze similarity

<table>
<thead>
<tr>
<th>Acknowledgements</th>
<th>Read out Loud</th>
<th>Interface</th>
<th>Problem Solving</th>
<th>Metacognitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>F(1,40.62) = 3.19, p = .08</td>
<td>N.S.</td>
<td>N.S.</td>
<td>F(1,30.23) = 7.98, p &lt; .05</td>
<td>Ack. &gt; Metacognitive</td>
</tr>
<tr>
<td>Ack. &gt; Metacognitive</td>
<td>-</td>
<td>N.S.</td>
<td>F(1,41.76) = 13.91, p &lt; .001</td>
<td>Read out loud &gt; Prob. Sol.</td>
</tr>
<tr>
<td>Interface</td>
<td>-</td>
<td>-</td>
<td>F(1,40.96) = 6.94, p &lt; .05</td>
<td>Interface &gt; Metacognitive</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>-</td>
<td>-</td>
<td>F(1,30.09) = 3.69, p = .06</td>
<td>Prob. Sol. &gt; Meta.</td>
</tr>
</tbody>
</table>

To investigate the relation between gaze similarity and dialogue abstraction, we ran a one-way independent ANOVA without assuming equal variances across the different abstraction categories. There was a significant effect of dialogue abstraction with gaze similarity, $F(4, 51.95) = 3.86, p < .05$. In a post-hoc pairwise comparison (see Table 3), we found that gaze similarity is significantly lower when students utterances are coded as metacognitive. Additionally, we observed a trend that higher abstraction levels tend to have lower similarity values with an exception of acknowledgments (see Figure 4).

![Figure 4. Gaze similarity by dialogue abstraction codes.](image)

Tutor response and abstraction
Finally, we ran a chi-square test to compare the tutor response types with the dialogue abstraction points (for a range of ± 3 seconds around the tutor response). For the different levels of abstraction and tutor responses, we found a significant relation, $\chi^2(8) = 15.61, p = .04$. However, Comparing the residuals from the chi-square fit, we did not find any significant differences.

Discussion and conclusions
In this paper, we presented a dual eye-tracking study within a remote collaborative setting where pairs of students solved fractions problems working with an ITS. We combined the gaze and the dialogues for each dyad with their interactions within the ITS. We observed three main relations: 1) the gaze similarity decreases as the level of abstraction in the dialogue increases; 2) the probability of the pair being focused is correlated to the pair’s gaze similarity when they receive a hint or an incorrect response; 3) the gaze similarity is highest for the correct response, followed by the similarity for incorrect response and it is lowest for the hint requests.

In respect to the relation between the tutor response and similarity, we observed that for the correct feedback, the similarity is highest. This might be because when students working together, they will be looking at the same thing (leading to a higher similarity) and have a higher chance of getting the solution correct. On the other hand, the similarity is lowest for the hint requests; one of the reasons for this could be that the hint message is displayed above the hint button and there could be a lag of gaze on the hint message between the student who requests the hint and their partner. The similarity for the incorrect feedback is lower than that for
the correct feedback. One possible explanation could come from the fact that students not working together are not sharing their knowledge so have less of a chance of getting the solution correct. Another reason could be the fact that once the students receive incorrect feedback they scan the interface for the mistake/correct answer and hence have a lower similarity.

Further, we also analyzed the relation between the tutor response, similarity, and focus of the two students. We found that the focus is correlated with the similarity, however this correlation is highest for the incorrect feedback and lowest for the correct feedback. Related to what we found with the similarity and tutor actions, this observation could be due to the fact that once the students receive incorrect feedback, they start by scanning the interface for the mistake/correct result and then they focus together on the same elements of the problem, which increases their similarity values. On the other hand, once the students receive correct feedback, they start by working independently on the next problem. This makes the probability of them being focused at the same time and looking at the same part of the screen almost independent from each other.

Additionally, we observed that the similarity decreases as the level of abstraction in the dialogue increases. A plausible explanation could be that the support required from the stimulus decreases with an increase in the level of abstraction because as students use higher level of abstraction they use a fewer number of physical (on visual stimulus) references. As an example, during a read-out-loud dialogue students are reading from the screen (a visual stimulus) and hence they have a high similarity; while during a metacognitive dialogue, they do not refer to anything present on the screen, thus not having any visual grounding and hence the similarity decreases. Finally, we observed a significant relationship between the levels of abstraction and the different tutor responses. However, the residuals did not reveal any further relations between the individual categories. We hypothesize that the abstraction is not the correct labeling for the dialogues in this case, as we could expect all the abstraction categories to correspond to each of the tutor responses as the students engage in the problem-solving. Instead, more nuanced measures may be needed to understand the student’s process around addressing tutor response, such as what we found with the gaze data.

In this experiment, the students were working within an ITS environment. However, we believe that our results would also extend beyond ITSs to other technology enhanced environments that also collect log data. One limitation of the current methods is that using eye-tracking, as the technology currently stands, is not necessarily feasible outside of a lab setting where the use of the technology does not scale-up. For future work, we would like to be able to understand how the correlations from this process data also correspond to the student learning that occurs. To investigate this question, we would want to find the correlation between the combined process data events and student learning measures. The work presented in this paper contributes to the field through combining multiple process data streams to form a better understanding of student knowledge acquisition. By combining more discrete and continuous data sources that capture the collaborative interactions between both students and the system, we can better understand how these events interact to influence the student learning process.

References


Cultural Repertoires: Indigenous Youth Creating With Place and Story

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Abstract: In this paper, we present an example of culturally-responsive making in the context of developing location-based community stories. Working with members of an Indigenous community in the Southwestern United States, we co-designed and implemented a two-week summer camp in which middle school youth used Augmented Reality and Interactive Storytelling (ARIS), a narrative-based programming tool, to create virtual community tours for the purpose of sharing the information they learned about tribally owned locations with others. We developed case studies of two groups of students who incorporated culture into their community tours of a tribally-owned golf course complex and stadium complex to address the following question: How did small groups of youth conceptualize culture and how did they integrate it into their community tours? In the discussion, we address what can we learn from youths’ design processes and completed products about designing culturally responsive learning experiences.

Introduction

The increased interest in promoting the development of maker culture in education is strongly connected to a growing need to expand youth interest and knowledge in STEM disciplines and careers (Dougherty & Conrad, 2016). Maker activities are particularly promising alternatives to traditional STEM pathways, because they not only engage youth with authentic disciplinary knowledge by generating creative solutions to important problems, but also connect with a culture of entrepreneurship and manufacturing by bringing solutions to market (e.g., Peppler, Halverson & Kafai, 2016a; 2016b). Even though research on maker activities, technologies, and spaces has expanded significantly over the last few years, some have raised critical concerns about what types of maker activities are promoted, how maker technologies are used, and who participates in making (e.g., Calabrese Barton, Tan, & Greenberg, 2017; Vossoughi, Hooper, & Escude, 2016). With all the interest and promise of the maker movement, these shortcomings highlight the need for more intentional efforts toward equity, access, and broadening participation, in particular for indigenous communities who have complex histories and contemporary relationships with the cultures of schooling and technology.

One approach to address these shortcomings has been the development of culturally responsive computing and making, which grow out of the research on culturally responsive schooling (Ladson-Billings, 1995). At the most basic level, culturally responsive schooling connects youth’s out-of-school cultural repertoires to academic content. While most curricular examples of culturally responsive schooling for Indigenous youth have been developed in the context of literacy and language education (Castagno & Brayboy, 2008), culturally responsive computing focuses on connecting computing content with heritage and vernacular cultural practices that are familiar to students (Eglash, Gilbert, & Foster, 2013). These cultural connections are also present in culturally responsive making which moves beyond the screen, with a particular focus on connecting to artifacts, activities, and spaces to improve educational experiences for indigenous youth and meet community needs (Searle & Kafai, 2015).

In this paper, we examine culturally responsive making in the context of developing location-based community stories. Working with members of an Indigenous community in the Southwestern United States, we co-designed and implemented a two-week summer camp activity using the Augmented Reality and Interactive Storytelling (ARIS) platform (Holden, Gagnon, Litts, & Smith, 2014.). In this context, ARIS was a promising fit because it allowed youth to engage in thinking about place and narrative, two central aspects of how Indigenous knowledges are located and transmitted (Brayboy, 2005). Knowledge is often connected to particular places and stories are used to communicate community history and values (Basso, 1996; Brayboy & Maughan, 2009; Smith, 2012). Middle school youth (12-14 years-old) visited important locations throughout their community and, with the assistance of a community relations tour guide to point out key features, documented the kinds of cultural
knowledge located at each site. Youth were then asked to create a virtual community tour to share the information they learned with others, with an ultimate goal of sharing their tours with the community’s public relations department for their use. The sites youth visited varied in their cultural significance from a series of large metal sculptures designed by a local artist to a skydiving facility. For this paper, we developed case studies of two groups of students who incorporated cultural elements, such as signs with words in both English and the community’s heritage languages, into their community tours of a tribally-owned golf course complex and stadium complex, to address the following question: How did small groups of youth conceptualize culture and how did they integrate it into their community tours in ARIS? In the discussion, we address what can we learn from youths’ design processes and completed products about designing culturally responsive learning experiences.

Background

During the last decade, indigenous scholars have argued for a broader view of technology as tools. Tools have always been adapted by Indigenous peoples and serve as vehicles in service of self-expression, as well as tribal sovereignty and self-determination (Bang et al., 2013; Duarte, 2017; Kawagley, 2005). Further contemporary Indigenous identities for individuals and communities are complex: economic success is often accompanied by historical development of individuals and communities) and the kinds of disciplinary approaches valued in repertoires of practice (Bell, Van Horne, & Cheng, 2017). By making connections between repertoires of practice patterned and that individuals may acquire multiple, sometimes overlapping and even competing or conflicting interests and intersectional identities. Research in the learning sciences recognizes that learning is culturally bound to youth to investigate their intersectional identities. While such work can be challenging in formal schooling environments where teachers and students are held accountable to standards, out-of-school learning contexts provide opportunities to engage youth in more open-ended problems, such as designing a tour of important community sites for use by the community.

In the work we present here, we assume that technology is a tool of youth self-expression and community self-determination. Youths’ ARIS games highlight aspects of heritage culture, but also culture’s adaptability to new contexts as it is intertwined with economic development projects and youths’ exploration of their own interests and intersectional identities. Research in the learning sciences recognizes that learning is culturally patterned and that individuals may acquire multiple, sometimes overlapping and even competing or conflicting repertoires of practice (Bell, Van Horne, & Cheng, 2017). By making connections between repertoires of practice valued in youth’s lives (i.e., cultural artifacts and tools, community norms, division of labor, social relations, and historical development of individuals and communities) and the kinds of disciplinary approaches valued in science, technology, engineering, and math (STEM), research has shown that youth more easily identify with and persist in STEM disciplines. One approach to making connections across multiple repertoires of practice in youth’s lives has been to develop culturally responsive learning environments. Often, such learning environments have relied upon a material connection to heritage culture (e.g., using beadwork to learn about Cartesian coordinates in math) or upon particular linguistic practices (e.g. hip-hop literacies). While these approaches have an important place especially in Indigenous communities in the United States where linguistic and cultural

Everyone doesn’t have to do everything the old Indians did in order to have a modern Indian identity. …We need a larger variety of cultural expression today. I don’t see why Indians can’t be poets, engineers, songwriters or whatever. I don’t see why we can’t depart from traditional art forms and do new things. Yet both Indians and Whites are horrified when they learn that an Indian is not following the rigid forms and styles of the old days. This is nonsense to me but it has great meaning to a lot of people who have never considered the real meaning of cultural change and national development” (qtd. in Warrior, 1995, pp.93-94).

In his analysis of this quote, Warrior highlights that “the real meaning of cultural change” refers to its adaptability to change. We also think it is important to consider what it means to be Indigenous in the 21st century, bringing notions of “modern Indian distinctiveness” into stark light.

Culturally responsive computing (Eglash, Gilbert, & Foster, 2013) is one promising approach to making connections across youths’ multiple repertoires of practice by incorporating heritage and vernacular cultural practices into technological engagements. For example, the culturally situated design tools developed by Eglash and his colleagues connect practices from Shoshone beadwork to skateboarding to mathematical concepts. Each web-based design tool is accompanied by a page that describes its cultural origins and connections to math. In this example, the focus is on using culture as a way to engage youth in both identity work and school-based curriculum. Scott, Sheridan, & Clark (2015) have pushed theories of culturally responsive computing to include a more explicit focus on youth’s intersectional identities and youth as creators rather than consumers of technology. Rather than close ties to school-based curricula, they suggest we would be better served to pay attention to “who creates, for whom, and to what ends” (p. 421). Technology in this vein serves as a vehicle for youth to investigate their intersectional identities. While such work can be challenging in formal schooling environments where teachers and students are held accountable to standards, out-of-school learning contexts provide opportunities to engage youth in more open-ended problems, such as designing a tour of important community sites for use by the community.
revitalization are crucial (McCarty & Lee, 2014), they do not represent the whole spectrum of practices that Indigenous individuals and communities engage in today.

Methods
The work presented in this paper is part of a larger research project to understand how we co-design culturally responsive making activities and makerspaces with two distinct Indigenous communities in the Southwestern United States. This present paper presents findings from a two-week camp that took place during the summer of 2017 in a small Native American community (10,000 enrolled members) in the Southwestern United States and focuses on understanding (1) how small groups of youth conceptualized and documented cultural elements and (2) how they integrate these elements into their community tours using the ARIS platform. Summer camps like the one described here allow us to more fully explore youth's design processes as they work to create something meaningful for themselves and their communities over a more extended time period.

Our research team worked with the community’s education, cultural resources, and public relations departments, as well as staff from the American Indian program at the community college where the program took place, to co-design an activity in which youth visited a series of significant artistic and economic development sites in their community and used the ARIS platform to make location-based community tours that shared information about these places in a fun, interactive way (DiSalvo, Yip, Bonsignore, & DiSalvo, 2017). Ultimately, our goal was that the youths’ games would become something used by the community’s public relations department to share information with community visitors.

Over the course of a two-week summer camp, forty-seven Native American youth participated in our ARIS workshop and thirty eight (12-14 years old; 23 females, 15 males) fully consented to be part of the research. ARIS is an open-source, location-based programming platform. Individuals with no prior programming experience can use ARIS to create narratives with interactive characters, items, and media placed in real-world locations. We met with our participants over seven days, with each day consisting of 1-2 sessions of 1-2 hours each. After introducing the project to the whole group on day 1, we randomly divided the youth into 15 small groups (2-4 students). On day 2, youth visited their community sites using iPads and a paper and pencil “investigation checklist” to document their site visits in words, photos, and videos (see Figure 1). Five groups went on each field trip: Groups 1-5 visited a series of large metal sculptures created by a local artist, groups 6-10 visited a tribally-owned golf facility and raceway/virtual reality facility, and groups 11-15 visited a tribally-owned stadium complex and an indoor skydiving facility located on tribal lands. On day 3, participants began a paper and pencil storyboarding process, with youth continuing to add to their storyboards in an iterative fashion as they built out their games in the ARIS editor (see Figure 2). Days 4-7 were devoted to translating their storyboards into digital form in the ARIS editor, iterating on their storyboards, and play testing their own games and those of other groups.

Data collection and analysis

Figure 1. Youth using iPads to document the golf course during the field trip on Day 2.
The research team collected a range of qualitative data, including field notes, final reflective interviews, photographs documenting the groups’ making processes, and artifacts produced by each group (storyboards, in-process screenshots, and completed games).

To demonstrate the range and variation in how youth conceptualized cultural elements and integrated them into their community tours, we developed two case studies (Stake, 1995): Groups 6 and 11. We selected these groups because of the distinct ways in which culture was incorporated into their tours, from very little in the case of group 6 to a lot in the case of group 11. Both of these cases also illustrate how locations that might not be immediately deemed culturally responsive within a narrow framing of culture as material culture or heritage culture are, in fact, cultural. Group 6 consisted of two girls and one boy, Hope, Carla, and Eddie, who explored the community golf course and raceway. Group 11 was comprised of two girls, Selma and Tess, and a third individual who was not part of the research. On their field trip, they visited the stadium complex and indoor skydiving facility. All participant names are pseudonyms.

Findings

Culture as backdrop: World politics at the tribal golf course

Based on an idea by group member Eddie, Group 6 configured their community tour as a game where world politics play out on the community-owned golf course. Though they did not name their game, the opening screen describes it as “has something to do with World War 3, Kim Jong-un, Donald Trump, and a hero guy named Robert.” In a reflective interview, Eddie described the freedom to design their own narrative as his favorite part of the task, “I would say that the best part of this project, as of right now, is that we—it’s not a full straightforward thing where you have to choose your particular topic. We just got to choose the weirdest thing. Yeah” (06/13/17, p.6). Here, we see Eddie and his group members taking advantage of the opportunity to exercise design agency (Eglash & Bennett, 2009) over their community tour, something which more than likely would not have been possible within their day-to-day formal school environment. Choosing the weirdest thing is rarely the option available to them in school.

Like other groups, Group 6 began their design process by visiting the golf course and raceway on a field trip, where they took 66 photos and 13 brief video recordings. The majority of the photos and the two videos Group 6 took at the community golf course document natural phenomena (22 photos). Group members snapped 14 pictures of the water features and both videos capture footage of running water. Overall, this group documented the water features the most (second only to selfies and goof off pictures), but they also took photos of waterfowl, trees, and the greens. Moreover, Group 6 took several pictures of the signs indicating the name and number of each hole on the two golf courses at the site, which included names in the community’s two heritage languages. At the raceway, they took 11 photos and 11 short videos of the raceway demonstration and 1 photo of a virtual reality suit. They also documented their peers holding racing trophies. To the best of our knowledge, this group did not make use of their paper and pencil investigation checklist.

When it was time to begin storyboarding on day 3, Group 6 struggled to come up with a narrative that would set their community tour apart from the others and, in reflective interviews, both Hope and Carla noted that they struggled to come up with unique ideas and “figuring out a good storyline” (Int., Hope, 06/15/17, p.5) was one of their biggest challenges. As Hope elaborated in her reflective interview, “[W]e didn’t wanna be like everybody else with the characters and with all pictures. We wanted to figure out something different” (06/15/17, p.5). Additionally, group members did not want to make themselves characters in their game so they “decided to make other characters to be different” (Int., Hope, 06/15/17, p.2), ultimately choosing two controversial world leaders and a classmate, Robert, as characters. At the end of day 3, their storyboard was hardly built out at all, with only two characters (Trump & Jong-un) and one item (the VR suit) that could be acquired by a player in the game. Over days 4-6, they added one character (Robert), one quest, two informational plaques, two conversations, and three items. Interestingly, while group members expressed in reflective interviews that creating the dialog between the world leaders was one of their favorite parts of storyboarding, they did not develop extensive conversations on the paper cards and only one substantive conversation in their game. As Carla reflected, “Fun parts were probably trying—fun parts would be making your character’s own conversations with another character, because you can be creative in your own mind that way. A few weeks ago, I would have never thought that I would be making a game with Donald Trump, Kim Jong-un, Robert, and at [tribally owned] Golf Course” (6/13/17, p.7). Time and again, member of Group 6 stressed that the creative aspects of the project were what made it fun. From a programming standpoint, most youth also found conversations to be the easiest narrative element to program.

Ultimately, the group developed their narrative to include a main character named Robert, after a summer camp classmate. In the game, players help Robert get Donald Trump to specific locations at the community golf
course to meet Kim Jong-Un. They used media downloaded from the Internet for each of these characters. In their final reflective interviews, group members collectively described three quests that comprised their game: (1) Robert meets Donald Trump and takes him to the golf course to discuss peace, (2) the player must navigate Trump to Hole 15 on the golf course where Kim Jong Un and Donald Trump get into a fight about golfing things and must come to an agreement, and (3) a quest where Robert must acquire a virtual reality suit. This third and last quest did not make it into their ARIS game due to time constraints. Further, the group only incorporated one photo that we might describe as having heritage cultural elements, a photo of one of the hole signs from the golf course. The other photo they took themselves was of their classmate, Robert, holding a trophy. and the conversation they detailed in their game consists of a brief exchange with little content. Generally speaking, Group 6’s game remains somewhat undeveloped as they neglected to incorporate elements from their storyboard in the ARIS editor. In this game, what is compelling is the overall narrative and the way in which community cultural elements (the hole sign with heritage languages) and economic development projects (the golf course) serve as a backdrop against which youth were able to explore their interest in world politics and their desire to make “the weirdest thing” (Eddie, Int., 06/13/17, p. 6). Their mere foray into world politics runs counter to popular narratives about Indigenous youth as disengaged in school or uninformed about the world around them (McCarty, Romero-Little, Warhol, and Zepeda, 2009; McCarty & Wyman, 2009; Quijada Cerecer, 2013).

Figure 2. Youth engaged in the paper and pencil storyboarding process and close-up from Group 11’s storyboard.

Culture as key: Escaping the stadium through knowledge
Group 11 created a fantastical narrative in which players were locked in the tribal stadium complex and, with a dog named Milo (depicted by a photo of a German Shepherd downloaded from the Internet) as their guide, had to acquire various pieces of cultural knowledge in order to escape the stadium and their official, evil tour guide. As Tess explained, “We could’ve just left it as a boring thing, like, ‘Okay, go here, and you’ll learn this.’ We added stuff that we had in our imagination. Just adding off each other’s ideas until we got this whole story and plot” (Int., 6/15/17, p. 4). In their desire to make their community tour more exciting, the group members highlight an important point about culture, and especially material culture. Culture matters in context, when it is lived, and this is what the members of Group 11 work towards when they integrate the cultural knowledge embedded in signage at the stadium complex into a fantastical game of their creation (Hermes, 2005).

Group 11 began their game design process with a visit to the tribally-owned stadium complex where two Major League teams conduct spring training and an indoor skydiving facility, both of which are located on tribal lands. The members of this group made extensive use of their investigation checklist, writing several sentences for each question, and identifying picture taking as a favorite part of their field trip experience. Group members took 20 photos at the stadium complex and none at the skydiving facility, reasoning that “there wasn’t that much cultural” there (Selma, Int., 6/15/17, p.4). Later, in her reflective interview, Selma expressed that her least favorite part of the field trip was visiting the stadium complex because, “we weren’t really having that much time to go around and try to get [the] pictures that we needed cuz there was only certain places where they had most of the cultural elements” (Int., 6/15/17, p.1).

In their photo documentation, group members took pictures of signs that had community meaning, either through the use of specific symbols or tribal languages. Examples include a wall-mounted sign displaying basketwork from the community, a series of symbols on the scoreboard, and bathroom signs with “male” and “female” written in both heritage languages used in the community, each of which became the central feature of a knowledge quest in their game. As Selma described the bathrooms signs, “It’s just like—it looks like a regular one, and then on the bottom of it, it has restrooms male or whatever, and then on the bottom it has the different
languages with the language on the side” (Int., 6/15/17, p.1). They also took more general establishing shots, including section markers, the bullpen, and dining options. In their investigation checklist, group members collectively reflected, “Pictures we took were of the important designs of the interior and exterior. We’ll use these pictures to try explaining/showing parts of the culture using the locations.” In addition, group members were aware of the economic significance of the site, writing, “At games/spring training, many people come to watch the teams play. The money that is earned then goes into economic growth/development.” In the pictures they took and their reflections written on the investigation checklist, Selma and Tess make evident that they are aware of both the cultural and the economic significance of the stadium complex.

Figure 3. A conversation from Group 11’s game, where the players meet their guide Milo.

Group 11 went on to develop one of the most robust storyboards of the entire camp, with 16 cards on their storyboard at the end of day 3 and 31 cards at the end of the camp. These cards included the full complement of game elements available to them, including 3 characters, 8 conversations, 12 informational plaques, 5 quests, and 3 items that had to be picked up by the player in order to escape the stadium. Their robust storyboard then translated into a fully-developed game with a beginning, middle, and end. Of the 5 quests, 4 involve demonstrating some sort of cultural knowledge, such as learning heritage language words by visiting the restrooms, reading the captions on the basketwork display, and deciphering the symbols on a sign for the stadium complex. Ultimately, players in the game, upon acquiring three knowledge points by completing the various quests, are given a key that will let them out of the stadium complex. If they don’t use the key to escape, they risk getting turned into dogs like Milo, their tour guide in acquiring the various knowledge items needed to escape the stadium and win the game. In contrast to Group 6, members of Group 11 were primarily focused on learning about the cultural elements at their designated sites from day 1 so that they could create a virtual tour that would teach others. At the same time, they couched this cultural knowledge within a fun, fantastical game with a magical dog as a tour guide. Thus, while culture was a key element, it is not the only element, providing space for youth to explore multiple aspects of their identities.

Discussion

Often, when we think about designing culturally responsive learning spaces, we focus on heritage cultural practices, particularly as they are instantiated in material culture and the act of making, such as weaving a basket or a rug (Dewhurst et al., 2013). While there is meaning in the completed artifact (Hill, 1997), there is also meaning in the process of making. As Tess from Group 11 described, “It was pretty cool, because … you’re like, I’m making this. I’m helping to make this. Then when you actually see the final product, it’s really cool because you’re like, ‘I made that’” (Int., 6/15/17, p.5). In this quote, we see Tess taking ownership of her own learning. Similarly, when Eddie guided his group to make “the weirdest thing.” (06/13/17, p.#), we see them collectively exercising agency and taking ownership over their own learning, as well as narratives about Indigenous peoples. In other words, we see youth exercising both self-education and self-determination (Brayboy & Castagno, 2009), two of the three pillars of how sovereignty is exercised (Wilkins & Lomawaima, 2000).

In the workshop described here, we began from two central tenets of many Indigenous Knowledge Systems (Barnhardt & Kawagley, 2005) and emphasized the process of learning and creating. First, we began...
with the idea that knowledge is connected to particular places and we tasked youth with visiting, learning about, and documenting places that community members had identified as important. Sites like the tribally-owned golf course and stadium complex speak to both the community’s present and future, but also to its past, as evidenced in the cultural details that both members of Group 6 and Group 11 incorporated into their games. Second, we designed the ARIS workshop and community tour assignment from the premise, central to most Indigenous Knowledge Systems, that stories matter. They are used to communicate community history and values (Basso, 1996), but they are also how we build relationships and connect with one another (Williams, 1997). Indeed, youth not only learned stories about the cultural significance of various symbols or places, but they also worked with other community members, some of whom they did not know at the beginning of the camp, to author their own stories about what it means to be young people in an Indigenous community in the Southwest who are interested in world politics and also like fantastical stories about magical creatures. Further, they authored these stories not using pencil and paper, but through programming a computer to create interactive games/tours.

Another aspect of making the ARIS workshop culturally responsive was in providing youth with an authentic, community-based audience for their virtual tours (Magnifico, 2010). As Scott, Sheridan, and Clark (2015) remind us in their conception of culturally responsive computing, it is important to consider “who creates, for whom, and to what ends” (p. 421). In her final reflective interview, for instance, Selma expressed that making her group’s virtual tour was different than other video game kinds of things, which she wasn’t really into, “because it had actual knowledge, and it had real-life things into it instead of just playing a game that has some made-up stuff in it and stuff like that” (Int., 6/15/17, p.6). Similarly, youth who participated in visiting a series of large metal sculptures created by a local sculptor, many of which had stories associated with them, felt tremendous responsibility to get “the facts” right (Searle et al., 2017).

In conclusion, we suggest designing computational making activities that focus not only on the completed artifact, but also on the process of making and on the less tangible ways of knowing, being, and valuing that undergird how cultural communities operate, such as beginning with the significance of narrative and place. While here we focus on these principles as they relate specifically to Indigenous communities and Indigenous Knowledge Systems, place and narrative are significant to most, if not all, cultural communities. In future work, we hope to also explore the pedagogical choices made in culturally responsive computational making activities like the one described here.

References
Calabrese Barton, A. Tan, E., & Greenberg, D. (2017). The Makerspace Movement: Sites of Possibilities for Equitable Opportunities to Engage Underrepresented Youth in STEM. Teachers College Record, 119(6), 1-44.


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Exploring Practices on the Move: Facilitating Learning Across a Neighborhood

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Abstract: As scholars conceive of learning as connected across time, space, and social structures of participation, new questions arise about how to better coordinate learning experiences along those dimensions. In this study, we leverage a design experiment developed with two low-income neighborhoods, to facilitate science learning across the everyday settings of these communities. We focus our analysis here, on how different actors facilitated a common practice that arose organically—probing learners for their understanding—and how that practice moved across different social and material configurations of the neighborhoods. As this practice was taken up by different actors—teachers, parents, and others—we observed the different variations of this practice that learners may experience. By understanding practices on the move, we argue that smart and connected learning ecosystems will require more nuanced noticing, coordination, and layering of different flavors of a practice that can be taken up by a network of actors.

Introduction

Learning is increasingly seen by scholars and practitioners as connected across time, space, and informal and formal settings (Ito et al., 2013; Kumpulainen & Seflon-Green, 2014). From this framing, new questions arise about how to better coordinate learning experiences on the move. The idea of movement can take different forms. For example, first, one might start with the notion of a setting such as a classroom versus an after-school program and note the different learning practices that can be facilitated or experienced across those settings. Education research has a long history of studying a single place as a site of learning and comparing across places (Leander, Phillips, & Taylor, 2010). One might also consider settings that blend diverse values, practices, and goals to create hybrid spaces that can be more inclusive for learners (Calabrese Barton & Tan, 2009). An analytical choice to examine learning across settings attunes one to the features of settings and the distribution of resources and practices across settings in comparison to one another. Second, movement might focus on an individual, following them as they move through time, to different settings, and experiencing different material resources, interactions, social relations and power structures (Bell, Tzou, Bricker, & Baines, 2013). A focus on an individual moving through space, time, and social and cultural structures then, brings attention to the developmental trajectories of learners.

In the following paper, we articulate how recent scholarship has conceived of learning as connected and on the move through lenses such as the above. We then focus on a third possible lens, examining a practice as it moves across people, settings, time, and social and cultural structures (Kumpulainen & Seflon-Green, 2014; Leander et al., 2010). Our context is a broader research project called Science Everywhere (SE) where we purposefully co-designed neighborhood ecosystems of informal learning programs, classrooms, and institutions like the local church, with the goal of connecting science learning across contexts for young people (Ahn et al., 2016). In this connected learning context, we were able to collect observations, recordings, and interactions of learning practices as they occurred across different settings in the neighborhood, enacted by various actors and learners, and in different times and situations. We focus on one practice in the initial analysis presented in this paper—how different actors probed young learners for their science understanding—and trace the nuanced flavors of that practice as it was taken up in these different situations.

Specifically, we look at how this practice can be taken up by a network of actors, buttressed by diverse social and material resources, morphed into different forms, and layered over time. This lens then attunes us to rethink the goal of coordinating, or connecting learning, for learners. In addition to providing learners with access to a wider variety of learning situations (a focus on place), or helping broker connections between spaces (a focus on person moving through places), we might also think of coordination as ensuring that learners encounter the
full range of a learning experiences or interactions that are possible. Coordination may then mean distributing and providing access to all the flavors of a practice across entire neighborhood ecosystems, and not seeing one place or person as responsible for facilitating a given learning experience.

**Theoretical framework**

In the study of how learning connects across time, space, and settings, researchers take different analytical lenses that illuminate different facets of the process. A common perspective is to examine learning in a contained place such as a formal classroom, informal learning setting such as a library, or an online site such as an affinity space (Gee & Hayes, 2012; Leander et al., 2010; Pinkard & Austin, 2010; Subramaniam, Ahn, Fleischmann, & Druin, 2012). Such an orientation attunes us to examine the features of a place and how learning interaction, discourse, or participation comes to be there. The resulting implications then focus on how one might design and structure a place to facilitate deeper forms of learning and interaction, and how we might provide access to diverse places of learning for learners.

However, individuals bring their past experiences, present goals and actions, and future imaginations to bear in a given learning activity (Brown & Renshaw, 2006; Polman & Miller, 2010). This realization begins to orient us to understand how a person moves across experiences, and develops their learning trajectory along the way. This orientation follows a learner through their experiences over time. Scholars have begun to theorize how learners move through different structures of participation. They meet different people along the way, experience learning settings that have different materials and activities, and face different power dynamics where they may be valued in one setting and devalued in others (Bell et al., 2013; Calabrese Barton et al., 2013). This viewpoint starts to enrich our understanding of learning on the move. Not only must we create diverse places of learning that a learner different and rich learning experiences, but we must also figure how to broker and point a learner to a next opportunity in their trajectory (Ching, Santo, Hoadley, & Peppler, 2015).

Finally, we forward a different lens in the following study. Instead of a single place as the focus of analysis, or a learner moving through space and time, we sought to understand how a learning practice could be taken up and coordinated across multiple spaces, people, and situations. Kumpulainen and Sefton-Green (2014) highlight the idea of a chronotope, which is a socially constructed practice that evolves as people make sense of their past, present, and future. Thus, when a researcher observes how students interact with each other in a classroom setting, they can see how the students’ pasts interact with their current interaction or participation, and can relate to their potential practices in the future (Brown & Renshaw, 2006).

In this study, we leveraged a context—two neighborhoods (detailed below)—where we were able to observe several learning settings, neighborhood residents and children (who were present across contexts), and the learning interactions that occurred across time, configurations of materials, and combinations of people. From this larger corpus, we were interested in following a chronotope—a practice—as it manifested across these social and material settings. Specifically, we pulled out a common practice that arose organically in our neighborhoods. We noticed that many different actors (e.g. teachers, informal educators, parents, pastors and others) engaged in questioning behaviors that probed young learners for their understanding of science. However, by looking at this common practice as it moved across people, settings, time, and events, we were able to appreciate the nuanced flavors of that practice, or how different actors took questioning up. Then, as a whole, we foregrounded how layers of questioning can develop different ways for learners to engage in explaining their thinking and connecting with science across their neighborhood. We took up two exploratory research questions from this idea:

1. How did different actors in a neighborhood probe young learners for their understanding across different situations?
2. Were there diverse features of that probing for understanding practice, as it took place across the neighborhoods?

**Methods**

**Context**

All names are pseudonyms in this paper. The context of this study occurred in two neighborhoods: Rockdale (Northeast USA) and Susquehanna (Pacific Northwest USA) where we co-designed neighborhood ecosystems of learning, often taking the role of facilitators. In both neighborhoods, we partnered with institutions such as local schools, churches, and afterschool programs, and then engaged cohorts of young learners across those settings. A major component of our design-experiment was to develop technologies that helped connect learners across these settings. For example, learners shared their everyday science experiences using a social media app that we developed for the project. In addition, we designed large, tangible public displays that were placed across the
neighborhood settings, that made parents, educators, peers, and other neighborhood members aware of the activities that were occurring across the neighborhood (Yip et al., 2016).

Both neighborhoods have Title I schools that serve communities from predominantly lower socioeconomic families. In Rockdale, we worked with Grace Covenant Church, a religious organization that hosts various learning programs (including SE, our own afterschool science learning) within a two-mile radius of our partner school, Westland Middle School. At Susquehanna, we ran afterschool programs, summer programs, and informal family gathering for science learning at Soaring Eagle Middle School. We also worked with Mr. McDonald, a science teacher at Soaring Eagle Middle School. At both sites, Science Everywhere includes hands-on learning activities such as food experiments and engineering projects. In this context, we were able to follow learners as they moved across learning experiences. For the analysis presented here, we were also able to observe and draw out common learning facilitation practices that different actors in the neighborhood enacted across these settings.

Data collection and analysis

Data for this paper is drawn from a larger corpus consisting of field notes (92 pages), videos and audio recordings (59 hours), interviews (22), and application logs (over 4,000 posts). First, in each context, the research team made observations and wrote up field notes and analytic memos. Second, in Susquehanna, we video recorded interactions in afterschool programs (single camera), classrooms (multiple cameras), and informal family science gatherings (multiple cameras). In Rockdale, we video recorded science activities at Grace Covenant Church and placed audio recorders the public, interactive displays. Third, we examine application logs from our social media app that include pictures, timestamps, and textual posts. Finally, we interviewed 12 parents, youth, teachers, and community members across both Rockdale and Susquehanna neighborhoods. We asked questions about participants’ engagement in their communities, the science activities, and their interactions with our technologies. From our larger corpus of data, we focused narrowly on interactions that we observed and recorded between learners and different actors across the neighborhood. We transcribed these interactions and synthesized important aspects of community interactions and learning practices as they unfolded across time and space. One prominent practice occurred when an adult would question and probe a learner’s understanding around a topic or activity. Thus, for our initial analysis in this paper, we pulled out the transcripts of that particular practice from our larger corpus of data, selecting only interactions where clear video or audio files were available, which resulted in 12 interactions. To represent the richness and range within of our data corpus, we purposefully selected interactions that spanned across our study settings, locations, time, and individuals. While all 12 interactions were analyzed, we only reproduce snippets of 6 to demonstrate our findings. For the corpus of video and interview transcriptions, we created inductive codes to organize the data based on different ways in which learners, facilitators, teachers, community members, and parents interacted with each other, the context that surrounded them (e.g., informal learning, formal learning, community event), and their practices (e.g., socializing, questioning and inquiring, and brokering connections). In order to understand the practice enacted in each selected interaction, we drew upon our understanding of the larger context where they developed. In other words, we did not examine the interactions in isolation but also considered each person’s position within the setting, the activities being carried out, and the social context surrounding them.

Findings

We observed two types of probing for understanding—confirmatory and explanatory—each with a different way of moving through contexts, people, time, and space. We use the term enactor throughout the findings to refer to different adults who interacted with a learner in a given situation. Enactors included teachers, researchers, community members, and parents. We use the common term for all these cases to reinforce our focus on the practice they enact as opposed to their positionality within the interaction. Additionally, we’ve emboldened parts of each interaction to show how they illustrate their respective type of probing.

Confirmatory probing

This type of probing consisted of adults checking to see if their statements were being understood during an explanation or observation. Specifically, adults probed for understanding in a confirmatory way by introducing short questions after their statements and sought agreement or a fixed answer from a learner. These questions usually included an affirmative word (e.g., “right”) added at the end of statements. Below, we show three examples of confirmatory probing that illustrate the practice and analyze how confirmatory probing moves across adults, settings, space, and time.

Example 1: Facilitator with learner in front of large interactive display. Our first example involved a facilitator (Tanya) who was also a community member and researcher in Rockdale. The child involved
(Sebastian, 8 years old) had only been attending SE at Rockdale for a few sessions, so Tanya was showing him the SE application on the large interactive display. Throughout the interaction, the facilitator referenced content on the screen while she talked. This informal conversation was not part of a structured activity. Instead, Tanya was having a one-on-one interaction with Sebastian in the hallway, where the screen is installed:

Tanya: And so, what you can do is, you can take pictures… right? And you can write something under it. And you can share whatever you’re doing; it can be at home… like, you can post from home, you can post from school, you know how do you wanna use this at school, okay?

Sebastian: Ah [as in understanding].

Tanya: So, like, let’s look at it and see some ways that some other people have used it, okay? So, what did we do here, this is when we were doing our… what?

Sebastian: Our (inaudible)

Tanya: And what did we do with it?

Sebastian: Uh… we shared it

Tanya: Mhmm, we took pictures, right?

Sebastian: Yeah.

Tanya: We took pictures before and after, right? … And what else? We had here, when we had the concert people were sharing that, right?

Example 2: Teacher with learner who made a post. The following interaction took place in a science 8th grade classroom in Soaring Eagle Middle School. Mr. McDonald set-up an activity where students worked in groups to analyze numerical data related to environmental science and wrote down their conclusions from that data. The teacher asked students to share their thoughts by posting them to the Science Everywhere app, to which all students had access, and an interactive display placed at the front of the classroom where the teacher could review posts. In this example, Mr. McDonald is walking around the room, talking to groups about their posts and asking further questions to a student (Ana):

Mr. McDonald: [Reading a student’s post] “So, overall the weather—” wait, “the weather in the U.S. is increasing” … what does it mean for the weather to increase?

Ana: It’s getting hotter!

Mr. McDonald: It’s the temperature that’s increasing… Temperature and weather are not the same thing… alright?

Example 3: Mother with daughter playing with slinky. The following example takes place at an afterschool informal learning session called Family Science Night, where parents and relatives are invited to participate with their children in the programmed activities. For this session, facilitators had laid out multiple materials to explore the concept of waves without asking participants or their family members to follow any specific instructions. Therefore, this specific interaction did not stem from a structured activity, but emerged naturally from a mother (Susan) and her middle-school aged child (Christina) interacting with the available materials. In this case, Susan is confirming whether Christina is noticing the same phenomenon that she is observing by attaching confirmatory questions to her observations:

[Susan and Christina are playing by extending a slinky over 12 feet and creating waves on each side by tapping or hitting the end of the slinky. Both Susan and Christina shake the slinky and the waves meet in the middle]

Susan: Oh, look! It bounced back, it bounced back and went boom-boom. You can see it, right? Do it again. [Both shake the slinky] See? Boom.

Movement across settings and enactors

Confirmatory probing moved across contexts and enactors in a seamless manner. We found similar instances of this practice in numerous occasions throughout multiple settings. While the content or topic being discussed varied across interactions (from a discussion about a tool to environmental science to waves), the enactment of this practice by the adults remained quite stable. Moreover, these examples of confirmatory probing elicited similar
responses from the learners, who usually confirmed understanding through a verbal expression (e.g., “Mhmm” or “Yeah”) or a gesture (like nodding).

**Movement through time**
Akin to the stability of confirmatory probing across settings and enactors, we found the practice to have a similar role through time in different settings. Confirmatory probing usually preceded a different type of probing for understanding; explanatory probing (see below). Confirmatory probing was enacted during initial explanations or quick clarifications of knowledge that would be probed for in the future. For instance, in Example 1, after Tanya made sure that Sebastian was following along, she asked him to explicitly show his understanding (“And what did we do with it?”). In Example 2, Mr. McDonald confirmed that a student understood temperature and weather as different concepts, a piece of knowledge that had to be properly included later in student-led class presentations.

**Explanatory probing**
Explanatory probing consisted of prompting for an explanation or demonstration of knowledge from the child. As opposed to confirmatory probing, this type of practice did not involve adults explaining concepts or making observations. Instead, enactors asked children to show how they had acquired relevant concepts by including those concepts in their own explanations of phenomena or by correctly answering structured questions. However, our analysis also includes instances where the answer was co-constructed between enactors and learners. Below, we provide three examples of explanatory probing that demonstrate the practice’s variability. Then, we compare them by focusing on how the practice moved across people, settings, time, and space.

**Example 4: Facilitator asking why a circuit works.** In this fourth example, a facilitator and researcher (Justin) reacted when a child (Eric) who had successfully completed a task yelled in excitement. The interaction took place in an informal learning session in the summer in Susquehanna. The children were tasked to create their own circuits with conductive tape, a battery, and a small LED light. While each child was given materials to work independently, they were arranged in tables of four in the room. This interaction began when Justin heard Eric’s excited utterance and approached the table where he was sitting with three other peers (including Amy) who were working on the same activity.

**Eric:** Yeah, I did it!
**Justin:** [Walking over to table] You got it to work?
**Eric:** I did it! Boom!
**Justin:** Let’s see… boom! [goes to the side of child, pulls a chair from an empty table, and sits next to him] Okay so how does- how does it work? Tell me how it works.

**Eric:** So- so, the bottom is the negative.
**Justin:** The bottom’s the negative.
**Eric:** The top is the positive.
**Justin:** The top is the positive, okay.
**Eric:** The top needs to go all the way here to get to there [pointing at his circuit]
**Justin:** What did we say with the flow of electrons? What direction does it go?
**Eric:** Uh… [hesitates, his eyes leave the circuit and he looks up, smiling]
**Amy:** [From across the table] It goes to the positive, right?
**Justin:** [Calmly, redirecting his gaze to Eric] It goes from negative to positive.

**Example 5: Teacher giving guidelines for student presentations.** Our fifth example shows Mr. McDonald at Soaring Eagle Middle School introducing the format he expected to see during student presentations. These instructions were given from the front of the room, while the students sat closely as an audience. The presentations this teacher referenced were set for the end of the class, after the students analyzed different graphs and made conclusions from quantitative data. The interaction transcribed shows how the format of the student’s presentation matched Mr. McDonald’s modeling and criteria:

**Mr. McDonald:** Real quick, the presenter is going to be sharing: the title of the data, the context, and, I’ll actually write this down on the side, so we have it up while we’re looking at it [writes “title” and “context” on whiteboard]. So, we have
the title, we have the context, so, that’s that stuff at the beginning, we’re talking about: what is being measured? So, basically, if you were looking at this [holds a paper with a bar graph up], you’d be saying, “okay, in this, the bars are showing how much area was covered by ice in the lakes, and this is the years”. Just to give us a quick context; what is your graph all about? You’re also going to share your “summary statement” ( . . . ) and then the last is your “possible cause” ( . . . )

Cynthia: [Presenting] The title is “Global average sea level change” and it’s like, measuring how much the sea level has risen [makes an upward motion with right hand] over the years. [Looks at board] And, the sea level has risen ten inches over the 145 years, and we said like, the cause-effect is that humans, we make a lot of products and then that CO₂ [makes a convoluted gesture, like things mixing] it traps like the thermal energy, making the Earth warm, warmer. And then the ice melts and it goes in- it turns into water and then goes into the sea which makes the sea rise.

Example 6: Pastor asking child questions about his paper airplane design. The sixth example shows the pastor of Grace Covenant Church, Pastor Martin, acting as a facilitator. The interaction took place during an informal learning session in Rockdale where the activity was set for children to create their own paper airplanes to begin investigating the principles of aviation. In this case, Pastor Martin was trying to get a child’s (Brandon) attention, asking questions to guide his design, and providing help in answering those questions:

Pastor Martin: Brandon… What are you doing? How are you trying to lay it? What’s it going to do? … Your goals, what’s the goals? Is it gonna go far? Long? Do tricks? What’s it going to do?
Brandon Long
Pastor Martin: How are you going to make sure it does that? … you have to make sure you consider that when you design it.
Brandon [Nodding]
Pastor Martin: So, if we look at [points at other side of room] what people have already done, then we can figure that out. (. . . another child attempts to fly her plane, which does a loop in the air and falls quickly). Why do you think it did that? … My guess is because of these [points at post-its attached to the paper airplane]

While some of these examples of explanatory probing may resemble confirmatory probing in that enactors provide a partial explanation of important concepts, their main difference lies in the response expected from the children in the interaction. In confirmatory probing, enactors expect only a confirmation that their point is being followed or a factual answer. In examples of explanatory probing, enactors expected the children to show that the concept was understood by properly including it within a given structure.

Movement across enactors
Explanatory probing moved across enactors by changing in form and in the type of learning opportunity it created. For example, some enactors probed for understanding by asking for explanations from the children and then participating in co-constructing that explanation (Examples 4 and 6). But, even within these cases, enactors positioned themselves differently during co-construction. While Justin guided the explanation by repeating correct statements and making open-ended questions from a position of knowledge, Martin asked a series of targeted questions and positioned himself as a co-learner to answer his own questions (“we can figure that out”).

On the other hand, Example 5 shows how explanatory probing moved across yet another facilitator—Mr. McDonald. In this case, the teacher creates a clear expectation for the type of demonstration that he wishes to see. While, like in Example 4, Mr. McDonald is looking for a full-fledged explanation of the content, his focus is not on the accuracy of the understanding but on the practice of the presentation of scientific findings.

Movement across contexts
Our analysis shows that explanatory probing moved across contexts in a marked way. Particularly, some settings showed a personal and unstructured flavor of explanatory probing while others showed a more public and
Movement across space
Within a given context, we found explanatory probing to move across physical space. This movement usually marked a switch in probing practice subtype. For example, Justin was walking around the classroom and, after hearing Eric had completed the task, prepared to probe in an explicit way by grabbing a chair and pulling it next to the learner (Example 4). Once Justin was sitting at the same level than the learner, he probed: “How does it work? Tell me how it works”. In a similar way, Mr. McDonald rearranged the physical space of the classroom in preparation for explanatory probing. Before asking students to begin with their presentations, he asked the class to gather by the whiteboard, pulled a chair, and sat next to the students that were not presenting. In this way, Mr. McDonald moved down to their physical level and became one of the audience.

Taken together, these examples suggest that explanatory probing moved through physical space by leveling the enactors with the learners. Whether it is by sitting next to them or participating as a member of the audience, enactors took a secondary role in the space of the room before enacting explanatory probing. We do not have evidence to suggest this movement was purposeful, but it may respond to the intention of giving the learners a principal role during explanatory probing.

Movement through time
Previously, we suggested that confirmatory probing preceded other forms of probing for understanding. Explanatory probing, on the other hand, moved through time by coming after other facilitation techniques, such as adult explanations, activities aimed at developing understanding, and confirmatory probing. The understanding expected to be demonstrated was usually around concepts recently acquired. In Example 4, Justin probed for Eric’s knowledge that was used to create a circuit only seconds before. In Example 5, Mr. McDonald expected a demonstration of the work the students had done in the last two days. In the final example, Martin referenced design knowledge that had been addressed previously within the same informal learning session.

Conclusion, implications, and limitations
Our analysis suggests that the practice of probing for understanding can take multiple forms as it moves across learning settings, enactors, space, and time. Specifically, we noticed how a subtype of probing for understanding—confirmatory probing—remained similar in multiple scenarios and produced a consistent type of response. On the other hand, our analysis of explanatory probing across situations allowed us to make more nuanced distinctions of the different flavors that comprise the practice. For example, Justin used explanatory probing as a way of providing a space for the learner to have more agency over his learning by allowing Eric to create his own explanation. However, Justin maintained a position of knowledge and facilitated Eric’s explanation by providing guidance and asking questions to direct it. On the other hand, Mr. McDonald’s enactment of explanatory probing created a different educator-learner dynamic. In opposition to Justin’s open-ended questioning, Mr. McDonald provided a model to follow and allowed students to practice presenting their scientific knowledge within that structure. Although Mr. McDonald did not interrupt or guide students during their presentations, he evaluated their adherence to the presentation model. Finally, Pastor Martin enacted explanatory probing moved across formal and informal settings suggests that, while all enactors effectively probed for understanding, the specific form of their enactment of that practice affected the types of responses they elicited from the learners, and therefore the learning experience they created.
probing not only by providing guiding questions to the learners, but by co-constructing their responses and participating in the activity as a learner. We note that these subtle yet significant differences in enactment were made visible by our focus on a specific practice and analysis that zoomed into interactions among a wide range of adults and children in a multiplicity of settings, across time and space.

Therefore, this study has implications for how educators and researchers conceptualize connected learning. As our practice-based analysis shows, a focus on the enactment of these common practices reveals nuances and differences that can influence the learning environment and learner’s experiences. From this perspective, we argue for the coordination of learning practices across neighborhood ecosystems so that children might be exposed to all flavors of the practice of probing for understanding. For example, identifying the ways in which facilitators in an informal learning setting enact explanatory probing may assist in the designing of such learning environments to promote other forms of probing that create different learning experiences. Additionally, coordinating how, when, and where these practices are enacted across neighborhood settings can ensure that children have many and varied opportunities to show their learning in different ways.

Due to the exploratory nature of our questions, we note the limitations of this initial analysis. First, while our analysis allowed us to describe each interaction in detail, we cannot speak to each practice’s frequency in the observed settings. In other words, we did not attempt to determine which types of probing for understanding happened most often but sought instead to characterize how those interactions played out, when they played out. As described in our Methods, we purposefully selected interactions that covered a wide range of settings, facilitators, learners, and activities to show the full spectrum of the practice. We do not assume that these interactions are a representative sample of all interactions during our study. Additionally, we want to make clear that our analysis does not entail a judgment of each of the practice’s flavor. We do not suggest that one or another subtype of probing for understanding is better or worse than the other; nor we intend to prescribe a type of probing to a setting or person. Our findings along with the limitations of our study point to the importance of future work in coordinating learning experiences across settings by arguing for an integration of practice analyses in those coordination efforts.

References


From Theory to Practice: How Pre-service Science Teachers Learn to Become Social Justice Educators

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Abstract: There is a movement within teacher education programs to prepare social justice educators equipped to disrupt systemic oppression and inequity. While studies have looked at how programs prepare teachers to teach for social justice, they tend to focus on teachers’ beliefs and few examine teacher education programs as a whole. Urban teacher residency programs have emerged as hybrid spaces addressing the disconnect between campus courses and field experiences, attempting to support teachers applying theory to practice. This study follows a cohort of pre-service science teachers in an urban teacher residency program over the course of their 18-month teacher preparation program. We analyzed written artifacts collected throughout the year to examine the evolution of their definitions of and practices related to social justice. We present two contrasting case studies to highlight their divergent learning pathways and the specific residency program experiences that influenced their learning.

Introduction
How to effectively prepare the next generation of teachers with the knowledge, skills, and abilities to improve student learning and outcomes is a hotly contested policy issue. The stakes are particularly high for students in urban communities who have been historically underserved, impoverished, or marginalized, and the assignment of teachers with poor and/or limited training continues to be the norm (Goldhaber, Lavery, & Theobold, 2015). Deficit thinking continues to dominate the discourse for students in urban communities (Liou, Marsh, & Antrop-González, 2017, Ullucci & Howard, 2015). There is a movement to disrupt this deficit discourse within teacher education programs and to “prepare a teaching force capable of producing equitable learning opportunities and outcomes for diverse students in the context of enduring inequalities” (Cochran-Smith, Villegas, Abrams, Chavez-Moreno, Mills, & Stern, 2015, p. 114). Yet, teaching for social justice is a phrase that novice teachers may not know what it means (Lee, 2011), or may equate it with multicultural education (Mills & Ballantyne, 2016). In this paper, we examine an urban teacher residency context where the term social justice was used regularly and deliberately, but where even so the meaning could be difficult to nail down. We pay close attention to the voices of the pre-service teachers as they struggled with the concept and worked to put it into practice. We analyzed written artifacts, collected over the 18-month urban residency program, from secondary pre-service science teachers to understand how their participation in the residency program challenged, supported, and shaped the evolution of their complex understanding of what it means to practice social justice education.

We draw upon the work of Jurow, Tracy, Hotchkiss, and Kirshner (2012), which calls attention to and values the idea that pre-service teachers begin teacher preparation programs with different histories and experiences and thus respond differently to theories and pedagogies taught in university coursework. We view learning to become a social justice educator in the same manner, as an issue of teacher learning where the situated nature of learning shapes teachers’ historically and culturally informed interpretations of theories and pedagogies emphasized in university coursework and applied in their student teaching placements. We use the idea of situated sensemaking (Rosebury & Puttick, 1998) to trace teachers’ experiences in the residency program and examine their sensemaking as they 1) engage deeply with theories and pedagogies of social justice, 2) use tools and resources to facilitate making sense of these theories and pedagogies, and 3) enact and revise their practice relative to student experiences and responses.

Methods
This study asks two questions. What are pre-service teachers’ ideas about what it means to be a social justice educator? How do pre-service teachers’ experiences in an urban teacher residency program influence their ideas over time? In answering these questions, we aim to examine how pre-service teachers wrestled with understanding theories of social justice emphasized in the residency program and, more importantly, examine
how they enact those theories into their own teaching practice. Such an understanding will call attention to salient features of teacher education programs that promote teacher learning around issues of social justice and offer practical examples of how teachers make sense of theories of social justice relative to their teaching in urban science classrooms.

Study context
Inspiring Minds Through a Professional Alliance of Teachers (IMPACT) is an urban teacher residency program housed in the UCLA teacher education program. IMPACT prepares about 50 new secondary mathematics, secondary science, and elementary teachers each year. It situates pre-service teachers’ learning from university coursework in the context of mentors’ classrooms in small autonomous schools and urban communities. Within this program, secondary pre-service teachers are matched with a mentor and begin their student teaching on the first day of school and continue with the same mentor until the final day of school. Teachers spend three and a half days in the field and take courses during the remaining day and a half. The residency program employs a gradual release of responsibility model (Fisher & Frey, 2013), where teachers observe during the first few months of their student teaching, co-plan and co-teach during the next few months, and eventually take responsibility for two teaching periods from their mentor for the remaining months of the school year. After one year of coursework and student teaching, pre-service teachers obtain their preliminary teaching credential and find a teaching position within the program’s partner local education agency (i.e., Los Angeles Unified School District). During this second year, teachers continue taking courses in IMPACT towards the completion of a master’s in education degree.

The mission of both the UCLA teacher education program and IMPACT is to prepare teachers with the commitment, capacity, and resilience to work in the most underserved communities. The program works to develop teachers’ capacity to challenge deficit thinking around the academic achievement of students from historically marginalized communities through humanizing pedagogy that involves respecting students through an asset-based teaching approach (Bartolome, 1994). Yosso (2005) defines this asset-based approach as a call for social justice teachers to use the knowledge and assets of students, families and their communities to inform their classroom teaching. By doing so, teachers dive deeply into what it means to be a social justice educator by reflecting on their multiple identities in relation to privilege and power. By understanding their positionality (i.e., reflecting on their own experiences relative to the experiences of their students), teachers form a deeper understanding around why practices that value students’ voices, experiences, and histories are necessary for enacting humanizing pedagogy (Takacs, 2003). That is, teachers come to realize that in order to meet the needs of students in underserved communities, their students’ voices, histories, and experiences must shape the way they approach their own teaching.

University coursework for this residency program is organized around a program developed teaching and learning framework that positions social justice values as the foundation for rigorous science teaching (see Nava, Park, Dockterman, Kawasaki, Schweig, Quartz, & Martinez, 2018). The framework contains four core dimensions of teaching quality with eleven aspects of teacher classroom practice. Briefly, the four core dimensions are: 1) teaching with academic rigor, 2) promoting content discourse, 3) ensuring equitable access to content, and 4) building a positive classroom ecology. Our own work has shown how this framework has supported novice teachers’ development of an asset-based perspective of social justice (Kawasaki, Nava, & Francois, 2017) and encouraged teachers to come together as professional learning communities to provide feedback and promote productive content discourse (Nava, Park, & Kawasaki, 2015). Teachers also engage in a yearlong social foundations course that provides them with opportunities to wrestle with the historical and cultural factors (e.g., unequal distribution of power, addressing one’s own power and privilege) that contribute to systemic inequity and oppression (Philip, 2013). These courses are intentionally designed to provide teachers with opportunities to reflect on how these theories and pedagogies translate into everyday teaching practice. To further encourage productive discourse, secondary math and science teachers take classes together as a cohort, which enables them to support each other’s thinking about social justice in their student teaching placements. In combination with extensive field experiences in some of the most underserved schools and communities in the nation, these experiences create a fertile place for teachers to develop their ideas about what being a social justice educator means and how to enact that on a daily basis with their students.

Participants, data sources and analysis
In total, the secondary residency cohort included eight science and eight math teacher candidates. For this paper, we focused on the eight science pre-service teachers because we had complete data for each of them and felt that mapping these teachers’ journeys through the program might provide some insight into how they conceptualized
social justice oriented science teaching and inform any programmatic refinements that might be needed to support their development. We analyzed five specific artifacts collected within the residency program: 1) statements of purpose from entrance applications, 2) quarterly reflections assigned before teachers’ individual meetings with their faculty advisor, 3) philosophy of teaching papers written in the winter quarter, 4) community inquiry project reflections in the spring quarter, and 5) inquiry projects completed in the subsequent fall for their Master’s in Education. These documents gave us multiple data points across an 18-month period in which teachers shared their ideas about what it meant to be a social justice educator. For example, teachers were asked to describe why they were interested in becoming a social justice educator, or in the case of the reflections and papers, how their ideas of being a social justice educator had changed over the past academic quarter.

To understand how teachers conceptualized social justice at the beginning and at the end of the program, the first step in our analysis was to examine the application statements and the Master’s inquiry projects. Responses were analyzed thematically, by grouping similarly worded responses together and labeling them. These labeled groups were constructed independently by a researcher and then discussed and revised by a research team. The next step was to examine the quarterly written reflections and mid-year assignments (i.e., community inquiry project reflection, philosophy of teaching paper) to understand teachers’ experiences in the residency program (e.g., coursework, readings, student teaching) and how those influenced their evolving ideas about social justice. In these written reflections and artifacts, we used the approach from Rosebury and Puttick (1998), in which we looked for language that related to the theories and pedagogies discussed in university coursework (e.g., course readings, language from the program’s teaching and learning framework), the tools and resources made available to teachers (e.g., meetings with faculty advisors, discussions with cohort members), and how they related these ideas to student experiences (e.g., student teaching placement, discussions about students with their mentor). This allowed us to develop contrasting case studies to highlight the different ways that teachers made sense of their experiences in the residency program. In this paper, we highlight the sensemaking journeys of two teachers in the residency program, Cheryl and Nancy. We chose these two teachers to showcase because while both teachers were from communities of color and grew up in upper middle class neighborhoods, their experiences in the program represent the sensemaking divergence that can happen despite being in the same cohort, taking the same classes, and having similar experiences in their student teaching contexts. We place high value in this divergence because it honors the varying starting points, journeys, and ending points for teachers who are committed to becoming social justice educators.

**Findings**

We present these analyses through two contrasting case studies. The first, Cheryl, makes sense of her development as a social justice educator through a clear orientation towards learning about her students and embedding their stories into her lessons. Eventually her journey through the program leads to her root out deficit thinking by recognizing her own assumptions, privilege, and upbringing in relationship to the drastically different urban context where her students live and attend school. Then we share about Nancy, whose journey begins with a struggle to understand how to assimilate social justice into her everyday teaching and eventually comes to understand how the notion of being a good science teacher is an enactment of social justice. We begin with Cheryl.

**Learning about students and examining positionality**

Cheryl, a child of immigrants from Korea, grew up in a comfortable suburban environment. She spent a summer as a volunteer in rural Nicaragua and it was there that she discovered that for many, attending college was considered a luxury, and where she recognized that the same was true for many young people in the United States. “I want to fight against these inequalities,” she wrote in her application. She came to the residency program with a commitment to help students see themselves as “stewards of this planet” and a broad goal of fighting inequality. Early passion for protecting the environment had given her the desire to “teach … environmental science, to transform students’ attitudes towards education, and to inspire them to be responsible, contributing members of society and of the world” (application statement). Cheryl’s student teaching placement was at a large public comprehensive neighborhood school with a student population that was 91% Latino, 7% African American, 94% socioeconomically disadvantaged, 31% English language learners, and 14% students with disabilities. During her student teaching year, 18% of students scored proficient or advanced in state standardized science assessment.

As mentioned, Cheryl came to the residency program with a broad goal of fighting inequality. After beginning the program, she developed a much more personalized understanding of social justice that centered on cultural relevance, relationships with students, and fighting her own deficit thinking. In her first reflection,
she drew upon the summer social foundations course as she described how her vision for social justice was evolving.

I thought that there was a universal approach to being the best teacher, whether working in a high or low SES community. I’m learning that is not really the case. Teaching has to cater to the exact audience and students learn in different ways, but my teaching goal has evolved from a universal learning method. From ED406 [social foundations course] I learned that the best way of learning is influenced by their culture and environment (end of summer reflection).

Cheryl’s first course in the residency program immediately shifted her thinking about social justice as she came to the realization that getting to know students’ interests and experiences (i.e., “culture and environment”) matter for student learning. The social foundations course introduced Cheryl to new ideas that moved her thinking away from a universal teaching approach to one that values the knowledge and ideas that students bring to the classroom.

During the fall quarter of her student teaching placement, Cheryl had transitioned from observing to co-planning and co-teaching with her mentor. In her fall reflection, she described how she approached her lesson planning by considering students’ interests and experiences.

My vision for social justice is changing every day. I think about what my lessons mean for the kids. My first thought after writing out my lesson plans are “why should the students care”? This question requires me to think about how my lesson reaches the students and how the lesson culturally speaks to them (end of fall quarter reflection).

Cheryl’s earnest effort to design her lessons relative to students’ experiences and to think about how they might respond during class instruction was influenced by her desire to enact the theories she learned in the summer into her fall student teaching responsibilities.

During the winter, Cheryl attached a theoretical label to her evolving understanding of embedding students’ experiences and interests into her lesson planning.

Culturally Responsive Teaching (CRT) begins with me truly getting to know the students…view[ing] the student as who they are both at home and at school…taking to an account of the student’s cultural background, their families, and their academic potential…The holistic cultural knowledge of a student can only become useful when the teacher activates that knowledge within the curriculum…An analysis of the student’s household can greatly impact the teaching of a social justice educator (philosophy of teaching paper, winter quarter).

As she was exposed to new ideas and theories in her coursework and experiences with students in her student teaching placement, her understanding of social justice became more complex. Into the winter quarter, Cheryl’s understanding of social justice expanded beyond just getting to know students’ interests and experiences to include understanding their culture, home, and histories.

Cheryl enacted this expanded understanding of social justice in her community inquiry project, where she organized a schoolwide basketball tournament. She described how this tournament was an opportunity to build community within the school by removing behavior or academic restrictions on who could participate to reach as much of the student body as possible. She reflected on this experience as another way to build meaningful relationships with students.

Her desire to get to know her students expanded to an interest to understand the needs within the community.
Finally, in her first teaching assignment as teacher of record, Cheryl’s understanding of the importance of understanding her students’ interests, histories, and experiences relative to her own (i.e., positionality) became concrete as she came to intimately know her students and their community. She described this learning in her Master’s inquiry project.

The first lesson I learned as a first-year teacher in an urban environment was that the environment I grew up in was very different from my students. The streets I grew up on were isolated from any commercial areas. They were filled with parks, homes, swimming pools, and any kind of nature that could fill in the gaps. The streets my students know are beautiful and colorful in a very different way. Their streets are covered in artistic murals with colorful and vintage urban buildings… I need to continue to examine my own identity as well as engage in discussions that help me to get to know my students more… I had to learn to come to terms with this difference in our childhood environments. Not only were our childhood environments physically different, but I realized that the teaching styles I grew up with that worked for me may not necessarily work for my students (Master’s inquiry project, fall quarter, year 2).

Cheryl seemed to be faced with the stark discrepancies between her own experiences and the experiences of her students. Rather than take a deficit perspective on the features and experiences that her students’ community lacked, she found new beauty and value in these differences. Cheryl’s willingness to consider other teaching approaches given this new perspective depicts the intersection of social justice theories and practice, where Cheryl’s approach to teaching is being influenced by the theories emphasized in her coursework (e.g., see community cultural wealth, Yosso, 2005). The residency program gave Cheryl the means to develop her own vision of social justice education in response to her sensemaking journey through readings from university coursework, interactions with students, and other experiences in the residency program. Where she had initially focused broadly on global citizenship, her ideas became more complex and involved into self-critical thinking about classroom practice relative to her students’ interests, experiences, histories, cultures and families.

Social justice educators enact rigorous science teaching

Nancy, a child of immigrants from Iran and Egypt, grew up in an affluent community. Her draw towards teaching came from volunteering with a mentorship program for a local urban high school during her college years. She eventually took on a leadership position within the group and attributes this experience as her most valuable lesson on education, that “there are very real and systematic barriers to education that create unequal access to it, and that all comes with historical, political, economic and racial baggage” (application statement). Her commitment was solidified as she drew connections between her own experiences with microaggressions and racism as a Muslim and the struggles with systemic inequity and oppression of the African American students she mentored. Nancy came to the residency program wanting to “empower my students to think critically…to realize their ability to transform their communities through their own education” (application statement). Nancy’s student teaching placement was a large environmental and science policy magnet school with a student population that was 70% Latino, 24% Asian, 1% African American, 70% socioeconomically disadvantaged, 17% English language learners, and 15% students with disabilities. During her student teaching year, 44% of students scored proficient or advanced in state standardized science assessment.

In contrast to Cheryl, Nancy’s journey through the program began with an initial struggle to make connections between the theories of social justice emphasized in the residency program and her everyday classroom teaching. Through specific experiences in the program, she developed the sense that social justice educators enact rigorous science teaching. Nancy began with an admission that it was not clear to her how theories of social justice and everyday teaching merged together.

I think I have an easier time understanding how I can implement social justice in individual conversations with my students rather than how I can implement it into science content… I’m still trying to comprehend the different places to include social justice, [but] have not reached a synthesis stage (i.e., teaching NGSS with a social justice framework) (end of summer reflection).

This reflection was written after the summer social foundations course, which emphasizes critical theories and pedagogies that center social justice teaching around the assets and community cultural wealth (see Yosso, 2005) that students bring to the classroom. Nancy’s admission that she struggled to see how she could enact
social justice in building relationships was a reasonable response to the emphasis in the course around getting to know students. During her fall reflection, she described getting to know students in this way.

It was surprising for me to realize how much I think about my students outside of school. I already care about them so much and watching them give up or go through struggles genuinely hurts me as well…teaching for social justice is a long process and is never full finished. Now I don’t see social justice teaching as a fixed goal…but rather a process of teaching that I must constantly engage with and use. I also want to learn more about the community, and be more of a learner from my students in that sense (end of fall quarter reflection).

Nancy began co-teaching with her guiding teacher during the fall quarter and realized the challenge of enacting theories of social justice in the classroom. Her resolution seemed to be to continue to listen to students and understand how to best support them despite their own frustrations and struggles.

In the winter quarter, the methods course incorporated two instructional rounds where teachers video record their teaching and engage in peer feedback. The promoting content discourse dimension from the teaching and learning framework is emphasized in the methods course and instructional rounds during the winter quarter. During this quarter, it seemed that Nancy was beginning to develop a sense of how to reconcile her early struggles of separating social justice and teaching science.

Whereas I first saw a silent classroom with all eyes on the teacher as the epitome of excellent teaching, my views have since dramatically changed. I now see discussions between teachers and students, and amongst students engaged in content discussions, as the epitome of excellent teaching…I have also seen how important family and community is to my students, and it has helped me to see the necessity of involving my students’ families and community into my teaching practice. For example, a field trip to the Los Angeles River where students collected data on species and water samples was very exciting for my students, as many of them live nearby the LA River, but understandably have never really explored it from a “scientific lens” (philosophy of teaching paper, winter quarter)

By learning about the importance of content discourse in student learning, Nancy found a way to enact the theories of social justice that she struggled with during summer and fall. Nancy seemed to be making the connection, emphasized in the program, that excellent science teaching is an imperative part of being a social justice educator. Also, Nancy started on her community inquiry project during the winter quarter, which highlighted ways that she could further connect social justice theories to her own classroom teaching (e.g., studying the LA River). In her community inquiry project reflection in the spring, she expanded on the idea of how to use local scientific phenomena in her science teaching and how that served as an act of social justice.

I feel that the community is vibrant, with lots of rich celebration of Latin American culture. The [project] has taught me to view the community with an asset-based mentality as opposed to a deficit mentality. As a science teacher, I would like to explore the ways in which my students might tap into community resources to “do science”. This could range from studying and documenting urban wildlife and green spaces, to examining the prevalence of certain diseases and the availability/accessibility of health care. In this way, I hope to develop a more culturally relevant and culturally responsive curriculum for my students (community inquiry project reflection, spring quarter).

Nancy, like Cheryl, learned to name the theories and pedagogies of social justice she was trying to enact. Nancy’s understanding of social justice seemed to be getting clearer as she was able to identify some concrete and actionable ideas to use in her teaching. Nancy reiterated her growing appreciation of the community and how she could leverage this in her teaching as well as the importance of content discourse as the epitome of good science teaching.

I now see…students engaged in content discussions, as the epitome of excellent teaching…I want students to recognize that when they work together, they will be amazed at how much they can think of and solve without me as a teacher being the ultimate dispenser of knowledge…it takes effective collaboration and building off of one another’s ideas to lead
them to those great solutions. I rarely experienced the benefits of effective collaboration throughout most of my time as a student, but I became fascinated with the importance of collaboration when learning about sociocultural learning theory...students must be given opportunities to share their ideas and thoughts constructively with one another in order to develop solutions to the issues that matter to them (Master’s inquiry project, fall quarter, year 2).

The residency program gave Nancy, like Cheryl, the opportunity to struggle through and make sense of how to enact theories of social justice into her classroom teaching. Initially this was a struggle for Nancy, who admittedly did not see how these theories unfold in the classroom aside from individual interactions with students. Over time and through experiences in the residency program, she developed a sense of how rigorous science teaching that promoted content discourse and collaboration was itself an essential part of being a social justice educator and concrete way to enact social justice theories in her everyday teaching.

Conclusions and implications

Our study sought to examine how novice science teachers develop into social-justice oriented teachers and how the opportunities within an urban teacher residency program supported their development. Although Cheryl and Nancy brought different life experiences to the program and gave their own versions of social justice education, the key insights from their journeys were that socially just science education required rigorous and equitable teaching on the one hand and caring relationships with students on the other. We found that these ideas were developed through 1) deep engagement in content (e.g., coursework reading, discussions, written reflections), 2) engagement with tools and resources (e.g., quarterly debriefing with faculty advisors), and 3) enactment and revision of one’s own understanding through interactions with students (e.g., lesson planning and teaching in student teaching placements). Cheryl and Nancy came to the residency program with similar experiences working with children in their undergraduate studies and similar initial ideas about social justice. Yet, their experiences in the residency program depicts the situated sensemaking that occurs in these programs as teachers wrestle with complex ideas, such as race and poverty, and attempt to enact theories and pedagogies aimed at disrupting systemic oppression and inequity. We argue that there is value in the different understandings, enactments, and journeys that teachers take as they are built from their own experiences, histories, and interests and in response to the urban contexts in which they teach.

The IMPACT urban teacher residency program is a teacher education program established to provide low-income urban schools districts with high quality, highly prepared, and committed teachers. The secondary teachers who enroll in this residency program know a lot about their placement classrooms in advance: they will focus on STEM in classrooms populated by minority and low-income students, many of whom are also English Language Learners and come from immigrant communities. The incoming pre-service teachers, who themselves come from various racial, ethnic, and socioeconomic backgrounds, chose this program with this foreknowledge in concert with a commitment to social justice education, even though the definitions of what counts as social justice might vary widely between applicants. As these two case studies reveal, the applicants came to their residency program to become teachers to “make a difference,” be role models to students, empower their students to learn, teach STEM, and increase minority participation in STEM fields. In ways both general and specific, at the outset of their teacher preparation program, they saw themselves already connected to their future students and saw their mission as teachers to engage their students within a larger community of practice, a community of practitioners working together in a project towards social justice. All participants saw social justice education as a life-long process and results from this study suggest that the journey can take unexpected and divergent pathways as teachers learn and enact these theories and pedagogies of social justice relative to their own experiences, histories, and interests and the students in their classrooms. These findings shed light onto the multiple meanings of “social justice” in education and can help inform future research about how programs can effectively prepare and support the diverse needs of aspiring social justice educators.

Current science, technology, engineering, and mathematics (STEM) policy in the United States calls for teachers to ensure equitable access to rigorous STEM instruction for historically underserved communities (Next Generation Science Standards, NGSS Lead States, 2014; Common Core State Standards for Math, CCSSO, 2010; National Education Technology Plan, Office of Educational Technology, 2017). These recent STEM policy reforms seem to have sparked an increased interest among learning scientists to study and understand teacher learning from the perspective of learning science theoretical and methodological frameworks. With equity as a central idea within each of these policy reforms, it is imperative that we understand how teachers learn to become a social justice oriented STEM teachers in order to shape professional learning for pre-service and in-service teachers around the intersections of content, theory, and practice.
References

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Design Considerations for Capturing Computational Thinking Practices in High School Students’ Electronic Textile Portfolios

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Abstract: Assessing computational thinking in making has proven a challenge, in part because student creations are intrinsically diverse and unique. In this paper we consider portfolios as a way to document and assess students’ learning processes in the context of designing electronic textile (e-textile) projects. We describe students’ use of portfolios at the end of an introductory computing course, Exploring Computer Science, during which 33 students created a series of electronic textile (e-textile) projects as part of a new curricular unit. Our analysis not only illuminates the capability of portfolios to capture computational practices and certain concepts, but also reveals students’ lack of effective use of non-textual evidence in their narrations. We consider the affordances and limitations of portfolios for supporting student reflection and metacognition of their own learning as well improvements that could be made to scaffold students’ communication and use of visual evidence in more effective ways.

Introduction
Assessing student learning in computationally-rich maker activities has been a challenge for practitioners and researchers alike. While early discussion about educational making assumed the creation of an artifact could demonstrate the acquisition of skills, content and even a ‘maker mindset’ (Honey & Kanter, 2013; Dougherty, 2013), continued spread of these activities into formal educational settings has made researchers interested in not only asking what students learn, but also how to appropriately assess learning (e.g., Papavlasopoulou, Giannakos, & Jaccheri, 2017). Recent efforts in this arena include the development of traditional evaluative tools such as written tests or surveys (e.g., Litts, Kafai, Lui, Walker & Widman, 2017; Chu et al., 2015) and more novel approaches such as hands-on engineering performance tasks and eye tracking (e.g. Davis, Schneider & Blikstein, 2017). However, these assessments do not capture the process of making or the kinds of learning that students gain while working through mistakes, errors, and changes in their project. For this we turn to portfolios.

Portfolios have long been used as an assessment tool in disciplines such as art, design, writing and more recently in STEM fields (Chang et al., 2015; Byrgyn & Adnan, 2007). Not only can portfolios provide more holistic measures of learning, capturing process and growth over time (Paulson, Paulson & Meyer, 1991), they can also be situated within students’ everyday work and context (Byrgyn & Adnan, 2007). Within computer science education portfolios have recently gained more traction through the newly launched Advanced Placement Computer Science Principles (AP CSP) course (College Board, 2017), where they have supplemented the standard multiple-choice exam. Beyond assessment, however, portfolios can be powerful learning tools in and of themselves, allowing students to reflect upon their own experiences and regulate their own pathways of learning—in other words, develop metacognition skills, something that can support more equitable learning (Darling-Hammond, 2008). However, though portfolios are acknowledged as a powerful channel for both assessment and reflection within a wide range of established disciplines, less is known about how well they are able to capture and support student learning of computational thinking, or skills involved in “solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science” (Wing, 2006, p. 33), such as abstractions, iterations, and algorithms.

In this paper, we report on a study focused on the design and implementation of a portfolio assignment that aims to capture students’ computational thinking. We worked with a high school computer science instructor teaching electronic textiles where students sew and program sewable microcontrollers, actuators, and sensors attached to fabric based artifacts such as clothing and toys (Buechley, Eisenberg, Catchen, & Crockett, 2008). Based on previous research looking at the effectiveness of teacher-designed portfolios in capturing students’ processes of working with electronic textiles (Lui, et al., under review), we designed a portfolio assignment that was given to (and adapted by) the high school teacher for the purpose of capturing his students’ learning, practices and reflections. Students were provided prompts regarding content and media use, with a specific focus on capturing students’ computational thinking practices (Brennan & Resnick, 2012) including...
revision and iteration as well as debugging and troubleshooting, and concepts including coding, circuitry, design, and crafting (Kafai, Fields, & Searle, 2014). Analyzing the text, images and videos of the students’ portfolios, we addressed two research questions: (1) How did this portfolio implementation support students in documenting and sharing their processes of making a computational artifact? (2) What are the affordances of the portfolios for revealing students’ computational thinking and concepts learned? In our discussion, we address affordances and challenges of using portfolios and report on recommendations which include more defined scaffolds, as well as models of effective computational communication. We also discuss avenues for future research in these areas.

**Background**

Though portfolios have been used across many disciplines and fields for assessment, their actual formats and contents vary widely, providing different models for measuring and supporting computational thinking. In art and design, the predominant form promotes the curation of one’s best projects over time, allowing a ‘showcase’ of overall competency and skill (Byrgyn & Adnan, 2007). STEM portfolios tend to follow another format derived from writing (Williams, 2002), which focuses more on continuous documentation of students’ learning and growth (Paulson et al., 1991), sometimes through progression of just a single project (Chang et al., 2015). These ‘process-portfolios’ often focus on collection of different kinds of in-progress evidence compiled over a student’s trajectory. This includes a range of often non-textual forms such as initial prototype ideas for engineering projects (Eris, 2007), code throughout the development process (Higgs & Sabin, 2005), or photos of projects in progress (Chang et al., 2015). Rather than merely presenting their artifacts, students provide textual explanations for this evidence, whether explanatory captions and annotations (Byrgyn & Adnan, 2007), articulation of underlying concepts (Phelps, LaPorte and Mahood, 1997), or narrations of growth and learning (Paulson et al., 1991). For this reason, these types of portfolios highlight the actual aspects of creation and reasoning around production that are normally hidden when only relying on final products as a form of assessment (Chang et al., 2015).

Little is known about how well portfolios are able to capture novice students’ computational thinking through the creation of an artifact, digital or not. As highlighted by Brennan and Resnick (2012), opportunities for youth to describe their experiences while creating computational artifacts can provide a window into their understanding of their computational thinking skills, something that can encompass knowledge of particular concepts, practices, and perspectives. Much of this depends on students’ communicative abilities, a skill that is not often stressed in the context of computer science, let alone other STEM fields (Michael, 2000; Williams, 2002). In CS education, this is not just a factor of knowing the “vocabulary of computing” (Grover, Cooper & Pea, 2014), but also being able to use these terms in context, something that has been proven to foster “deeper computational learning” and nurture students’ abilities to think about “computational ideas more effectively” (p. 58). This lack of emphasis on communication in computational contexts seems especially problematic, considering that it has recently been highlighted as a key computational practice within the AP CSP (College Board, 2017). There, it is described as a student’s ability to report on one’s own computational choices and justifications, well as describe the results or behaviors of computational artifacts (p. 10). Notably, the way that students are expected to accomplish this includes leveraging “accurate and precise language, notations, or visualizations” (p. 10)— in other words, focusing on both text and images. However, as noted by Williams (2002), expecting that students can effectively communicate about technical issues without assistance is not practical; not only does this require more careful scaffolding, but also actually defining what ‘counts’ as effective communication within this realm and explicitly sharing this with students.

The difficulty of using portfolios to promote student communication about computation was highlighted within a previous study (Lui et al., under review), where we also analyzed the use of a teacher-designed portfolio assignment for assessing computational thinking. There, students created portfolios to reflect their process of making an electronic-textile sign. The format of that portfolio was based primarily on the four established domains of e-textiles work: design—the planning of the aesthetics of a project, circuitry—the creation of electrical connections between components, coding—the programming of students’ projects, and crafting—the physical sewing and construction of the project. Students were asked to describe their experiences within each of these domains, with recommendations to discuss challenges and include non-textual evidence such as photographs, diagrams, and code excerpts. While this portfolio format was successful at capturing the general nature of students’ processes and practices in making their artifacts, it was not as successful in capturing the actual details of these experiences or the students’ understanding of underlying computational concepts, whether in coding or circuitry. Furthermore, students’ use of images and code as evidence varied greatly; most students primarily used them as a part of their aesthetics, offering little explanation or contextualization. Based on these findings as well as research on how process-portfolios can be structured, we designed a portfolio...
assignment to address these potential weaknesses in capturing students’ computational thinking. This included an initial focus on computational practices rather than concepts and requiring the use of non-textual process evidence such as photos and diagrams. Our goals were to look at how well the portfolios were able to capture students’ experiences and reflections for the purposes of student learning as well as assessment.

Methods

Context and participants

The Exploring Computer Science (ECS) initiative comprises a one-year introductory high school computing curriculum with a two-year professional development sequence (Margolis & Goode, 2016) to increase diversity. We co-developed an e-textiles curricular unit (Fields, Kafai, Nakajima & Goode, 2017) that takes place over eight weeks and consists of a series of four projects, with the final project incorporating a handmade human sensor created from two aluminum foil conductive patches that when squeezed generate a range of data.

In this study we focus on one high school teacher’s implementation of portfolios in the e-textiles unit during Spring 2017. An experienced ECS teacher and leader, Ben taught at an independent charter high school located in the suburbs of a large metropolitan city on the U.S. West Coast. He had many years of experience teaching ECS and one prior year of teaching the e-textile unit in his class. His class included 35 students, 16 girls and 19 boys, mostly from 9th grade (14-15 years old) as students were encouraged to take ECS in their first year of high school. The school enrolls about 4,600 students: 4% African American, 18% Asian, 10% Filipino, 40% Hispanic or Latino, 25% White, 1% two or more races, and 2% race not reported. Fifty-four percent of the students come from socioeconomically disadvantaged families.

Design of portfolio assignment

The portfolio assignment was designed to capture students’ descriptions of their final projects and discussions of their process, through the use of both textual (written) and non-textual (photos, diagrams, code) evidence. Refining the format of the assignment to accommodate his needs, Ben provided a Google Slides template for students, which included the following prompts: 1) Describe their final human sensor project (in a video or using pictures and text, one slide); 2) Discuss their process for making the human sensor project, including their initial design and any revisions made, and at least one challenge that they dealt with (in written form, two slides), (see Figure 1 for example) and 3) Reflect on their experience and identity as a computer scientist across the entire e-textiles unit (in written form, one slide).

For both of the written sections, students were required to provide non-textual evidence for their learning whether drawings of their designs, circuit diagrams, code snippets, or excerpts and photos from their engineering design notebooks and journals. Some of these journal prompts included questions about their design processes such as “What were some modifications you had to make in your design?” and occasionally the teacher would prompt students to take a picture of their projects so that they could track changes. Students only had a few days at the end of the unit to work on their portfolios, partly by design (because of the need to limit the unit to a certain number of weeks in line with the other ECS units) and partly by necessity (because it was the end of the school year and priority was placed on finishing projects). During these days in Ben’s class, most students chose to focus their time on putting finishing touches on their human sensor projects and therefore, worked on their portfolios at home. This means that we have little observational data to draw on regarding how students put their portfolios together.

Data collection and analysis

At the end of the class, we collected the digital portfolios from 33 students (two students did not turn in portfolios), which consisted of a combination of text, photos, and videos embedded in Google Slide presentations. Data from the broader study included weekly observations of classes documented in field notes, short interviews with six students (including a brief question on their thoughts about the portfolios), and pre/post interviews with the teacher (also including some reflection on the portfolios). The portfolios themselves were the focus of analysis, though we also triangulated some of the findings with the teacher post-interview. Across the portfolios, we analyzed the two written sections of the portfolios, which included: discussion of process and reflections on learning.

Within each of these sections we analyzed: 1) Computational practices—The process-related activities referenced, whether revising their projects—making changes to their design based on interest or requirements, or dealing with challenges—diagnosing and solving problems. These draw from existing research on computational practices that identify being incremental and iterative, and debugging and testing as key activities when creating computational artifacts (Brennan & Resnick, 2012). We also looked for if students referenced
additional practices (e.g., planning their projects, remixing); 2) Computational concepts—The e-textiles domains referenced (e.g., design, circuitry, coding, crafting), and level of detail included, such as allusions to related sub-concepts (e.g., polarity, conditionals, mechanics of sewing). Given the interdisciplinary nature of e-textiles, multiple concepts often emerged in the sections; 3) Language—The level of detail and specificity included in their narration. We looked to see if students provided ‘full explanations,’ which meant discussions of both their problems and solutions for challenges, their before and after-state for revisions, or their justifications for their learning and reflections; and 4) Non-textual supporting evidence—What forms of evidence were provided (e.g., drawings, diagrams, code, other), as well as how effectively it was presented as part of their argument (i.e., without any explanation at all; referred to in text/prose; included extra annotation or a captions). After analyzing these portfolios, identified trends within students’ communication of their process and reflections on their learning. We not only highlight what they said about these topics (e.g., concepts addressed), but also how these areas were communicated through the different media forms and language styles.

Findings

Revisions, challenges, and reflections in student portfolios

Overall, the portfolio assignment was successful in getting students to document and share aspects of how they created their projects and some of the difficulties that arose as they created them. However, students completed the portfolios with a high degree of variance, both in meeting the requirements for each section that Ben required and in the quality of the descriptions and evidence they shared. One major area of difference we found related to revisions (changes made from the initial design of the project) and challenges (an issue that came up in making the project). Though both were required with dedicated slides assigned in the template, 85% of the students included challenges in their portfolios, while only 45% of students wrote about revisions (36% completed both parts).

There are several possibilities for why students completed the challenges section more than the revisions section. First, the prompt for revisions asked students to think about their initial design and how it changed. This required thinking back to the beginning of the project of what would normally be a 2-3 week period. However, this was extended even farther for these students because of the two weeks of paternity leave that Ben took, something that likely further hindered their memory. Second, students might not have been diligent in recording changes or taking pictures of early stages of the project, which would have allowed them to think about how their project had changed from beginning to end. In his post-interview, Ben commented that, while he encouraged students to document progress, students’ records were very disorganized with “papers all over the place like a fifth grader’s exploded backpack.” One proposed change he made for the future was to “be a little bit more conscious of referring to the design notebook, that when you make [design] changes [to] make the changes in your notebook.” Ben’s reflection as a teacher that students needed to keep track of and document changes therefore highlights the potential reason for the lackluster record of revisions in the portfolios. Finally, the assigned journal questions that students answered during the project and Ben’s discussion on the portfolio assignment featured challenges, bugs, and fixes far more than ideas about revisions. Thus, the curriculum and teaching likely emphasized working through challenges and mistakes more than thinking about revisions independent of those issues.

Along with discussing challenges and revisions, portfolios provided opportunities for students to reflect on their learning, not only in the human sensor project but also in the overall electronic textiles unit. A mandatory part of the portfolio, all 33 students reflected on their learning in this overarching way and in doing so mentioned at least two of the four domains on average. In their reflections, 38% explicitly mentioned acquiring debugging and testing skills through the experience of making e-textiles projects. Additionally, 30% of students believed that planning was a practice they developed, while 18% even mentioned some soft skills such as “being patient,” or “not … procrastinating” which helped them with the process of making the e-textiles projects. These types of comments suggest that the portfolios were a place where students could reflect metacognitively about their learning across the many weeks of the e-textiles unit.

Content and detail (or lack thereof) in student portfolios

Across each of the areas where students reflected on their processes of making and learning, there was a predominant lack of detail in student reporting. Only 46% of challenges, 35% of revisions, and 27% of reflections provided detailed explanations about with explicit references to specific areas of design, craft, circuitry, or code. As an example, compare the slides on the left and right in Figure 1. On the left, Leon wrote vaguely that having a plan was important as was working through mistakes, but without explaining what any of the specific mistakes were or why a plan would have been helpful. In contrast, Aditya’s slide on the right
provides a very clear explanation an error that arose in coding. He had mislabeled one of the variables naming his pins and this resulted in abnormal readings from the sensor (since he named the same pin, #9, both as an LED—an output, and as the sensor—an input). These types of details were lacking in many students’ portfolios overall, making it difficult to understand in what areas students struggled and learned.

Figure 1. Leon’s portfolio page (left) and one of Aditya’s portfolio pages (right) on the human sensor project.

In addition to the general lack of specificity in students’ portfolios, differences appeared within conceptual domains in terms of how specific students were in their descriptions. Most discussions around crafting (83%) and circuitry (84%) explicated specific areas that needed fixing or revising. For example, Alejandra’s description of challenges in making her stuffed cookie pillow project provided relatively detailed reports of where she had issues in circuitry and designing:

…[W]hen 2 of my LEDs were not lighting up. I was really confused on what was wrong, but then I noticed that conductive thread from both a positive and negative were touched when I put the ends of my project together and that was what was wrong. To fix this problem when sewing my project shut, I put some stuffing between those two ends so they wouldn’t touch.

(Alejandra, portfolio)

Here, she explained a circuitry design issue that was complicated by the circuitry going across the front and back of her cookie pillow. When the pillow was closed together, those two sides touched in the middle, creating a short circuit. Adding stuffing separated the two sides and resolved the issue. More often than not, students were relatively specific about issues related to design, craft, and circuitry.

In contrast to design, circuitry, and crafting, only half of the mentions of coding (54%) provided detail. For example, Vivian described her challenge with coding in only one sentence: “Earlier into the project i had difficulties on coding [sic] and understanding the light sensors.” Her explanation makes it impossible to deduce what specifically she struggled to understand, though we might expect it to relate to sensors through conditionals or mathematical expressions. Other students were even more vague, saying things like “I know that coding is pretty fun” (Amy) or “In the beginign [sic] I had no idea what to call a LED, but know I can code my own code that can feel pressure” (Kevin). In contrast to these more generic statements, the descriptions of students like Aditya (above, see Figure 1) and Lien stand out. Lien explained some complex coding issues that came up in her handbag creation:

[T]rying to get the computer to read information from both the light sensor and the human sensors like in the code on the slide caused to computer to not be able to read either of them. I decided to use the switches on the playground to use for coding more light patterns instead…Despite both sets are fine [sic], the computer could not read and work the code made up of both sets. (Lien, portfolio)

Here Lien described problems with her ambitious effort to use readings from two sensors. Though she knew how to independently code each sensor and link it with lighting patterns, “Trying to mix two sets of working code together does not automatically make a working set of new code” (Lien, Portfolio). The contrast between Vivian’s and Lien’s descriptions of their coding issues shows the importance of using specific language to clarify a challenge faced or a revision made. Overall, this difference in use of detailed language within the different domains highlights the need to consider not only what prompts students are given within portfolios, but also how to support students to more effectively communicate technical details through specific language.

Students’ use of non-textual supporting evidence
The portfolio also allowed students to employ non-textual evidence in form of photos, diagrams, and sketches to support their narratives about their process and their reflections. As seen in the examples previously (see Figures 1, 3), portfolios were helpful in eliciting a range of non-textual information about the process of making these artifacts. Out of the 33 portfolios, 25 students provided some form of evidence. Of these students, most used pictures (48%) or diagrams (45%) of their projects (see Figure 1, left), while much fewer (33%) included excerpts of code (see Figure 1, right). Interestingly, although a majority of students referred to coding as the most challenging domain, code emerged as the least prevalent artifact used as evidence throughout the portfolios. The lack of coding evidence furthers the points mentioned above about students needing support in explicating their coding problems and learning.

Further, across all types of non-textual evidence, many students provided no explanation, annotations, or references within the text while discussing their challenges (62%), revisions (45%) or reflections (62%). Only a few made direct reference to this non-textual evidence within their text (e.g., “in the picture below...”, “the diagram illustrates...”), and even fewer included relevant visual annotations or notations (e.g., arrows, labels, color-coding). As an example consider Leon’s portfolio page (Figure 1, left) where he included two pictures of his project. There were no arrows or explanations as to what these pictures showed, or how they related to his statements that he learned the importance of planning or working through mistakes. Aditya’s use of evidence (Figure 1, right) is comparatively better in that he uses and labels two examples of code so that viewers know which came first. A viewer with experience in Arduino could match his writing with the examples to identify the issue (i.e., labeling both variables “led1” and “aluminumfoil” as pin 9), though additional annotation such as arrows pointing to the problematic line (top line of the upper code image) would make that more clear. The predominant lack of explanation and annotation amongst students suggests that more effective scaffolds, examples, and modelling may be needed to help them utilize non-textual evidence effectively.

Discussion
This study is part of a larger effort to test the feasibility of and develop appropriate formats for the use of portfolios (or process-folios) for measuring and supporting students’ computational thinking within the ECS e-textile unit. We observed different affordances and challenges in the portfolio design in getting students to document and share their processes, as well as assessing their computational thinking. These, along with recommendations for improving the utility of the portfolio as both a learning and assessment tool, are further described below.

Portfolios as tools to support student learning
In contrast to performance-based testing, the portfolios that Ben implemented provided opportunities for students to articulate their design processes (design, crafting, circuitry or coding) and reflections and support them with evidence. They were successful at getting students to document, share, and reflect upon their overall experience and learning trajectory. Most students provided at least some documentation (and others quite rich explication) of their learning in ways that demonstrated some metacognitive awareness (Darling-Hammond, 2008). Students would often conclude with mentions of being proud of their project or their growth, an important aspect of identity and motivation in learning with implication for their future trajectories in the field (e.g., Pinkard et al, 2007). Further, the simple act of documenting their project along the way and choosing which pieces of evidence to include is inherently a form of reflection since it requires students to conceptualize and produce a narrative of learning and process (Paulson, Paulson & Meyer, 1991). The types of portfolios used in this curriculum clearly had some potential benefits for students’ learning and reflection in CS.

However, there was great variance in the quality and quantity of descriptions. Some students moved past the initial requirements and mentioned several challenges and learning gains, describing their learning in great depth, while others stayed at very low levels of description. Yet most students neglected to describe the revisions they made within their project, something that is surprising considering that Ben specifically asked students to address changes made to their initial designs within his slide template. In addition, many students’ descriptions lacked details that allowed readers to fully understand the problems they dealt with and failed to explain what they actually learned outside of generic statements about improvements in sewing and especially coding and design. In other words, even though all students did provide narrations of their process, these were often opaque because of the lack of detailed language and included inefficient use of non-textual evidence. Clearly we need to equip students better so that they can articulate their learning more effectively.

Portfolios as tools to assess computational thinking
While the teacher did scaffold the portfolio process in several ways—through journal questions, reminders to take photographs of projects, and the template for the portfolio—we need to explore additional scaffolds to
assist students in improving their computational communication skills. One potential change is to focus on what Grover, Cooper and Pea (2014) call the “vocabulary of computing,” which moves beyond word choice toward giving students actual communicative tools through which to articulate and concretize abstract computational knowledge. This is particularly needed since, as noted earlier, students mentioned coding often as a challenge, yet were unable to describe their issues in precise ways. In practice, an emphasis on the vocabulary of computing would involve being more explicit about developing shared classroom discourse around computational thinking. By giving students access to this language, teachers would not only have more opportunities to assess what is actually occurring, but also help increase student understanding of these concepts and practices. Another possible change would involve collecting and sharing exemplars of good computational communication with students. Following Williams (2002), teachers cannot just expect that students become effective communicators if this has not been defined for them beforehand.

In future implementations of the curriculum we will provide different models of portfolios, recommend that teachers discuss these with students early in the process, and study whether this helps students develop better communicative competence about their computational learning. There is also an opportunity to use whole class peer critique sessions, already used in the design of the e-textiles projects in the unit, on the portfolios. We also hope to explore with teachers like Ben how to better integrate active reflection and documentation throughout the e-textiles unit (not just in the final project) in an effort to support communication as a computational practice that is fully integrated into the curriculum, rather than something engaged at distinct timepoints apart from the process. However, time is a very explicit limitation on all of these efforts. There is no room to expand the units in light of the other material that must be covered as a part of the ECS curriculum. How can we balance the importance of creating these projects with the benefits of reflecting on the process of creation?

Portfolios and computational communication beyond classrooms

Portfolios are becoming more significant options within STEM disciplines for academic and professional assessment. Not only are they being used for college admissions and the AP CSP course, but also for career advancement (Chang et al., 2015). Introducing students to portfolios within the ECS classroom gives them opportunities to practice this new format of explaining STEM knowledge and skills in addition to the personal learning awareness they offer. Further, portfolios can also be used within personal contexts. Recognizing the potential short lives of student-made artifacts, portfolios can serve as a vehicle to keep the learning and making experience alive when a fully functional artifact may long be gone. Finally, portfolios can also serve a social purpose, enabling students to connect to the larger maker culture that exists beyond classroom. Sharing has been promoted as key tenet of the Maker Movement (Dougherty, 2013), wherein makers of all backgrounds and ages share their projects and expertise with others in various formats. Research indicates that learning to become a maker is as much about creating artifacts as it is about learning to participate in communities (Pinkard et al., 2017). Thus, students’ engagement with the practice of computational communication can promote participation at-large, following the idea that computation is an essentially social practice (Kafai & Burke, 2014). For all these reasons, more research is needed to explore the affordances of different types of portfolios in supporting and assessing computational thinking, classroom supports for encouraging deeper reflection and communication, and students’ own perceptions about the benefits of creating these personalized narratives around their learning and process.

Endnotes
(1) All participant names are pseudonyms to protect confidentiality.

References


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Revising Biology Misconceptions Using an Online Activity With Retrieval Practice and Explanation Prompts.

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Abstract: Conceptual change instruction is crucial in domains like science, where students come into the classroom with intuitive misconceptions that need to be revised. While previous conceptual change instruction has focused on classroom-based environments, this study designed an online activity that identified misconceptions with a retrieval-practice task and compared the effects of subsequent self-explanation and instructional explanation prompts on knowledge revision. Results indicated that the retrieval practice activity induced cognitive conflict in learners who had misconceptions, and learners who received subsequent prompts to explain the correct answers had significantly higher post-test scores than students who read refuting explanations. We suggest that self-explaining is a particularly effective revision task for online Biology courses, where students may not actively engage with the refuting explanations that are used in classroom-based conceptual change instruction.

Keywords: conceptual change, self-explaining, misconception, refutation text, photosynthesis

Introduction
When learners enter classes with pre-existing misconceptions about the content, traditional instruction is not sufficient to correct those misconceptions, and learning is hindered (Chi, 2013). Specially-designed instruction is often necessary to correct misconceptions through conceptual change, and most of this instruction continues to assess and utilize revision activities in classroom-based learning environments (Tippet, 2010).

Bridging the gap between traditional conceptual change instruction and adaptive educational technologies could optimize distance learning in domains like science and potentially increase the fit of adaptive models (Liu, Patel, & Koedinger, 2016). To begin building this bridge, we should examine the effectiveness of revision tasks in online environments and design ways to identify misconceptions—and thus the need for adaptation to a revision task—during normal instruction. In this study, we designed an online retrieval practice activity that used misconception inventory items coupled with confidence ratings to identify misconceptions and compared the effects of two revision tasks, self-explanations and instructional explanations, on conceptual change.

Theoretical framework
Conceptual change
Students naturally interpret new information according to what they already know and bring with them knowledge from both informal and formal learning experiences (Chinn & Brewer, 1993). However, often learner’s prior knowledge is misconceived and inaccurate. To optimize subsequent learning, misconceptions need to be revised through conceptual change; a complex type of learning that replaces the misconception with correct knowledge (Chi, 2013).

While encountering new information that conflicts with prior, intuitively-based knowledge is considered to be a fundamental aspect of learning science (Chinn & Brewer, 1993), it is notoriously difficult to get learners to revise their misconceptions and achieve conceptual change. Conceptual change is composed of a number of component processes that need to be facilitated through instruction for revision to occur. First, instruction should elicit cognitive conflict, where the learner noticeably experiences a conflict between the misconception and correct information, by simultaneously activating the misconception and correct information in working memory (Chi, 2013). After cognitive conflict is induced, instruction must encourage outdateding of the incorrect knowledge and updating of the correct knowledge into the learner’s knowledge structure (Kendeou & O’Brien, 2014).

The effectiveness of conceptual change instruction is often assessed qualitatively in interviews or quantitatively using pre-post changes in misconception inventory accuracy. However, the process of conceptual change is gradual (Kendeou & O’Brien, 2014). Learners will experience cognitive conflict for some amount of time before revision occurs, which would not be indicated in a posttest. The effects of a single task are better understood by examining relative changes in learner’s confidence. Increased confidence in the inaccuracy of a misconception (i.e., knowledge outdateding), increased confidence in the accuracy of the correct answer (i.e.,
knowledge updating), or decreased confidence in either (i.e., cognitive conflict) would indicate that conceptual change is underway to some degree.

Revision tasks
Most work on conceptual change instruction investigates the usefulness of modified instructional explanations, referred to as refutation texts, in facilitating change. Refutation texts typically include three primary components: the statement of the misconception, the refutation of that misconception—which the inaccuracy of the misconception is pointed out—and an explanation of the correct scientific understanding (Tippet, 2010). Refutation texts are designed to promote cognitive conflict in learners, and research consistently indicates that they are more effective than traditional instructional texts at facilitating conceptual change in science classrooms (Tippett, 2010).

Self-explaining may also be an effective revision task, because it actively engages students and encourages them to monitor their own learning (Chi, 2000). Like refutation texts, self-explaining prompts can encourage misconception revision by highlighting inconsistencies in knowledge to promote cognitive conflict. The positive effects of prompts to self-explain particular parts of content, a problem, or an answer are indicated in numerous studies looking at knowledge building—a finding known as the self-explanation effect (Chi, 2000)—and research has more recently evidenced effectiveness for knowledge revision online (Williams, Lombozo, Hsu, Huber, & Kim, 2016).

We were interested in misconceptions found in Biology education, where students start and finish college level-biology courses with intuitive, but inaccurate, understandings of how plants get energy and mass for growth (Boomer & Latham, 2001). Like most work on conceptual change, refutation texts are the most commonly assessed method for revising misconceptions about photosynthesis and respiration (Tippett, 2010). While some studies designed and examined computer-assisted conceptual change instruction for photosynthesis misconceptions, like digitally presented content modules or computer-based concept mapping, the activities were incorporated into traditional face-to-face classes and facilitated by an instructor or peer group (Çepni, Taş, & Köse, 2006). Previous work provides little insight into the revision of these misconceptions in distance-learning environments and has not assessed whether providing revision activities to students who do not hold the targeted misconceptions is detrimental to learning.

Current Study
Multiple-choice questions with misconception lures are often used as pre-post assessments to measure the effects of revision activities like refutation texts, but their ability to be used as a revision activity for biology-based misconceptions has not been assessed. We designed an activity using multiple-choice questions with known misconception lures to activate existing misconceptions and employed confidence ratings to identify the component processes of conceptual change. Subsequently, some learners received prompts to self-explain or received prompts to read an instructional explanation of the correct answer. When paired with the correct answer feedback, the instructional explanations had all the components of a refutation text. We compared the effects of the activity with and without specific explanation prompts on conceptual change learning. We used changes in confidence ratings and posttest scores to answer the following research questions:

1. Which type of explanation prompt, self-explanations or instructional explanations, is more effective for learning about commonly misconceived biology content in an online activity?
2. Does retrieval practice, with and without explanation prompts, affect participant’s confidence in correct answers and misconception lures?

Methods
Participants
Participants were 403 undergraduates in the second part of a two-sequence introductory Biology course at a large Southeastern university in the United States. 71% of participants were female, 28% male, and 1% preferred not to answer; 39% identified as African American, 28% Caucasian, 13% Asian/Pacific Islander, 8% Hispanic, 8% other/multiracial, and 4% preferred not to answer. Participants were randomly assigned to one of three conditions. After excluding participants who did not complete both sessions from analysis, group distributions were as follows: self-explanation condition (n = 118), instructional explanation condition (n = 140), or no explanation condition (n = 145). All participants passed a Biology I course that covered photosynthesis and respiration before participating in the study.
Procedure and materials
Participants completed two sessions of online activities housed on Qualtrics. The first session included a brief multiple-choice assessment of prior domain knowledge, followed by a 12-item revision activity to identify participants’ misconceptions and to prompt them with an opportunity to revise them. One week later, the second session included a posttest to measure changes in knowledge from the revision activity. Participants’ biology instructors assigned the sessions as homework by sharing links to the Qualtrics-based forms.

**Session 1: Revision activity questions**
We adapted previous measures of photosynthesis and respiration misconceptions (AAAS 2016; Amir & Tamir, 1994; Boomer & Latham, 2011) to create 12 revision activity questions. We worked with biology instructors to identify common photosynthesis and respiration misconceptions and to confirm the appropriateness of our revision activity questions. Each question was multiple choice and had 4 answer choices: 1 correct, 1 target misconception, and 2 incorrect answer choices. We included 4 target misconceptions in the items: 1) plants get their food from the soil (AAAS, 2016), 2) plants do not respire (Amir & Tamir, 1994), 3) plants only respire when they are not photosynthesizing (Boomer & Latham, 2011), and 4) respiration in plants is synonymous with breathing in animals (Amir & Tamir, 1994). We designed the revision activity to include both knowledge and application questions. Knowledge questions prompted participants to correctly identify facts or basic concepts (e.g., “Which of the following about respiration is true?”). Application questions prompted participants to apply their knowledge to a scenario (e.g., “In the experiment depicted above, what happened to the mass lost in the ‘water, no light’ treatment?”).

**Session 1: Confidence ratings**
After reading a question, but before selecting an answer choice, the activity prompted participants to report how confident they were in the accuracy of each answer option using a 5-point Likert scale. Instructions prompted participants to, “Please indicate how confident you are in the accuracy of each answer choice,” with 1 indicating absolutely confident it’s wrong and 5 indicating absolutely confident it’s right.

**Session 1: Explanation tasks**
After rating their confidence in each answer choice, participants saw the question again and were prompted to select the best answer. On the following page, the question was presented with correct answer feedback (i.e., correct answer highlighted and labeled correct). Directly below the correct answer feedback, any relevant explanation prompts were presented, followed by a cognitive load measure. See Figure 1 for a visual depiction of an activity procedure.

For the self-explanation condition, participants were prompted to “in 3-5 sentences, please explain why X is the correct answer to the question” and subsequently entered their explanation into a text box. Participants in the instructional explanation condition were prompted to carefully read an instructional explanation, which was provided below the correct answer feedback.

For the instructional explanation condition, biology instructors wrote twelve paragraph-long explanations (~4 sentences). They explained the correct answer to each question and either indirectly refuted or directly refuted relevant misconceptions contained in the question. For example, in a question including the misconception respiration only takes place when photosynthesis is not in an answer choice, the instructional explanation for that question indirectly refuted the misconception (i.e., “respiration is taking place in plants at all times…”). In a different question including the misconception plants get food from the ground in an answer choice, the instructional explanation directly refuted that misconception (i.e., “Plants do not ‘get food’ from anywhere. Plants make their own food…”). Both direct and indirect refutations can be effective (Chi, 2013) and were chosen based on their appropriateness for the question format. Participants in the no explanation condition were only provided with the correct answer feedback and did not receive any explanation prompts.

**Session 1: Cognitive load measure**
Following their assigned explanation prompts (or lack thereof), all participants completed a cognitive load measure using a 7-point Likert scale. The scale in this study asked participants to self-report how hard it was to complete the activity, with 1 indicating not difficult at all and 7 indicating very, very difficult. After completing the cognitive load measure, the activity routed learners to the next activity question. The procedure (see Figure 1) continued like this for all 12 activity questions. The order of questions was randomized.
Figure 1. The procedure for each of the 12 activity questions.

Session 2: Posttest measure
One week later, participants completed the posttest. The posttest included 24 questions: the 12 original activity questions and 12 new transfer questions. Transfer questions addressed the same knowledge and maintained the same structure as activity questions; only the wording or specific examples differed. Similarly to the activity, participants were prompted to rate their confidence in the accuracy of each answer choice before selecting their answer to each question.

Findings

Photosynthesis misconceptions
Percentages of misconception lures selected with high confidence suggest that participants entered the activity with persistent misconceptions about photosynthesis and respiration. High confidence ratings distinguished between misconceptions and guessing; a low confidence rating of 1, 2, or 3 would indicated a guess, and ratings of 4 or 5 indicated the participants were confident the misconception lure was correct. The four primary misconceptions addressed in this study, the most commonly selected answer lure for each of those misconceptions, and percentages of participants that selected each overall and with high confidence are listed in Table 1. Percentages reported in Table 1 are likely underestimated; question order was randomized throughout the activity, and participant’s likelihood of selecting a misconception may have decreased through the activity as they received correct answer feedback.

<table>
<thead>
<tr>
<th>Misconception</th>
<th>Associated Answer Choice</th>
<th>Selected</th>
<th>High conf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Plants get food from the ground.</td>
<td>Absorption of organic substances from the soil via the roots</td>
<td>43%</td>
<td>23%</td>
</tr>
<tr>
<td>2) Plants do not respire.</td>
<td>$\text{CO}_2 \rightarrow \text{animals} \rightarrow \text{O}_2 \rightarrow \text{plants}$</td>
<td>47%</td>
<td>37%</td>
</tr>
<tr>
<td>3) Respiration only takes place when photosynthesis is not.</td>
<td>It will weigh less because no photosynthesis is occurring.</td>
<td>20%</td>
<td>22%</td>
</tr>
<tr>
<td>4) Respiration is the same as breathing.</td>
<td>It is the exchange of carbon dioxide and oxygen gases…</td>
<td>35%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Explanation prompts
To investigate how the effects of self-explaining and instructional explanations compared to no explanations, we used an ANCOVA to compare the effects of condition after controlling for prior knowledge. There was a significant effect of condition on overall posttest scores, $F(2, 399) = 7.07, p = .015$. Pairwise comparisons indicated that the self-explanation group ($M = 40.71, SD = 19.44$) had significantly higher posttest scores ($p = .01$ and $p = .01$, respectively) than instructional explanation group ($M = 35.71, SD = 15.63$) and no explanation group...
(M = 35.98, SD = 15.74), but posttest scores for the instructional explanation group were not significantly different than the no explanation group (p = .99). The same results were found when separately analyzing non-transfer posttest item scores, $F(2, 399) = 7.56, p = .001$, and transfer posttest item scores, $F(2, 399) = 3.51, p = .03$. It should be noted that for overall posttest scores and transfer posttest scores, means for the instructional explanation group were lower than means in the no explanation group, but not significantly. Mean comparisons of conditions can be seen in Figure 2.

![Figure 2. Differences in posttest accuracy compared to the no explanation condition. Scores are presented in relation to the no explanation condition as a baseline and are adjusted for prior knowledge scores.](image)

Time, which may generally indicate engagement, in the activity provides context for some of the effects of condition. Participants in the self-explanation condition (M = 29.92) spent more minutes in the activity than participants in the instructional (M = 24.24) or no explanation condition (M = 22.27), $F(2, 400) = 19.44, p < .001$. After controlling for the effects of time and prior knowledge, the main effect of self-explaining was only marginally significant, $F(4, 397) = 2.46, p = .08$.

**Changes in confidence**

Item-level analyses on how confidence changed in relation to the neutral center of the scale–the selection of which indicates that the learner was neither confident in the accuracy nor the inaccuracy of the answer–provides insight into the specific processes associated with conceptual change. Movements towards the middle of the scale suggested cognitive conflict, because learners were becoming unsure of what they were previously confident in. Movements towards the upper end of the scale suggested updating, because learners were becoming more confident in the accuracy of that knowledge. Movements towards the lower end of the scale suggested outdating, because learners were becoming more confident that knowledge was wrong. See Figure 3 for an illustration of these processes.

![Figure 3. Graph illustrating changes in confidence and the conceptual change processes they suggest.](image)
Figure 4. This array of graphs illustrates activity to posttest changes in the mean confidence for misconception lures and correct answers across conditions. The left side illustrates confidence for participants who selected the misconception lure. The right side illustrates confidence for participants who did not select the misconception lure. Statistics reported are based on Sign Test comparisons.
We examined changes in confidence ratings for the four most commonly selected misconception lures and separately analyzed learners who selected the misconception (i.e., indicated a need for conceptual change instruction) and learners who did not (i.e., did not indicate a need for conceptual change instruction). Confidence changes are illustrated in Figure 4. It should be noted that the activity was not a pretest; learning was occurring throughout, and question order was randomized. Any differences in activity confidence ratings across conditions may indicate the effects of the conditions up to that point.

Learners who selected the misconception
Confidence changes for learners who selected the misconception indicated that conceptual change was occurring. All conditions elicited outdating of misconception 1—plants get food from the soil—which was situated in a declarative knowledge question. All conditions elicited cognitive conflict for misconception 2—plants do not respire—which was situated in an application question that asked learners to identify which diagram correctly illustrated the carbon cycle. Cognitive conflict was also indicated across conditions for misconception 4—respiration in plants is the same as breathing in animals—which was situated in a declarative knowledge question. Interestingly, the self-explanation and instructional explanation conditions elicited cognitive conflict for misconception 3—plants only respire in the dark—which was situated in an application question that required a scenario-based prediction, but learners who did not receive an explanation prompt (i.e., no explanation condition) retained high confidence in the accuracy of that misconception. This interaction was also supported by a repeated measures analysis, $F(2, 137) = 3.15, p = .04$. Concerning the correct answers, there was no evidence to suggest that learners were updating their knowledge with the correct answers. However, confidence changes suggest that learners were moving towards cognitive conflict for the correct answers, indicating they were becoming less confident that the correct answers were wrong.

Learners who did not select the misconception
For participants who did not select the misconception lure, we expected their confidence in the misconception to remain the same or move towards cognitive conflict. This was largely the case; participants across conditions became more conflicted, or remained conflicted, about the accuracy of misconceptions 1, 2, and 4. However, for misconception 3—plants only respire in the dark—learners in the self-explaining condition moved towards updating their knowledge with the misconception; whereas learners in the other two conditions appeared to remain conflicted. This interaction was also supported by a repeated measures analysis, $F(2, 244) = 5.29, p < .01$. Further, self-explaining the correct answer associated with misconception 3 also decreased learners’ confidence in the accuracy of the correct answer. Learners in all conditions appeared to outdate the correct answer associated with misconception 2—plants do not respire—and became more confident that the correct answer was wrong. Correct answer confidence did not change significantly for misconceptions 1 and 4.

Discussion and conclusions
Many of the undergraduate learners in this study indicated persistent misconceptions about photosynthesis and respiration. Even after covering photosynthesis and respiration in their previous biology course, almost 40% of our learners were confident that plants do not respire, and thus incorrectly believed that plants do not take in any oxygen. Other common misconceptions were indicated as well, and our activity aimed to simultaneously identify these misconceptions and provide an opportunity for revision.

The retrieval practice activity provided all students with correct answer feedback and prompted some students to self-explain or read explanations of the correct answer. Students who were prompted to self-explain the correct answers had the greatest improvements in posttest scores, and much of this effect may be because they spent more time in the activity. Reading instructional explanations, which included all the components of a refutation text when paired with correct answer feedback, did not have any effects above and beyond that of the retrieval practice portion of the activity alone. The learners in this study completed the activity as a homework assignment that was graded for completion, not accuracy. Thus, their motivation to actively engage the in activity may have been low. Self-explaining prompts appeared to require more engagement in the activity (i.e., time), which subsequently increased learning. More passive revision activities, like refutation texts, may not facilitate sufficient engagement in the conceptual change process when used in distance-learning environments.

Conceptual change is a gradual, multi-component processes that we did not expect to achieve through the single activity designed here. Rather, we aimed to see what effects the revision tasks had on the component processes of cognitive conflict, outdating, and updating. For learners who indicated a need for conceptual change instruction, retrieval practice alone (i.e., the no explanation condition) was sufficient to induce cognitive conflict for 2 of the 4 misconceptions examined and was sufficient to outdate the misconception in a declarative knowledge question. However, for an application question that required learners to use their knowledge to make predictions,
Explanation prompts were necessary to make learners doubt their misconception and experience conflict; although the type of explanation prompt did not seem to matter. Confidence changes did not provide any evidence that learners updated their knowledge with the correct answers. Although posttest scores indicated that self-explainers were better able to identify the correct answer—they may have just memorized the correct answers without changing the knowledge structure they use to solve problems. Thus, updating may be the challenge posed by persistent misconceptions that should receive special attention in conceptual change instructional design.

Two of our findings indicated that conceptual change instruction had unexpected effects on learners who did not hold the targeted misconceptions. In one case, learners lost confidence in the correct answer and began to think it was inaccurate. In another case, self-explaining an application question made learners more confident in the accuracy of a misconception. These observations may illustrate that conceptual change instruction is inappropriate in the absence of misconceptions, or these observations may just be the result of learners evaluating the accuracy of their knowledge more stringently in light of evaluating their own confidence in misconception lures, other incorrect answers, and correct answers. Further research is needed to provide additional context and distinguish between these two possibilities.

Although the activity in this study was not adaptive, it illustrates the potential for adaptive technologies to use retrieval practice activities to identify misconceptions and adapt instruction accordingly. It also indicates the utility of conceptual change retrieval practice activities (i.e., those with misconception lures and immediate correct answer feedback) in non-adaptive course management systems. We provide evidence that prompts to explain, but not refutation texts, are an effective way to engage learners with correct answer feedback and facilitate cognitive conflict in a distance-learning environment. Our future work will aim to identify the specific components of self-explanations (i.e., content, engagement, cognitive load, etc.) that predict conceptual change.

References
Using Iterative Design to Create Efficacy-Building Social Experiences With a Teachable Robot

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Abstract: Teachable robots are a form of social robot for education, where learners engage in conversation to teach the robot like they would a peer. Part of the popularity of social robots is their ability to utilize social channels of communication to foster productive social experiences, interactions which help individuals grow and develop. Teachable robots have potential to utilize social channels of communication to create social experiences which can help learners develop self-efficacy, an individual’s belief in their ability to succeed. In this paper, we present a fully autonomous robot for middle school math; we iterate through three design phases and analyze responses to identify how to better foster productive social experiences for self-efficacy. We report six design recommendations; for example, for low self-efficacy individuals, an ideal design should incorporate problem-solving statements and positivity to foster social experiences of mastery and social persuasion.

Introduction

In this project, we investigate how robotic teachable agents can be designed to create social self-efficacy experiences, or social interactions that may aid learners in improving their self-efficacy, their belief that they can succeed in a domain. Teachable agents are agents that learners can teach about a subject domain (Chou, Chan, and Lin, 2003). When teaching others, learners attend more to the problem, reflect on misconceptions when correcting their peers’ errors, and elaborate on their knowledge as they construct explanations (Roscoe and Chi, 2007). Learning by teaching can improve domain knowledge (Kauchak and Eggen, 1993), self-efficacy (Frager and Stern, 1970), and peer attitudes (Griffin and Griffin, 1998).

Implementing a teachable agent as a physical robot might enhance the learner’s social experience, which may then improve learning and motivation within a domain (Dillenbourg et al., 2016). Social factors play a strong role when learners teach agents. Those that feel invested in their agents’ learning (Leelawong and Biswas, 2008) or feel rapport with their agent (Ogan et al., 2012) are more likely to benefit. Because robots have a physical presence and rich channels of communication, they have under some circumstances developed a deeper social engagement with users than their virtual equivalent (Liu et al., 2013). The use of teachable robots may increase users’ social engagement and thus enhance the impact of social factors in learning by teaching.

Our goal is to implement a teachable robot to improve learners’ self-efficacy. Self-efficacy, or belief in one’s ability to succeed, is a significant predictor of task performance (Bandura and Schunk, 1981). Self-efficacy in STEM plays a major role in learner persistence and success. However, it is not easy for learners to develop self-efficacy. We aim to provide a learner with the following social experiences, theorized by Bandura (1977) to have positive effects on self-efficacy:

1. **Mastery experiences**, facilitated by experiences where learners successfully teach the robot
2. **Vicarious learning experiences**, where a social model exemplifies good learning practices
3. **Social persuasion**, through social interaction learners are convinced of their success as domain experts
4. **Building rapport**, or a feeling of connection, with the learner

It is not clear how exactly a robot can be designed to achieve these goals. In this project, we examine the design of social experiences within the context of a teachable robot for middle school mathematics, where learners teach the robot about ratio problems. Our contributions are two-fold. First, we present the implementation of a fully autonomous teachable robot for mathematics, Nico. Nico is a Nao robot that can interact with the learner using spoken dialogue and realistic gestures. The richness of Nico’s interactions makes it a unique platform for exploring social factors and effects on self-efficacy. Second, we present the results of a multi-phase iterative design process with 14 learners; through this process, we specifically explore how Nico’s dialogue can foster these social, self-efficacy experiences. We pose the following research questions:
• How do different dialogue design strategies based on human-human peer tutoring and theories of rapport enhance mastery, vicarious experience, social persuasion, and rapport with a teachable robot?

• How might individual differences, such as initial self-efficacy, influence responses to different dialogue design strategies in a teachable robot?

Motivated by the literature on peer tutoring and rapport, we iterated on the design of Nico’s dialogue for each social experience. We explored how Nico’s dialogue can facilitate mastery by balancing the challenge learners face in articulating knowledge while enabling them to feel successful. We investigated how Nico’s dialogue can model different learning practices such as question-asking and optimism and spark a corresponding response in the learner as vicarious experience. We explored both subtle and overt approaches to social persuasion. Finally, we explored rapport by iterating over rapport signaling behaviors of friends versus strangers. We analyzed learners’ responses in each phase, yielding six design recommendations with an emphasis on how different individuals might benefit from different dialogue designs.

Prior work

Human-human peer tutoring literature indicates the importance of social factors and the presence of social outcomes in tutoring interactions. One meta-analysis suggests that peers who give help experience many social and motivational benefits, including improved attitudes towards school, academic self-concept, and academic self-efficacy (Robinson et al., 2005). Recent work on peer tutoring has suggested the rapport between two collaborating partners may correlate with learning outcomes (Ogan et al., 2012b). Madaio, Ogan, and Cassell (2016) found when tutees and tutors are friends, they engage in different tutoring strategies which may be more productive. These factors, if reproduced, may contribute to productive social experiences with a teachable robot.

Our work is also inspired by the broader teachable agent literature, where learners teach a virtual agent. Teaching a computer agent can be beneficial for the learner doing the teaching: it can lead to more learning than being taught by a computer agent (Leelawong and Biswas, 2008) and can be more effective than classroom instruction at improving learning and self-efficacy (Pareto et al., 2011). Chase and colleagues theorized that these benefits originate from the protégé effect, which occurs when learners become more motivated to teach their agent because: (1) they feel more responsible for their agent’s success and, (2) failures reflect on the agent rather than on them (Chase et al. 2009), and this may then facilitate learners experiencing greater mastery and social persuasion. Other human-agent work has suggested that the benefits of teachable agents come from feeling more rapport for an agent partner (Ogan et al., 2012a). Less work has focused on explicitly designing interactions to promote social experiences. One exception is Gulz, Haake, and Silvervaarg (2011) who demonstrate that adding off-task dialogue to a teachable agent can facilitate learning and positive outcomes.

Despite the promise of teachable agents in general, there has only been a small body of prior work on teachable robots. Co-Writer is a Nao robot that learners teach about handwriting. Through adaptation of the robot’s learning behavior, studies have shown the robot can engage learners in the task and potentially promote motivation and self-confidence (Jacq et al., 2016). Tanaka and Matsuzoe explored a Nao robot that learners can teach about vocabulary through physical demonstration (Tanaka and Matsuzoe, 2012). The interaction showed teaching a robot can support learning and suggested that both verbal and gestural communication is natural for teaching robots. rTAG is a Lego Mindstorms-based learning environment where learners teach the robot coordinate geometry (Walker et al., 2016). rTAG explored how physical embodiment affects social engagement; social engagement increased in low prior knowledge learners but learning gains decreased. A subsequent iteration of rTAG known as Quinn explored the role of dialogue; Lubold and colleagues found a combination of verbal and paraverbal social dialogue influenced perceptions of social presence (Lubold, Walker, and Pon-Barry, 2016). Collectively, this work indicates that teachable robots have potential to support learning, but the role of social factors remains unclear. In rTAG, physical embodiment alone was not enough to foster social engagement, while mastery experiences in Co-Writer was. Quinn revealed verbal and paraverbal features may enhance social experience but how dialogue can be designed to promote self-efficacy is an open question. We build on this prior work by introducing a fully autonomous teachable robot and exploring how empirically motivated, theoretically grounded dialogue can be designed to foster social experiences and self-efficacy.

System

We have developed an autonomous teachable Nao robot for middle school mathematics named Nico. In addition to the Nao robot, our system includes a user interface (UI) and a dialogue system. The learning domain for the teachable robot is middle school mathematics, specifically reasoning about ratios. We designed four narrative-style ratio word problems for learners to teach Nico based on the Common Core Standards for 6th
grade. For each problem, Nico and the learner are given partial information; Nico requests the learner’s help in how to use ratios to solve for the missing information. An example problem is depicted in Figure 1.

![Image of problem interface](image.png)

**Figure 1.** Example of a problem as depicted in the user interface.

Learners interact with Nico using spoken language and a touch-screen interface on a tablet computer (Microsoft Surface Pro) that displays each problem. The UI supports speech recognition and displays visual progress as the learner moves through the problems. To speak to Nico, the learner presses a button on the interface. After they are finished speaking, a notice appears on the interface indicating that Nico is ‘thinking’ while the system processes the input and generates a response. Average response time is less than four seconds. The UI tracks progress as the learner guides Nico through each problem step at their own pace, using buttons to advance forward. The current step is highlighted and enlarged on the screen. When Nico ‘answers’ a step, the corresponding table cell is updated from question marks (see Figure 1) to the correct answer.

The dialogue system is composed of an automatic speech recognizer, dialogue manager, and the Nao robot’s text-to-speech synthesizer. The interface captures the user’s speech using the tablet’s default microphone and speech recognition is performed using the Google Speech API. We find an average word error rate of 22.2%. Nico takes the initiative in the dialogue whenever a learner starts a problem, typically to request help. We utilize the Artificial Intelligence Markup Language (AIML) (Wallace, 2003) to process the learner’s input and identify Nico’s response. AIML is an XML-compliant pattern matching language. We designed and developed the dialogue by mapping all possible solutions for each problem step to potential explanations. After a learner speaks, a potential explanation pathway is identified based on keywords in the speaker’s speech. If a potential explanation cannot be matched, Nico requests a clarification. For example, Nico might say “I’m actually not sure what you said. Can you try saying it again but differently?” Clarification requests occurred on average 4% of the time. The frequency of clarification requests did not differ substantially across design phases.

In addition, we programmed Nico to produce eight emblematic or easily recognizable gestures. Gestures include waving ‘hello,’ nodding head as in ‘yes,’ shaking head ‘no,’ putting hands on hip to make a point, raising either hand, raising hands in celebration, and shrugging. The dialogue manager identifies whether there is an appropriate gesture in the set to accompany Nico’s utterance. We also enabled ‘autonomous life’, a default capability of the Nao robot which displays slight movement and listening behavior. Gesture and autonomous life were present in all phases. We do not explore gesture in the iterative design in this work, rather focusing on dialogue. The role of gesture in social, self-efficacy experiences is an opportunity for future work.

**Iterative design**

With the platform described above, we can iterate over the design of a teachable robot’s dialogue and explore (1) how different dialogue design strategies might enhance mastery, vicarious experience, social persuasion, and rapport, and (2) the role of individual differences in response to different strategies.

**Method**

Fourteen participants between ages 10 and 13 (M: 11, SD: 1.0, 4 female/10 male) participated across three exploratory design iterations with 5 participants (1 female/4 male) in the first phase, 5 (2 female/3 male) participants in the second phase, and 4 participants (1 female/3 male) in the final phase. All participants were...
native English speakers. Sessions lasted 90 minutes. Participants were recruited via flyers and emails shared during local programs offered to middle schoolers on the university campus.

The procedure for each session was the same across all phases. Participants began by completing a 10-minute pretest on ratios. Next, each participant was given a pre-survey on self-efficacy and comfort-level towards robots. Before interacting with Nico, participants were given a few minutes to review the worked-out solutions to the problems they were to teach. Participants then watched a 3-minute video introducing Nico. After the video, Nico initiated a brief ‘introduction’ interaction by saying “Hello, it’s nice to meet you. What is your name?” The ‘introduction’ gave participants an opportunity to practice talking to Nico before teaching. Participants utilized the tablet and spoken dialogue to teach Nico and moved through the problems at their own pace. Time to complete teaching the problems varied from 12 to 35 minutes. After the interaction, participants completed a post-survey; twelve participants also took a 10-minute posttest (isomorphic to the pretest). We then conducted structured interviews; the same questions were asked of every participant.

To evaluate the design and impact of each phase, we collected self-reported measures of rapport, self-efficacy, and learning gains and performed a comparative analysis on the interviews, experimenter observations, and dialogue transcripts. For the self-reported rapport, we posed a set of 14 Likert scale questions about rapport to each participant. The questions were based on a combination of prior work exploring rapport in human-human (Tickle-Degnen and Rosenthal, 1990), human-agent (Cassell, Gill, and Tepper, 2007), and human-robot interactions (Lubold, Walker, and Pon-Barry, 2016). Questions related to feelings of general rapport (i.e., “Nico and I worked well together”), positivity (i.e., “I liked Nico, Niko liked me”), attention (“Nico paid attention to me”), and coordination (“I was awkward in talking to Nico”). We asked participants in post-interviews to explain their understanding and interpretation of each survey question; these validations enabled small iterative changes to improve the wording. We aggregated the questions for each participant into an average rapport score.

Self-efficacy towards math was measured with six questions based on work by the Friday Institute for Technology (2008). Participants answered the six questions both before and after interacting with Nico. Averaging the responses, we calculated whether participants experienced a change in self-efficacy as post-score minus pre-score. Additionally, we asked how comfortable individuals were interacting with robots and human-looking robots. Finally, we calculated learning from the pre- and post-tests as a normalized learning gain score, as recommended in (Hake, 2002).

We focused our qualitative analyses on the interviews, experimenter observations, and transcripts of the interaction dialogue. Since we are interested in identifying the degree to which the dialogue can influence social experience, we coded the data for themes regarding mastery experience, vicarious experience, social persuasion, and rapport. We identified a set of decision rules for identifying themes, as suggested by Miles, Huberman, and Saldana (1994). For example, for mastery to be present, the learner must give evidence they feel Nico learned. An example decision rule for mastery was: participant is marked as having a degree of mastery experience, which is defined in terms of both the degree of experience and the degree of feeling they experienced that experience. Additional rules were developed for each theme to help identify whether or not a participant experienced a particular theme. These rules were then applied to the data by two researchers, who then compared and contrasted their results. The final rules were then applied to the data, and the results were compared to the original data to ensure that the rules were effective.

Table 1: Example dialogue from each phase. In Phase I, Nico asks questions, is polite but slow to understand, and has low specificity. Phase II maintains the same level of questions and politeness but Nico is more specific, understands more quickly, and exhibits positivity. Phase III maintains the positivity and specificity of Phase II but Nico is less polite, asks fewer questions, and is slightly slower to understand than Phase II.
Five participants took part in this phase, 4 males and 1 female. The results for the rapport, change in self-efficacy and qualitative observations are summarized in Table 2. We found that for mastery experience four of five participants in this phase were not convinced of Nico’s learning, reporting Nico only “kind of learned” (P1, P2). We observed no evidence of vicarious experience. Participants’ did not appear to experience or observe Nico’s model of question-asking and attention through responsiveness. The majority of the participants in this phase did not exhibit any form of social persuasion; they did not feel like Nico learned and also felt that they were not successful as tutors. The one participant who felt like Nico learned did not attribute Nico’s success to himself. P5 felt that Nico succeeded despite his own flaws as a tutor. Finally, participants were largely neutral in the degree of rapport they felt for Nico. Few of the participants exhibited any sense of general rapport for Nico, and while participants responded in the interviews that while they ‘liked’ Nico (P1, P2, P3), Nico was still ‘a robot, not a person’ (P2, P3). Differences in verbal behaviors emerged; unlike the others, P5 praised Nico and was more inclusive.

Individuals overall did not appear to be having productive social experiences; we found no evidence of mastery, vicarious experience, social persuasion or rapport. We did find one participant with dissimilar responses, which suggests individual differences play a pertinent role in these types of experiences.

Phase II
In our first design phase, we attempted to facilitate experience of mastery by challenging learners to explain each step to Nico. However, they clearly did not experience mastery. It was possible the content of the problems and act of tutoring is challenge enough; for Phase II, we increased the speed at which Nico understands and we increased the level of specificity to see how this influences mastery. For vicarious experience, we kept the question-based design and responsiveness indicating attention but we explored whether other learning practices may be more suitable to vicarious experience with Nico. Positive social behavior during learning and staying optimistic in the face of challenging problems is correlated with learning outcomes (Pampaka, Williams, and Hutcheson, 2012). We introduced positivity (i.e. “Oh okay! Great!”) and optimism (i.e. “these problems are hard but I think I’m getting it”) into Nico’s dialogue. For social persuasion, we had explored a subtle approach in Phase I; in Phase II, we introduced an overt design by framing messages to give outright encouragement success as a tutor (i.e. “You’re so helpful!”). While these messages could be perceived as disingenuous, participants’ belief in themselves may be positively influenced. Finally, for rapport, ‘stranger-like’ behaviors may have been distancing but it was also possible there were too few dimensions of behavior. We incorporated additional rapport-building behaviors while maintaining a model consistent with that of a stranger. Individuals who are strangers may introduce more positivity when building rapport (Tickle-Degnen and Rosenthal 1990). Increasing Nico’s positivity to build rapport aligned with supporting vicarious experience and social persuasion.
They noted that when Nico was specific, as in “Oh I guess we divide six by three?” (P7), they felt he was expressing a sense of mastery, higher social engagement, and behaviors expressive of rapport. However, of participants (4 of 5) exhibited changes in self-efficacy, and praised Nico, “Good job” and “Nice job.”

Finally, average intelligence was just very smart, very intelligent, as one participant noted - “I didn’t explain it very well but he was really smart so he got it”. Also, P8 felt Nico’s praise, designed to socially persuade the learners, was “undeserved.”

Participants continued to express a sense of mastery and high expressions of rapport. We finally saw evidence of accountability in helping Nico learn as well. This phase had the highest degree of decision rules met for all participants in a particular phase for a given social experience. We found this to be the most productive phase of the study, with all participants expressing feelings of responsibility for Nico’s success.

In this second design phase, evidence of productive social experiences increased. More participants expressed a sense of mastery, higher social engagement, and behaviors expressive of rapport. However, experiences of social persuasion in the form of feeling responsible for Nico’s success and especially evidence of vicarious experiences of good learning practices were not substantial.

**Phase III**

In the second design phase, we observed positive responses to mastery. However, we also observed that individuals felt Nico was “very smart” and they did not experience social persuasion. The prior phase may have over-simplified the tutoring task in a way that could not be overcome by either subtle or overt persuasion and contributing to feelings that Nico’s praise was disingenuous. We re-adjusted the level of challenge required in explaining to Nico how to solve the problems where Nico is slightly slower to understand than in phase II. We also did not see substantial evidence of vicarious experience; for this phase, we decided to focus on how increasing rapport might influence vicarious experience. For rapport in this final design phase, we emphasized behavior which would typically be found between friends rather than strangers. For example, Madaio, Ogan, and Cassell (2016) found that tutees who are friends tend to verbalize problem-solving statements more often than asking questions. We modified Nico’s dialogue to incorporate statements about problem solving.

For this final phase, we had four participants take part, 3 males and 1 female. Again, we found evidence that participants experienced mastery, implying that slowing Nico’s understanding did not influence whether participants felt like Nico learned. We did find evidence of vicarious experience. Participants commented on how teaching Nico was like teaching a friend and three participants noted the positivity of Nico’s learning behavior. For example, P11 stated that he “doesn’t get mad” and “Nico doesn’t get frustrated at you” (P13), he stays “positive.” Participants also noted Nico “doesn’t get distracted as people tend to do” (P13) and was a good listener (P12). All four participants in this phase gave evidence of feeling socially persuaded that they taught Nico. It was “because they explained it well that he understood it” (P11, P12, P13). In post interviews, participants’ comments reflected feelings of accountability in helping Nico learn as well. This phase had the highest rapport compared to the two previous design iterations; participants commented Nico “reminds me of my friend,” is “pretty cool,” “funny,” and “cute.” Verbal behaviors when interacting with Nico showed two out of the four participants praised Nico. We find their use of praise similar to prior phases. However, one participant gave Nico a little sass. (P13: “Thank you, Nico. Now get back to the questions!”)

This iteration resulted in the most evidence of social experiences for enhancing self-efficacy. Participants continued to express a sense of mastery and high expressions of rapport. We finally saw evidence that individuals vicariously experienced models of good learning practices, and individuals not only felt success in the task but they expressed feelings of responsibility for that success.

### Table 2: Summary of results and observations for each design phase; qualitative observations aggregate number of decision rules met for all participants in a particular phase for a given social experience

<table>
<thead>
<tr>
<th>% of Decision Rules Met</th>
<th>Mastery</th>
<th>Rapport</th>
<th>Vicarious Experience</th>
<th>Social Persuasion</th>
<th>Self-reported rapport</th>
<th>∆ in Math Self-Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20%</td>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td>3.52 (1.2)</td>
<td>.16 (.19)</td>
</tr>
<tr>
<td>20–50%</td>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td>3.91 (1.2)</td>
<td>.50 (.20)</td>
</tr>
<tr>
<td>50–75%</td>
<td>Phase 3</td>
<td></td>
<td></td>
<td></td>
<td>4.67 (.29)</td>
<td>.68 (.17)</td>
</tr>
<tr>
<td>75–100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Five participants took part in this design phase, 2 females and 3 males. We found an increased number of participants (4 of 5) exhibited mastery, feeling Nico learned and that this learning was due to their tutoring. They noted that when Nico was specific, as in “Oh I guess we divide six by three?” (P7), they felt he was learning from what they told him. We still did not see any acknowledgement from the participants of vicarious experience; they did not comment on Nico’s question-asking, attention, or positivity and optimism. In terms of social persuasion, while most of the participants in this phase felt Nico had learned, few felt they were “good” tutors. It is possible we over-simplified the process for explaining steps to Nico, leading learners to feel Nico was just very smart, very intelligent, as one participant noted - “I didn’t explain it very well but he was really smart so he got it”. Also, P8 felt Nico’s praise, designed to socially persuade the learners, was “undeserved.” Finally, average rapport was higher in this phase. All five participants in post-interviews expressed higher engagement and two expressed feelings of accountability. These two learners also had the largest corresponding changes in self-efficacy, and praised Nico, “Good job” and “Nice job.”
Cross-phase trends
In addition to qualitative observations, we measured rapport, self-efficacy, and learning. The average rapport and change in self-efficacy are summarized for each design phase in Table 2. While participants in different design phases experienced different interactions, we explored cross-phase trends for insight into overall design directions. We found a significant correlation ($r = .71$, $p = .02$, $n = 10$) between rapport ($M = 4.0$, $SD = .9$) and learning gains ($M = .47$, $SD = .2$). We also found that rapport is significantly correlated with change in self-efficacy ($M = .46$, $SD = .3$) across all participants ($r = .62$, $p = .03$, $n = 14$). Change in self-efficacy was not correlated with learning gain ($r = .46$, $p = .17$, $n = 10$). These results support the theoretical argument that rapport is related to learning and self-efficacy and imply designing to enhance rapport may result in positive outcomes.

We did not observe a correlation between self-efficacy and learning. While this may be due to the iterative design and the small sample size, it is possible the relationship is obscured by individual differences. Within each phase we observed a single individual who was very socially engaged, from their self-reported rapport to their interview responses and verbal behaviors. Regardless of phase, these individuals praised Nico more, included Nico in the learning process with inclusive language, and were more likely to anthropomorphize Nico. Viewing Nico as socially and cognitively capable, these learners had high social responses, a low bar for social experience, and higher gains. Comparatively, individuals with the lowest rapport and the lowest change in self-efficacy (P3, P6, and P8) responded to Nico with less inclusive language, little to no praise, and spoke of Nico as “the robot.” We found two other individuals, who interacted with Nico in phase III, reported initial self-efficacy scores as low as P3, P6, and P8; however, their change in self-efficacy was much higher. This suggests the third design phase may have been more effective for individuals with low self-efficacy.

Discussion and conclusion
In this paper, we described Nico, a fully autonomous teachable Nao robot for mathematics learning that can interact with learners using natural language. We explored through iterative design (1) how different dialogue design strategies can foster four social, self-efficacy experiences: mastery, vicarious learning, social persuasion, and rapport and (2) how individual differences influence responses to different dialogue design strategies. Our final design, which yielded the highest self-reported feelings of self-efficacy and rapport, was the most successful at fostering these four experiences. It consisted of human-robot dialogue based on two human learners who are friends and introduced a moderate level of difficulty for achieving mastery experience. Overall, we find several interesting design suggestions:

1. For mastery, dialogue design should provide the learner with the impression they are effective; if the robot reaches an answer too quickly, this reduces feelings of effectiveness. Design that incorporates equal question-asking with problem-solving statements can facilitate mastery.

2. For both vicarious experience and social persuasion, our analysis suggests if learners do not feel adequate rapport, they are less likely to have genuine social experiences and this will influence their overall self-efficacy. This implies initially focusing design on fostering rapport.

3. To foster rapport, designing dialogue based on that of friends may produce stronger responses. We are not suggesting designing a robot to act like a long-time friend from the first interaction but targeting initial design strategies to incorporate ‘friend-like’ moves in initial interactions.

4. Different dialogue designs interact with learners’ social predispositions and attitudes towards robots. Problem-solving statements, positivity, and high specificity may increase positive effects for individuals who are less inclined to social interaction with robots and may help influence a positive change in self-efficacy for these individual learners.

5. For individuals with initially low self-efficacy, design for fostering social experiences is more critical. Individuals with initially high self-efficacy responded positively across all phases while individuals with initially low self-efficacy responded positively only to the third design phase.

6. Gesture design should potentially differ depending on the learner’s initial level of self-efficacy. We did not perform a full analysis of the design of gesture, keeping emblematic gestures and autonomous life movement, while individuals with high self-efficacy preferred it.

Moving beyond the specific design insights presented in this paper, we see Nico as a platform for exploring the larger space of design questions related to the effects of dialogue and gesture on social learning experiences. This platform allows us to explore small variations in the design of dialogue and ultimately the combination of dialogue and gesture that could have a large impact on learning and motivation, through the creation of social experiences which can help learners develop self-efficacy.
References


Rethinking Loafers: Understanding the Productive Functions of Off-Task Talk During Collaborative Mathematics Problem-Solving

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Abstract: This study examines the role of off-task participation in collaborative mathematics problem-solving among fourth graders. Results show that majority of instances served productive functions in relation to the collaborative problem-solving process. These functions include: warming up to the collaboration, gaining the attention of others, gaining access to the collaboration for self, recruiting others into the collaboration, extending the task, and resisting concentrated authority.

Students commonly get off-task when working together in small groups, whether because they start playing with manipulatives, discussing games or movies, or singing together. Teachers, like most adults, typically assume such activity is counter to the work-at-hand, and some studies have suggested that off-task interactions are detrimental to learning (Baker, Corbett, Koedinger, Wagner, 2004; Sabourin, Rowe, Mott, & Lester, 2011). Yet, off-task interactions can serve a variety of functions, some of which have the potential to support important aspects of the collaborative process (Langer-Osuna & Esmonde, 2013; Sabourin, et al, 2011, Baker, D’Mello, Rodrigo, Graesser, 2010). Students utilize various strategies, often implicitly, to manage the attention, engagement, and cognitive activity of collaborative academic work (Barron, 2003; McCaslin, 2009; Volet, Vauras, & Salonen, 2009; Webb, 1982, 1991).

The functions of off-task talk during collaborative work is less often studied from positioning theory, though recent work suggests that particular kinds of subject positions enable productive collaborative work, while others constrain possibilities for engagement (Wood, 2013). Subject positions become available through socially constructed storylines (Davies & Harré, 1990; Holland, Lachincotte, Skinner, & Cain, 2001). While on-task participation draws from storylines of schooling and school mathematics, off-task participation can draw on a greater range of storylines, including those of friendship, popular culture, and so on, potentially making a greater range of positional resources available to students to leverage during their collaborative activity (Esmonde & Langer-Osuna, 2013; Langer-Osuna, 2015). These storylines interact through both on-task and off-task talk. Langer-Osuna (2015) found that students drew on a variety of storylines including but going beyond the storyline of school mathematics as they engaged with one another in collaborative work. The storylines that organized much of the off-task interactions, such as youth popular culture or the armed forces, offered the focal student, Terrance, positional identities that ultimately supported engagement in the mathematical work.

Bringing these bodies of work together to bear on the potential role of off-task participation during collaborative work, we hypothesize that off-task participation can contribute to collaborative problem-solving process by making a greater range of positional resources available to students. As such, it suggests the possibility that off-task participation plays an even more robust role in collaborative problem-solving than previously considered (Hickey, 2003; McCaslin, 2009).

Data sources and analytic approach
We analyzed 13 videotapes of collaborative mathematics problem-solving among fourth graders during a unit on place value (Fosnot, 2007). The unit included about 20-30 minutes of student-led small group collaborative work each day, always around an open-ended conceptual problem that required students to compose and decompose numbers, as well as combine numbers, as units of 10s and 1s. These activities were in the context of a story problem where the main characters, a young boy and his grandmother, start a T-shirt factory and must find a system of organizing T-shirts for selling. The characters ultimately decide to sell T-shirts as bundles of ten and loose T-shirts. Students had access to materials such as paper and pencil, clothes hangers and rubber bands, as well as linking cubes and base ten blocks, for use during their activity.

For each of 7 instructional days, we collected video of the entire classroom, as well as 2 additional representative small groups (1). Because in this classroom, students had the autonomy to choose both who they worked with and where they worked, the students captured in each of the focal small groups varied. We additionally collected pre- and post-assessments and student interviews. Here we focus exclusively on the videos of the small groups. For each small group table, we used a video camera mounted onto a tripod raised...
over the small group and pointed in a downward angle in order to capture all students and their collaborative work artifacts. We used a table mic connected to the camera to capture small group talk.

For each of the 56 instances, we coded the functions of off-task interactions on the collaborative dynamics. We coded the entire data corpus, drawing from both the literature (e.g., managing attention, Barron, 2003; resisting domination, Esmonde & Langer-Osuna, 2013) and an inductive analysis of the video data itself (e.g., gaining entrance into the collaborative work) until saturation. To do so, we created analytic memos describing: (a) the content of words or actions, and (b) the spatial arrangement of students’ bodies and resource, before, during, and after the off-task interactions. The spatial arrangement of the collaboration included students’ eye gaze and bodily positions in relation to one another, as well as physical access to the artifacts of the collaborative work (e.g., manipulatives, worksheet). We determined the function of off-task talk in relation to shifts in the spatial and verbal aspects of (on-task) collaborative work directly subsequent to off-task interactions.

Codes for off-task function were discussed and refined across the four authors for all instances until consensus was established and the data was saturated. In limited cases an instance was coded with more than one function when the same off-task interaction served different functions for pairs of students at a table of four. In all of the double coded instances, an off-task interaction that served to fill time for one pair of students served a productive function for the other pair of students.

**Results**

Results show that off-task interactions served both productive and unproductive functions in relation to the collaborative problem-solving process. The functions of off-task interactions in our data set (n=56 instances), in order of prevalence, were: (a) filling time (n=17); (b) warming up to the collaboration (n=9); (c) gaining the attention of others (n=7); (d) avoiding work (n=7); (e) gaining access to the collaboration for self (n=6); (f) recruiting others into participation (n=6); (g) destabilizing collaboration (n=4); (h) extending the task (n=3); and (i) resisting concentrated authority (n=2). An additional 7 instances were coded as flops. Table 1 defines each function operationally and offers examples of the kinds of interactions that were coded as such.

<table>
<thead>
<tr>
<th>Function</th>
<th>Definition</th>
<th>Example</th>
<th>Percent Frequency (n=56)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill time</td>
<td>Off-task interactions that occur after a declaration that the task is complete and continue until end of collaborative session</td>
<td>A student utters aloud, &quot;we're done!!&quot; and high-fives his two peers in the group. Gigging, the students spend the remainder of the session time hitting their ten stick together, testing which are the &quot;strong&quot; or &quot;weak&quot; sticks.</td>
<td>30.36</td>
</tr>
<tr>
<td>Warm up to the collaboration</td>
<td>Off-task interactions that mark the beginning of the collaborative activity and functions to support initial connection/interactions with peers</td>
<td>Students walk over to their table for the first time as a group. A student asks her peer whether the purple pen is his and then starts to take all of her pens out of a bag to demonstrate their varied colors. As the rest of the table mates join the table, they acknowledge the display of pens and one another. Immediately after, a student offers the first on-task directive to the group.</td>
<td>16.07</td>
</tr>
<tr>
<td>Gain attention of others</td>
<td>Off-task interactions that serve to shift the gaze of others toward a marginalized peer</td>
<td>Prior to the off-task instance, a student bids for the attention of this table mates, who ignore him. He begins to tell a story about playing the game Minecraft. His peers' gaze shift toward him, gaining their attention.</td>
<td>12.50</td>
</tr>
<tr>
<td>Avoid work</td>
<td>Off-task interactions that occur after a declaration that the task is not complete and that serves to</td>
<td>A student bids for his partner to model the number 38 with connecting cubes. His partner counters by telling him the green</td>
<td>12.50</td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td>Example</td>
<td>Page</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Resist efforts to make progress on task</td>
<td>connecting cubes are peas and they will make soup. They begin to build with the cubes. As he attempts to make sticks of ten, his partner launches into a story about making soup and insists the blocks are her ingredients.</td>
<td></td>
<td>10.71</td>
</tr>
<tr>
<td>Gain access to collaboration for self</td>
<td>Off-task interactions that a) enable a student that was previously not participating in the collaboration to enter, and b) are followed by on-task interactions between now-collaborating peers</td>
<td>Student’s on-task bids for participation are rejected. He and his peer begin to play fight with connecting cubes. In doing so, their bodies and talk become oriented toward one another. Student’s subsequent bid for participation in the collaborative task is successfully taken up.</td>
<td>10.71</td>
</tr>
<tr>
<td>Recruit others into collaboration</td>
<td>Off-task interactions that a) bring a student or students previously not participating into the collaboration, and b) are followed by on-task interactions between now-collaborating peers</td>
<td>Prior to off-task instance, a student makes several bids to recruit his two table mates into the collaborative task, which they repeatedly reject. He then begins to play with the connecting cubes, loudly declaring that he is building a tower. His two table mates shift their bodies toward him and one another, enabling cooperation, smile and join him in creating towers of their own and comparing them to each other. Immediately subsequent, the student repeats his original contribution, which is now taken up by his peers who shift into on-task interactions.</td>
<td>10.71</td>
</tr>
<tr>
<td>Extend the task</td>
<td>Off-task interactions that are related to the context of the task, but that depart from the task instructions</td>
<td>Students are tasked with adding imagined orders for T-shirts, totaling the number of T-shirts in an order. Before starting on the expected task, students spend several minutes discussing who should be in charge of small, medium, or large sizes of T-shirts, elaborating on personal characteristics, such as height or preferred fashion style, that would make particular sizes reasonable for specific students to take on.</td>
<td>5.36</td>
</tr>
<tr>
<td>Resist concentrated authority</td>
<td>Off-task interactions that serve to ignore or deflect a directive or other move that positions one peer with concentrated social or intellectual authority</td>
<td>A student tells her peer to stop making sticks of ten and to instead write his name on a shared worksheet. Her peer begins to combine his ten sticks into a long stick, naming it a sword and launching into a story about its strength and importance. He then begins a new ten stick, naming it a new sword, ignoring the shared worksheet.</td>
<td>3.57</td>
</tr>
<tr>
<td>Sustain the collaboration</td>
<td>Off-task interactions that (a) occur simultaneous to on-task interactions and (b) promote or maintain peer interactions</td>
<td>Students break out into choral singing while building ten sticks together.</td>
<td>3.80</td>
</tr>
<tr>
<td>Destabilize the collaboration</td>
<td>Off-task interactions that serve to reject or deflect bids to join or remain in the collaboration</td>
<td>Two students work on representing the number 34 as 3 tens and 4 ones. One student asks his peer if she has another idea for representing the number 34. His peer responds with teasing him about who he &quot;likes&quot; and continues to tease him until he stops asking for her contribution.</td>
<td>7.14</td>
</tr>
</tbody>
</table>
Off-task interaction includes a bid to shift the group dynamics (e.g. gain attention of others or grow the collaboration) but no shift occurs, and/or the interaction is interrupted by teacher intervention.

A student repeatedly attempts to share an idea with his table mates. His two peers ignore his attempts, as they share a story about a classmate who got in trouble that morning and pass the shared worksheet between the two of them.

12.50

The most prevalent function of off-task participation, more than a quarter of all instances was to fill time when students perceived their task to be complete. Perhaps unsurprisingly, off-task participation occurred often when students acted as if they had nothing else to do. However, when students did perceive work to be done, the majority of off-task instances, 58.93%, served a productive function. Only 12.50% of the time did off-task interaction serve to avoid work, one of the primary concerns of teachers. Below we offer a brief illustration of each of the productive functions of off-task interactions, in order of their prevalence in the data set, and demonstrate the ways in which students used off-task interaction as a positional resource to shift the dynamics of the collaboration.

Warming up to the collaboration
16.07% of off-task interactions served to essentially launch the collaboration. Similar to filling time, which occurred when students believed they were done with the task, these interactions served to connect the students who were gathering together, before establishing the done to be done. While most often, the collaboration would begin with an on-task question, such as "so what are we doing?" or a directive "you get the hangers and I'll get the base ten blocks", students also initiated connection and interaction through some amount socializing before the work began in earnest. For example, in one instance at the beginning of the group work session, as students join the small group table, they interact with one another around the topic of the video camera near their table. One student waves at the camera, as two others look on. A student jokes, "It's recording us. Hi, my name is Vanessa. Just kidding. It is my name, so I'm not kidding." In doing so, their bodies orient toward one another and their gazes meet. The students then agree to get some building blocks to begin their task. The off-task instance functioned to orient students to one another at the start of the collaborative session, enabling the launch of the work.

Gaining the attention of others
The second-most prevalent productive function of off-task interactions, representing about 12.50% of instances, served to orient students to one another at the start of the collaborative session, enabling the launch of the work.

Gaining access to collaboration for self
10.71% of off-task interaction functioned for a student to gain access to the collaboration who was previously spatially marginalized. These off-task instances typically began after unsuccessful bids to work with others on the task. The off-task interactions created new opportunities for the students to engage with one another by disrupting the on-task dynamics and enabling students to either gain traction into and join existing collaborations. These instances typically occurred after a series of unsuccessful bids to either join or initiate participation.
collaborative work, suggesting that interactional pathways into the collaboration through on-task activity were restricted or more cumbersome. While our analysis makes no claims about student intentionality, the off-task interactions successfully functioned to grow the collaboration in ways that previous on-task interactional bids were not. The following example illustrates these dynamics between 3 students, Felix, Jose, and Mutya:

Felix and Mutya are discussing how many ten blocks they were supposed to build, leaving Jose out of the collaboration. Felix and Mutya then take all the blocks that are on the table, including blocks that Jose was holding. Jose takes back one 10 stick, made up of red and green blocks, and teases, "You want to fight me?" Felix's gaze shifts to Jose and he responds, "No, you Christmas tree." Jose reaches over and takes more blocks, switching the colors of his 10 stick to black and red (rather than the Christmas colors green and red), and jokes again, "You want to fight me now?" Felix holds his gaze on Jose and repeats "No, you Christmas tree." Jose responds, "Because you're scared. I'm stronger than you." Jose then suggests the group make his number first, stating, "Why don't we make mine first because it's like the shortest." The group takes up his suggestions and collaboratively represents his number with the manipulatives.

Just prior to the off-task instance, Jose was marginalized from the collaboration and lost access to the materials. Jose playfully takes one stick of 10's back and offers to battle his stick against one of Felix's. Through this action, Jose successfully gains Felix's attention as well as access to the materials. He extends the interaction, taking up Felix's retort that he would not battle a stick that looked like a Christmas tree, by gaining access to more materials and positioning himself as powerful ("...you're scared. I'm stronger than you."). From this relatively more powerful position, Jose bids for collaboration, suggesting they represent his number first as a group. The students follow his suggestion, growing the collaboration to include Jose.

Recruiting others into collaboration
10.71% of off-task interaction functioned to recruit others into collaboration. Even during a group task, students often pursue components of the task independently. Recruitment of group-mates into collaboration is central part of negotiating a collaborative task. Like gaining access to the collaboration for self, recruiting others into the collaborations entailed off-task interactions, which subsequently shifted back to on-task, after growing the number of participants working together in collaboration.

In one example, two pairs of students are working in parallel at the same table, not orienting to the members of the other partnership. Gabe and Katy form one of the two partnerships. When Gabe bids to recruit Lina, one of the members of the other partnership, through on-task talk, into a joint collaboration, his partner Katy resists. She tells Gabe “No, they're working together,” and later bids for Gabe’s attention by placing her glasses on top of the table mic and says “it’s a person.” Eventually Katy claims control of the materials and refuses Lina access. As Lina orient toward Gabe, Gabe being a conversation about Minecraft. He announces that he rode his horse and burned down the village. With this story, Gabe gains the gaze of both Lina and Katy and returns to the task at hand, directing them to “put all your tens in here, put all your tens in here.” As the episode ends, Gabe, Katy, and Lina are all building ten sticks and oriented toward each other.

Through the positional identity as warrior, Gabe is able to recruit a new collaborator into his existing partnership and resolve the resistance coming from his existing collaboration. Where on-task talk of recruitment and inclusion of Lina into the group was rejected, the use of the powerful figure of a warrior on a horse burning down a village, positioned Gabe with the authority to give a directive with regard to the work, finally bringing Katy and Lina into a joint collaboration on the task.

Extending the task
5.36% of off-task interactions extended the context of the task, often the storyline and in a playful way that departed from the task instructions. Arguably, these interactions might be considered "on task" since they are indeed related to the collaborative work. However, because the interactions took on a sense of fantasy and play, we included them in the analysis. Like Dyson (1987), we found these extensions could at time enhance or elaborate on the intellectual work of the group, even if these interactions did not necessarily progress problem solutions. For example, in one instance, three students sit at a table with five 10 sticks in the middle. They are representing the number 38 and must choose with of the five 10 sticks to include in their solution. One student decides that the "weak" sticks should not be included and begins to hit the sticks with a pen to see which fall apart and which don't. His peer joins him in this and they begin a discussion about the qualities of sticks that would make them weak or strong.

Resisting authority
3.57% of off-task interactions functioned to resist some kind of power move made by a peer. Often, these interactions served to resist domination, in particular of a peer issuing directives to another peer. Less often,
these interactions serve to reject a bid for someone to take on a position of authority. For example, in one instance, a student states that her peer, also at the table, is the smartest of their group and should thus lead the work. They then begin a conversation about the problems with the word, "smart", ultimately refusing the positional identity.

Discussion
In this study, we found that off-task interactions may play an important role in maintaining shared intellectual work among students, in particular through its role in making available positional resources that can function to support the collaboration. Specifically, students utilized these positional resources during off-task participation, which drew on storylines of youth popular culture, friendship/romance, and home life, in ways that initiated, grew, and sustained the collaboration, gained the attention of others, extended the task, and resisted concentrated authority.

These findings have implications for research on collaboration. For one, these findings build on the literature on collaborative co-regulation. In particular, we found that off-task participation not only helped renew motivation to participate (Sabourin, et al, 2011), but also offered alternate pathways into the collaboration and the maintenance of joint attention and sustained work (Barron, 2003). Further, relationships of power matter when it comes to managing and sustaining collaboration, and these relations emerge interactionally through positioning. Subject positions become available through storylines, and school mathematics as a storyline does not necessarily offer sufficient positional resources to navigate shared work. Off-task interactions, which draw from other storylines, broaden students' negotiating capacity.

These findings additionally have implications for teacher professional development. Teachers would benefit from understanding the functions of off-task interactions on the collaborative process and to develop a lens for noticing how students engage in relational struggles in addition to the conceptual and communicative struggles of collaborative problem solving (Langer-Osuna & Munson, 2017). All of the instances analyzed in this study likely represent moments when teachers intervene and attempt to stop the off-task talk to get student back on-task. But to do so would ignore the function that these interactions actually serve in getting students into mathematical work. That is to say, these interactions are work, and sometimes intervention derails the work students are doing and learning to do as they engage in collaborative mathematics. Certainly, sometimes intervention is necessary. We ought to support teachers in knowing when to intervene and when to allow students to navigate their own way into the mathematics. Our findings suggest that teachers might benefit from pausing to notice off-task interactional dynamics and ask themselves questions such as, "Are students using the off-task talk to gain access?" before deciding whether or not to intervene.

Endnotes
(1) One video had faulty audio and was removed from the dataset.
(2) For example, a student who initiated off-task talk in a bid to gain attention may have continued to be ignored, resulting in no perceivable function to the collaboration. These failed bids were coded as “flops”.

References


Reassembling Home-work: Mixing “Newer” and “Older” Technologies in Home Learning Environments

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Abstract: Home is the original place for children’s learning and a vital site for studying new technological practices. Families’ uses of new technologies present questions and opportunities for research at the intersection of family life, learning, and technology. With so much to do, how do families make use of emerging technologies to accomplish everyday tasks? Drawing on an ethnography of families’ media engagement, this paper examines the nature of young people’s assigned tasks at home. Through analysis of interactions between children, parents, the home setting, and material resources, we develop a theory of learning that accounts for how newer and older technological forms are reassembled in everyday tasks like homework and chores. We discuss how, through mixing media, repurposing space, and remote assistance families make home “work” with technology. These reassembly processes collapse tools, nesting old and new media together in ways that are increasingly relevant for designing learning environments.

Introduction
Every day it seems there is a new gadget or app available that potentially changes the nature of “everyday” practice and learning. Still, while devices and services fall out of use and others come to take their place, there is often continued coordination between old and new technologies (Stevens, 2000), while new skills are being acquired or infrastructures accommodate new systems. As danah boyd (2014) concluded, this exchange of different media does not usher in new practices as much as it provides new mediums for maintaining social practices over time. Technologies may disappear (or remain in play), but the social practices they reflect and enable are constantly re-worked. Thus, everyday sites of learning—like family life at home—are set pieces for studying how people arrange older (i.e. paper-based) media and newer (i.e. computer-based) tools and resources during collaborative activity (Stevens, 2000).

Home-work is a common site of such collaborative activity. Traditionally, “homework” was assigned in school. However, a wide variety of assigned tasks occupy children working at home, the original site of learning, where, historically, family routines have always entailed some version of children’s work contributing to collective endeavors (Rogoff, Najafi & Mejia-Arauz, 2014). What we are calling home-work includes: schoolwork assigned by a teacher; household chores; helping parents who are working from home; pet care; music practice; and tasks performed at home that are required for activities pursued during discretionary time (e.g. for clubs, sports teams, faith-based groups). Home-work, broadly defined as the routine tasks young people are assigned to do while at home, continues to occupy a sizable portion of out-of-school time (Kremer-Sadlik & Gutiérrez, 2013). While new forms of media have transformed how learners engage in sociotechnical practices, the amount of time young people spend on home-work has not shown similarly dramatic changes (Twenge, 2017).

This contradiction presents a number of questions about the relationship between home-work and media engagement or technology use. If children are doing as much home-work as ever and also using more- and more types- of media, then how (if at all) do they use these new media and emerging technologies to accomplish tasks at home? What types of materials and technologies are used during home-work? How are home-work routines re-mediated through new technological practices? This paper addresses these questions by analyzing how young people accomplish assigned tasks at home. We studied how changing technological practices reassemble families everyday home-work routines. In this paper, we describe three processes that were involved in this reassembly: mixing media, repurposing space, and remote assistance.

Framework
We take a situated and sociocultural approach (Brown, Collins & Duguid, 1989; Lave & Wenger, 1991; Vygotsky, 1978) to learning and its on-going re-mediation (Cole & Griffin, 1983) through technology. Accordingly, in this study, we took a historically broad perspective on what counted as technologies; paper-based tools like worksheets, sheet music, pencils, markers, and clip boards continue to be part of everyday home-work alongside new tablet computers, mobile phones, laptops, and other screens. Today, screens
monopolize the attention of users and researchers of technology and new media (e.g. boyd, 2014; Twenge, 2017)). With this intense focus on emerging digital spaces for learning, one might ask what the implications are of studying home settings as sites of technological re-mediation. When so much of kids’ media engagement today is digital and virtual, why bother examining physical spaces or material resources?

While one response to this is empirical- and we will address this in the current analysis- there is a real sense in which everyday activities are still very much mediated by “older” technologies. This is not only because these technologies are deeply embedded in sociotechnical practices (Star & Ruhleder, 1996), nor a simple consequence of persistent inequities in access to opportunities for learning with new media and technology (Ito et al., 2013; Rideout & Katz, 2016), but because they are still serviceable for users (Cole, 2017). Re-mediation involves less a replacement of one tool by another than a reorganization of the underlying activity that supports coarticulation of new technologies with old (Stevens, 2000). Coarticulation involves coordinating the use of different tools within interactions as people work together, divide their labor, and jointly perform a task (Stevens, 2000). In media environments where older and newer tools coexist, this process of coarticulation requires hybrid paper-digital practices and novel sociotechnical arrangements.

These new arrangements are a consequence of complex processes of reassembling social life (Latour, 2005), yielding new configurations of people, materials, and their spatio-temporal dynamics (Leaner, Phillips, & Taylor, 2010). New media practices do not only bring about proliferating virtual contexts, they also bring heightened awareness to physical spaces for learning where people and material resources are co-present. Everyday tasks cut across physical and virtual contexts and are populated by heterogeneous technologies; not all sociotechnical practices converge around interactive screens (c.f. Jenkins, 2006). Boyd (2014) found that the social lives of networked teens are complicated by how computer mediated communication and web-based services collapse contexts, spreading activity out across more spaces. In contrast, we are analyzing children’s work at home, because these learning contexts collapse tools, distributing learning across a range of technologies and reassembling domestic routines.

Reassembly disrupts what is taken for granted in sociotechnical practices, revealing the “invisible work” required to maintain everyday routines (Star, 1990). For example, when televisions became common fixtures in American living rooms in the 1950s, this domestic space (formerly used for formally entertaining guests) was repurposed for everyday family recreation, impacting the work of caring for children who could then congregate around TV screens (Spigel, 1992). Work processes that go unseen or unrecognized are associated with a gendered division of labor; child care and domestic work has historically been performed by women (Cowen, 1983), with the lion’s share falling to women of color (Star & Strauss, 1999). In general, in our study, mothers were primarily responsible for caring for children while homework was done. And while the advent of domestic technologies- from the washing machine to personal home computers- promises to streamline family life, new technologies have paradoxically not eased the work load of women at home (Cowen, 1983). Less still is known about how children’s work is impacted by technological change. This presents questions about the ways children’s home-work is being reassembled and the nature of work processes that are involved in their learning at home.

Design and methods
In this analysis, we draw on data collected in an ethnographic study of family life at home as it is currently being transformed by new (especially mobile) forms of media and technology. Participants included eighteen focal children in twelve families from diverse racial, ethnic, geographic, and socioeconomic backgrounds. Participants were recruited from local youth-serving organizations, camps, and other places where young people between the ages of nine and thirteen years old spend time; this period of development is significant for media engagement because it is about the time when children get their own devices (Rideout & Katz, 2016).

Data collection in this ethnographic study of families “daily media rounds” (Taylor, Takeuchi & Stevens, 2017) took place over two years in two separate US cities, and methods included the following: semi-structured interviews with parents and children (48 total); video recorded observations conducted during home visits, some of which were recorded by children using point-of-view cameras (i.e. GoPros®) (approx. 100 hrs); experience sampling through nightly phone calls (90 total calls), and a novel research activity for digital mapping of participants’ technology use (Silvis, Taylor & Stevens, in press), which was also video recorded (16 digital artifacts). To answer our research questions- how homework routines are re-mediated by newer and older technologies- we drew on ethnographic and interaction analysis (Hall & Stevens, 2016). We produced multimodal transcription of the talk, gesture, gaze, coordination of body movements (or lack thereof), uptake of tools, use of space, and other aspects that played into moment-to-moment interactions (Tulbert & Goodwin, 2011).
Analytic findings
A wide variety of assigned tasks took place across families participating in the study. During the school year, many of these tasks centered around schoolwork assigned by teachers. During discretionary time and summer break, children’s assigned tasks often took other forms, such as chores and housework, music or dance practice, or informal research projects (e.g. where to go on vacation). Because we were studying families’ new media engagement and technology use, we looked specifically at times when various technologies were being used to accomplish tasks. We found three processes of reassembly of children’s work that cut across these assigned tasks and reorganized the activities of home-work: mixing media, repurposing spaces, and remote assistance. In what follows, we focus on three instances of kids and parents working together during homework time. Each of these examples serves as a representative case of the three overarching processes of technological reassembly that happened in the course of assigned tasks.

Spreading homework across sheets of paper and screens
Children’s home-work often required collaborating with parents, and their division of labor involved asymmetrically distributing media and materials (Stevens, 2000). One Saturday afternoon, Natalie an eleven-year-old who participated in the study in a Midwest city, helped her mom complete an Excel spreadsheet containing information from a survey her mom had distributed at work. Natalie’s mom presented this to her as “work they needed to do together;” later, Mom told us she often enlisted Natalie in tasks for her job if technology was involved, in order to teach her daughter new technical skills. As they worked together on the couch in the living room, Natalie’s mom held the paper surveys, while Natalie was responsible for computer data entry. Using her mom’s laptop, Natalie created columns and rows and managed which information she placed in various fields. Her mom acquainted her with certain application functions, for example, by indicating the feature for expanding a row in order to view its contents. Natalie occasionally looked over at the sheets of paper surveys her mom held, however she primarily relied on her mom to verbally relay the information from the paper forms before transforming this into digital data.

Figure 1. Video stills of mixing media during homework. Clockwise from upper left: Natalie’s mom reports information from paper-based surveys (upper left), Natalie enters data into Excel spreadsheet (upper right), they collaborate over the screen (lower right), they collaborate over paper (lower left).

Natalie assisted her mom with her work, re-distributing their family’s labor across people but also across forms of technology. For the most part, they maintained a strict division of labor: Natalie managed the computer-based work, and her mom handled the paper-based materials (See Figure 1). At times, the distribution of the task was more fluid, and they used either the screen or the papers as a substrate for joint activity (Goodwin, 2013). As they coordinated this joint activity, they stayed physically huddled together side-by-side.
on the couch, their arms and hands repeatedly overlapping in activity. The task required that paper and digital forms be mixed together, similarly positioned side-by-side and interleaved in action. For Natalie, learning to manage data through Excel required coarticulation of computer-based and paper-based source of information through collaborative work with her mom (Stevens, 2000). This spreadsheet home-work activity literally spread the task out across sheets of paper, software, and screens, mixing together older and new forms of technology.

Doing homework at the scale of the house

Joint activity that involves mixing media is not always a stationary affair. As mobile technology becomes a ubiquitous aspect of family life, home-work can take place over more- and more distributed- spaces in the home. In the next instance of using technologies to accomplish assigned work, we turn to a more traditional version of homework, completing work after school that was assigned by a teacher. Oscar and Eddie, nine-year-old twins in a West Coast city, had been tasked with creating a paper book cover for their language arts class; the cover was to be based on a book they had read or wanted to read, so that they had some familiarity with the content. The instructions involved designing the cover, creating a synopsis for the front flap and researching the author or illustrator for the back flap. The twins, avid Pokémon fans, both decided to base their covers on their favorite book, *The Pokémon Deluxe Handbook*, an encyclopedia of over seven hundred Pokémon.

While they worked on this assignment one day after school over at least two hours (they were not finished by the conclusion of our scheduled visit), their activities spanned the entire home floor plan (See Figure 2). Eddie centered his work at the kitchen table, sketching his front cover design there and also consulting the assignment instructions and encyclopedia while watching TV in the living room; the twins’ mom had placed the instructions on a clipboard that traveled around the home, helping Oscar and Eddie remember the prompts and task structure. Oscar began his work at the table and then, having finished his cover design ahead of his brother, he opted to move to the living room couch, where he could research a Pokémon illustrator on his Mom’s laptop. The couch also afforded a better vantage point to watch TV, which remained on in the background while they worked. And yet, the living room was ostensibly a space for “technology breaks” from homework, not for legitimate “work.” Moving homework materials and mobile technologies into this area reorganized the underlying activity (Spigel, 1992). Both mobile devices and paper-based resources were instrumental in re-establishing what a given space could legitimately be used for and what technologies would “work” there to accomplish the task.

![Figure 2](image-url)

*Figure 2. Homework repurposes space in the home. A segment of the home floor plan used during homework, including available materials and technologies (left). Eddie uses the kitchen table primarily for paper-based work (top). Oscar moves to the couch to research illustrators on Mom’s laptop and discovers Bulapedia, Wikipedia for Pokémon (bottom).*

Remote time-keeping during piano practice

Reassembling home-work is a temporal as well as a spatial enterprise. In a third instance of reassembling homework, ten-year-old Brittany, who lived in the study’s Midwest city, practiced piano in the evening after
school, supported by different material resources across two separate days. On the first visit to the home, Brittany sat at the piano, reading sheet music and repeating several lines of music in one piece for approximately thirty minutes. Her mom, an accomplished piano instructor who assists her children’s piano practice, intermittently came to Brittany’s side, clapping out the beat and circling notes and bars on the paper sheets (See Table 1). Brittany’s mom encouraged her daughter’s repetition and constructively critiqued her technique. On a subsequent visit, after Brittany closed her sheet music, her Mom approached the bench and offered a new way to practice (See Table 2). She placed her cell phone on the piano’s music stand, and Brittany proceeded to use a mobile app to play “When the Saints Go Marching In;” Mom reported that her cousin, who also teaches piano lessons, had told her about this app. A virtual image of the keyboard on the screen indicated when to play each key, and a built-in metronome feature held the beat. As Brittany tried to keep tempo, her mom approached and indicated where the metronome feature was located on-screen and then told her to press “showtime” so they could hear the accompaniment.

Table 1: Practice session with paper-based time keeping

<table>
<thead>
<tr>
<th>Time</th>
<th>Technologies</th>
<th>Talk</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:39</td>
<td></td>
<td>Mom: So we’ll circle that and say “two” so you remember it’s a C and not a D</td>
</tr>
<tr>
<td>12:30</td>
<td></td>
<td>Mom: It’s slow, quick, quick, slow. Do you hear how it (snaps fingers twice)?</td>
</tr>
<tr>
<td>22:28</td>
<td></td>
<td>Mom: I just want to make sure you know how to do it, so I don’t have sit with you when you practice it all week… three, two, one, three, two and three and…G</td>
</tr>
</tbody>
</table>

Table 2: Practice session with mobile app time keeping

<table>
<thead>
<tr>
<th>Time</th>
<th>Technologies</th>
<th>Talk</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:14</td>
<td></td>
<td>Brittany: Is this middle C? Mom: Yes, it’s in practice mode, so it’ll wait for you. (walks into kitchen) Look at the metronome on the phone.</td>
</tr>
<tr>
<td>14:42</td>
<td></td>
<td>Brittany: (finishes playing) I did the wrong rhythm, totally. I did it way faster than the thing was going. That’s why I didn’t get too many points (applause from app plays in background).</td>
</tr>
</tbody>
</table>
Mom: I don’t understand this timing. Hit the “showtime” button.

Brittany’s family imported a new form of technological assistance into piano practice that was remote, in the sense that technical help was not immediately contingent on Brittany’s activity. While the device was co-located, it did not respond to Brittany’s mistakes by actively adjusting its assistance based on her performance in real time (however it did score her at the end of the song and give her a round of enthusiastic applause if she played well). The mobile app nonetheless maintained familiar aspects of piano practice to which Brittany was accustomed. Her mom placed the phone in the same location and position on the piano stand used for traditional sheet music; and Mom was still available to offer support. However, rather than standing next to Brittany, counting the beat, tapping the music with her pencil, Mom left her phone to act as a remote mentor and metronome; when she did offer support, it was mostly aimed at helping Brittany use the app- not play the piano. This temporary exchange of traditional tools- like sheet music, pencil, and manually tapping out the beat- with a form of remote assistance, reassembled the task. While remote assistance in and of itself is not exactly new to learning technology designs, learners now often engage in such temporal toggling between remote and co-located resources for learning during home-work.

Conclusions and implications

This paper has described three sociotechnical processes that reassemble families’ ordinary home-work routines: mixing media, repurposing space, and remote assistance. In the case of Natalie and her mom completing an Excel spreadsheet, the mixing of “older” and “newer” technologies was required for a task, supporting Natalie to develop technological fluency with a new software program. In the case of Oscar and Eddie, doing a homework assignment involved moving a variety of technologies from room to room, repurposing domestic spaces as a way of reassembling routines at the scale of the home. In the case of Brittany, practicing piano using the remote assistance of a smartphone app introduced a new way of keeping time where “collaboration” was out-of-sync compared to more proximal assistance her mother provided in prior practice sessions. These examples of young people accomplishing routine tasks at home show some common ways in which technology is re-mediating everyday learning and give specificity to how transformations in the mediational means of learning reorganize activities. We suggest that the reorganization of home-work involves less a replacement of paper materials by digital technologies than a reassembly and reordering of family life. This reassembly collapses tools, mixing technologies together over space and time in order to accomplish tasks.

There are several implications of these findings for understandings of how learning with technology and new media are changing in a digital age. For one, home-work represents an important site for studying how technology is transforming family life. Because so much of children’s time in and out of school is spent doing work assigned by other people, it is important to continue to ask how these tasks get accomplished and what children learn through participating in them. The tools and technologies children have available not only reorganize such tasks, they also make new learning possible and potentially change what counts as home-work, making visible how children’s contributions help stabilize sociotechnical systems (Star, 1990). Giving children credit for all the work they do and all the things they know is an important contribution of scholarship that re-centers informal sites like family life as valuable resources for learning (Rogoff, Topping, Baker-Sennett & Lacasa, 2002). Knowing more about how technology is involved in these unique and idiosyncratic funds of knowledge (Gonzales, Moll, Amanti, 2003) will be important as more technologies are incorporated into homes and families’ routines. The challenge that faces us now is how we will connect these important sites of learning, such as homework, to culturally valued technical opportunities beyond children’s homes (Ito et al., 2013) and throughout their “learning lives” (Erstad, 2012).

Our analyses of young people’s work at home also suggest that reassembling domestic routines through technology use is a collaborative endeavor. This finding is important for understanding how joint media engagement (JME) supports learning (Takeuchi & Stevens, 2011). Children often seek assistance from others to complete their homework (Kremer-Sadlick & Gutiérrez, 2013), and the increased prevalence of digital media at home presents opportunities for new forms of JME that bring people together over valued (and not so
valued) tasks like homework assignments from school, household chores, music rehearsal, pet care, sports practice, and other activities. Even parents’ work lives can bleed into children’s assigned tasks, as was the case for many of the families who participated in our study. These emerging configurations of people, tasks, resources, and space that constitute JME are continually reshaped as new technologies co-articulate in novel ways with older ones (Stevens, 2000).

A third and related implication follows from this: it is simply not the case that digital technologies remove young people from their family networks and isolate them from larger family routines (c.f. Turkle, 2010; Twenge, 2017). In fact, what these analyses have shown is that the presence of media and technology in the home present new opportunities for intergenerational teaching and learning in the family context, and what some of the configurations of families’ resources for learning can look like. This builds on prior studies of parents’ supports of children’s uses of technology (Barron, Martin, Takeuchi & Fithian, 2009) and families’ unique patterns of media engagement (Levinson, Siyahhan, Pressey & Taylor, 2015) and extends it in an important way. While digital technologies may be the natural focus of much of our work because of critical questions regarding learning technology design (Roschelle, Martin, Ahn & Schank, 2017), there are still many older tools and technologies we need to account for in studying families’ shifting sociotechnical practices.

Therefore, a final implication is that we should take an expansive perspective on what counts as innovation in learning designs. In the current moment, when so much of our work still relies on older technological forms whose utility and relevance are not diminished by digital tools, we ought to consider hybrid designs (Stevens, 2000; Ma, 2017) that draw on domestic processes we have described here. Repositioning families as generating novel forms of technological work, as we have done in this analysis, is not or not only a matter of making it possible for them to participate in activities we design. It is equally important to shift our view to the many ways families are already adept at using a variety of technologies to reassemble daily routines (Levinson et al., 2015). These vital sites for learning and living continue to situate heterogeneous tools and technologies together in ways that will require on-going study.

References


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We would like to thank all of the young people and their families who participated in this study and let us into their homes to watch them work and play.
Patterns of Classroom Talk Through Participation in Discourse-Focused Teacher Professional Development

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Abstract: The Next Generation Science Standards (NGSS) reforms in the United States present a number of serious learning challenges for in-service teachers. As states and school districts are assuming responsibility for the new standards, there are few professional development (PD) models for how to help working teachers meet these challenges. This study presents an analysis of teachers’ practice in the second of three years of professional development aimed at helping them learn to enact instruction aligned with the NGSS. The analysis focuses on changes to how teachers organize whole class discussions, looking particularly at how teachers support student-student dialogue. Comparing discussions from spot observations of teaching to PD-supported lessons, data suggest teachers struggle in both contexts to support productive student-student talk, although they are modestly more successful in the PD context. Conclusions from this analysis include that PD should provide clear models of productive discourse.

Introduction
In the United States, most states have adopted versions of the Next Generation Science Standards (NGSS Lead States, 2013). In California, with more than 6 million students in public schools, teachers in grades 7-12 are responsible for teaching to the new standards as of the 2017-18 school year. The shift from business as usual to the new standards entails radical changes to teaching practice. One very big change is that the NGSS ask teachers to organize curriculum around natural phenomena that require explanation, rather than around concepts students should learn. This shift is intended to subordinate science concepts to the phenomena they help to explain. A second change is that students should engage in science practices to explain and model phenomena, such that concepts are learned through practices of investigation, modeling, explanation, and so on, rather than maintain a false dichotomy between science concepts and processes. This reorganization of instruction requires a third shift in teaching practice in order to be successful: teachers must reorganize the discursive practices of their classrooms. Real engagement in science practice entails talking through the myriad questions and disagreements that naturally emerge during any real inquiry, in order to stabilize resolutions to empirical and conceptual problems that enable continued progress (Manz, 2014). Given the rarity of inquiry-oriented science instruction prior to the development of NGSS (Banilower, Smith, Weiss, & Pasley, 2006), it is safe to say the demands of the NGSS pose significant challenges for practicing teachers.

This study draws on data collected during the second year of a three-year professional development project. The overall project aims to help teachers shift their practice toward the kinds of science learning envisioned by NGSS, learning that relies on students’ joint construction of scientific knowledge, and of the practices that create such knowledge. Our view on creating such learning environments centers on developing productive disciplinary engagement (Engle & Conant, 2002), by focusing on framing instructional activities in ways that make students accountable to each other and to the discipline. This requires centering classroom discourse as the main lever of instructional change. Our approach has two stages. In the first stage, our aim is to help teachers “open up” their instructional activities to give students more agency and responsibility to negotiate and enact practices of experimentation, modeling, data analysis, argument, and so on. Productive disciplinary discourse can only emerge in such contexts, where students legitimately have to grapple with how to engage in the work. The second stage aims to help teachers learn productive talk moves that can help them manage the student discourse arising from these more open opportunities to do science. Here we draw on observations of class discussions for evidence that our PD approach is changing classroom discourse. We assume teachers, as learners, move along different trajectories in this work, and thus discourse patterns will vary. Here we describe variations in discourse patterns among teachers and how they change over the course of a year of professional development. These patterns of change provide insights into particular challenges teachers have in promoting a more expansive, productive disciplinary discourse, and how PD might support them.
Methods
The primary question we ask in this study is how participation in PD supported teachers in changing the nature of their whole class discussions. We use the character of whole-class discussions as an indicator of how teachers’ practice may or may not be moving toward alignment with NGSS. Whole class discussions are perhaps the primary site where norms and standards of accountability are developed and spread (Engle & Conant, 2002; Mercer, 2008; Rosebery, Warren, & Conant, 1992). We are not claiming that productive discourse happens only, or even mostly, in whole-class discussions. We simply assert that analyzing the qualities of teachers and students’ contributions to whole-class discussions provides an indicator of the epistemic agency students exercise in classrooms, and that such agency is central to productive disciplinary engagement (Engle, 2006; Michaels, O’Connor, & Resnick, 2008).

Study context
The data for this analysis are drawn from the second of a three-year professional development project. Professional development activities are led by dedicated staff experienced in science teacher professional development, in collaboration with research staff on the project. Each year of PD is organized as a 3-day summer institute (18 hours) where participating teachers explore a small set of issues to focus on during the school year. During the school year, teachers work in subject matter teams within grade bands (e.g., grade 8 physical sciences, high school biology) through two cycles of curriculum revision modeled on lesson study (Fernandez & Chokshi, 2002). Each lesson study cycle is carried out through 4 PD sessions (16h), an instructional round day (6h), and a final debrief session (2h). This sums to about 66 PD contact hours per year.

Lesson study cycles are organized around each teacher team choosing one unit of instruction to revise. During the first year of PD, 2015-16, revisions focused on creating opportunities for students to engage in one of the 8 science and engineering practices (SEPs) described in the NGSS. As teachers began this work in the first year, we found they understood SEPs as instructional means for either reinforcing concepts or assessing student understanding (Sandoval, Kawasaki, Cournoyer, & Rodriguez, 2016), rather than as intellectual means to develop an understanding of the natural world. Most of our teachers either did not believe their students could engage in something like authentic practice without being told key science concepts in advance, or themselves showed superficial understanding of science practice (Kawasaki, Sandoval, & Rodriguez, 2017). As a means of supporting teachers’ developing understanding, we provided them with the NGSS storyline tool (Reiser, Fumagalli, & Novak, 2015), a template for framing instructional units around an anchoring phenomenon and a series of questions that can organize instructional activities to generate answers that accumulate to an overarching explanation of the phenomenon.

During the second year of PD, teacher teams used storyline development as the primary means to organize their instructional revision work. PD staff pushed teachers particularly to focus on how they framed anchoring phenomena as objects of study, and how they framed subsequent instructional activities in relation to the anchoring phenomenon of a unit. Framing, broadly, refers to how we use speech to organize and interpret an understanding of social interaction (Goffman, 1974). Framing is an interactional accomplishment. In classrooms we can ask how students and teachers frame their activity, how they make sense of what is, or should be, going on and thus how to participate (Berland & Hammer, 2012). As we worked with teachers during the second year, PD activities focused on helping teachers think about how they could frame instructional activity such that students would be more likely to engage in productive disciplinary dialogues. This focus on framing emerged from our analysis of the difficulties teachers had in the first year of PD to legitimately open space for students to exercise epistemic agency (Sandoval et al., 2016).

Participants
The teachers involved in the project work in an urban school district in the western United States, serving a population of approximately 30,000 students. Ninety-five percent of students identify as Latino, more than two-thirds qualify for free or reduced lunch, and approximately 30% are classified as English learners. All participating teachers (N = 25) teach science in middle school (9 women, 3 men) or high school (10 women, 4 men). All participating teachers are designated as lead teachers at their schools, with responsibility for helping their colleagues implement NGSS. Most of the high school teachers participating in the project worked with this project’s professional development staff during the year prior to the start of this project. Teachers self-organized themselves into grade/subject teams to pursue their lesson study work. There were seven teams during the first year, collapsed into six during the second year because two teachers were unable to consistently attend PD sessions.
Data sources and analysis

The data for the present analysis come from video records of instruction collected throughout our second year of work with these teachers, 2016-17. During the early part of the fall of the school year (late August – October, 2016) we recorded one class meeting of each teacher, suggested by them as showing their best effort to enact NGSS-aligned teaching. We repeated this round of spot observations during the spring of 2017 (April – June), again for each teacher. During each instructional round, in November, 2016 and April, 2017, we video recorded two “research lessons” from each team, producing 12 videos from each round. The video corpus comprises 74 recorded lessons (50 spot observations, 24 research lessons), averaging 46 minutes apiece. This analysis works from the videos that have currently been transcribed: 25 from Fall 2016 (F16), 14 from Spring 2016 (S16), and 13 of the 24 videos from the two instructional rounds of research lessons.

To analyze the roles teachers and students played in discussions across such a large sample of video recordings, we applied the low-inference discourse observation protocol (LIDO; Michaels & O’Connor, 2015). LIDO counts the frequencies of categories of teacher and student talk moves in whole-class discussions (Table 1). There are six teacher codes and six corresponding student codes. Three codes for teacher talk address dialogic scaffolds (T1-T3), and correspond with codes for student dialogue (S1-S3). Three other teacher codes (T4-T6) characterize the nature of questions teachers ask. One code for student talk (S4) concerns whether students ask questions related to the lesson content, and two (S5, S6) capture how students respond to teacher questions. Under our framework of productive disciplinary discourse, we would prefer to see more dialogic scaffolds and dialogic responses from students, and open-ended questions from teachers with elaborated responses from students.

Table 1: LIDO codes for teacher and student contributions to whole-class discussions

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Get student(s) to respond to another student’s turn</td>
<td>S1</td>
<td>Student addresses another student</td>
</tr>
<tr>
<td>T2</td>
<td>Ask student to explain, clarify, or provide reasoning</td>
<td>S2</td>
<td>Student refers to another student’s contribution in some way</td>
</tr>
<tr>
<td>T3</td>
<td>Attempts to get student to continue speaking</td>
<td>S3</td>
<td>Student provides evidence or reasoning to support their claim</td>
</tr>
<tr>
<td>T4</td>
<td>Poses truly open, contestable question</td>
<td>S4</td>
<td>Student asks the teacher a question about lesson content</td>
</tr>
<tr>
<td>T5</td>
<td>Poses semi-open question, with a circumscribed answer set</td>
<td>S5</td>
<td>Other elaborated turn, longer than a simple clause</td>
</tr>
<tr>
<td>T6</td>
<td>Poses a closed, uncontestable question, or a test question</td>
<td>S6</td>
<td>Turn is a simple clause or less</td>
</tr>
</tbody>
</table>

We carried out this analysis in several stages. First, video records of each observed lesson across the 4 time points was transcribed in full. Then, segments of whole class discussion were identified and marked. Marked transcript segments were then coded, first for teacher codes then for student. Researchers calibrated our coding by first collectively coding 4 transcripts and discussing discrepant code assignments until they were resolved. Following calibration, the remaining transcripts were coded independently by the second author. Since each lesson varied in the amount of whole class discussion, code frequencies were standardized by dividing each code count by the total number of counts in that category (teacher or student).

Given the uneven distribution of transcripts across time points (and instructional contexts) we collapsed coding results from F16 and S17 into a single group we call “spot observations,” and we consider the 13 transcripts from the lesson study rounds as a single group of “research lessons.” To explore our question of how PD may be promoting change, we conducted paired-samples t-tests comparing the frequency of teacher dialogic scaffolds (T1-T3), and student-student dialogue (S1 & S2), and student justifications of reasoning (S3).

Findings

We first present the overall pattern of dialogic interactions observable in our video records, explicitly comparing spot observations to research lessons. Then, we provide brief examples of the nature of whole class discussion in both instructional contexts to provide a concrete sense of what the numbers describe.
Patterns of teacher and student talk moves

Overall, across all of the lessons we observed, whole class talk was dominated by what appears to be traditional triadic dialogue (initiate-response-evaluate, Mehan, 1979), as can be seen in Table 2. (The numbers in this table are standardized proportions of the frequency of each code in relation to the total frequency of codes in that category, teacher or student). The most common talk move from teachers, by far, was to ask a closed-ended question (T6), which were, unsurprisingly, replied to with simple, unelaborated responses (S6). Even during research lessons (IR3 and IR4 in Table 2), the sample of teachers we observed continued to ask mainly closed-ended questions.

Table 2: Standardized proportions of LIDO talk moves in each observation period

<table>
<thead>
<tr>
<th></th>
<th>Dialogic Scaffolds</th>
<th>Teacher Questions</th>
<th>Student Dialogue</th>
<th>Student Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
<td>T4</td>
</tr>
<tr>
<td>F16</td>
<td>25</td>
<td>0.01</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>S17</td>
<td>14</td>
<td>0.00</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>IR3</td>
<td>6</td>
<td>0.02</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>IR4</td>
<td>7</td>
<td>0.02</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 1. Discourse differences between spot and research lesson observations in teacher dialogic scaffolds, student-student talk, and student justification of reasoning.

During the research lessons, then, teachers were more likely to elicit student reasoning about the topics under discussion and, naturally, students were thus more likely to provide that reasoning. While there is more student-student talk during the research lessons, these are not truly dialogic discussions in which students challenge each others’ ideas and strive to reach a consensus understanding.

Examples of discussions across contexts

The quantitative patterns in these data suggest this group of teachers were, on one hand, beginning to enact discursive strategies consistent with our professional development and aligned with NGSS, but, on the other hand, struggled to extend these strategies into their regular classroom instruction. We present two excerpts from one teacher to illustrate this struggle. Ms. Grant (a pseudonym) used a relatively high number, compared to her peers, of dialogic scaffolds in the research lesson we observed her teach (during IR3), but her spot observation during S17 looked very typical of triadic dialogue. Comparing the nature of these discussions suggests some of the struggles Ms. Grant and her colleagues navigate to learn the new reforms.

Spot observation: Standard I-R-E

For the Spring 2017 observation, Ms. Grant invited us to observe an activity about natural selection. Working in groups, students timed each other conducting a series of tasks with and without the use of their thumbs (taping down thumbs and trying to open a door, or tie a shoe, is a classic activity in the US to demonstrate selective fitness of traits). Ms. Grant opened the class with general instructions for the activity, then she went from group to group to check on their progress. After about a half hour, she brings the class together to review their results, although she specifically tells groups who haven’t finished all of the tests to continue to do so. She calls one group to share their data, displaying their recorded data for the class, through a projector. The excerpt below
starts with Ms. Grant reviewing the data the group recorded, after one group member has claimed that the “primates” completed tasks faster than “non-primates” (students whose thumbs had been taped against their hands):

1 Teacher: This is 54 seconds, this is 47 seconds, yes?
2 SI: [Inaudible comment]
3 Teacher: That’s 47. So it actually took the primate longer than the non-primate.
4 SI: Those are not seconds. [Inaudible comment].
5 Teacher: Yeah, but regardless this is more and this is less so it kind of rebuttals what you’re claiming. So why do you think it is in this activity that the bottlecap it took longer for the primate than the non-primate? Is there something else you could have done differently in the experiment? Is there something that made the results come out differently? Okay, let’s think about this. You guys see this, primates are this, right? Primates have the thumbs, correct? The non-primates do not have thumbs, right? But you guys said that you think that the primates have a better chance of getting the activities done quicker, right? But right here, does this data support that? Does this evidence support that?
6 SI: No.
7 Teacher: No. Can you tell me why it doesn’t support it or what could have caused this result in your experiment? Think about how you actually conducted the experiment. So who is this?
8 SI: Brian.
9 Teacher: Brian? And who is this?
10 SI: Me.
11 Teacher: Okay. You guys see that, right? You heard that? This is Brian and this is Anthony. Those are two separate people. And remember, the primates are supposed to be taped up tightly and they’re not supposed to have any mobility of their thumb. So why is it do you think that the non-primate got it done quicker than this? Can you guys explain to us how you actually – what did you do with the bottlecap? Explain to us the procedure, the process. What did you do? You took the bottle and then what?

Notice that Ms. Grant notices that the data the group presents supports their claim that students who could use their thumbs would complete tasks faster than those students whose thumbs were taped. She address the problem in line 5 by asking, in very rapid succession, a series of questions that imply a procedural error in the group’s work, asking if something made the results come out in this unexpected way? In line 7 and 11 she elaborates by first asking students to think about how they “actually conducted the experiment” and then asking them to explain to the class their process. Students here have very little role in the dialogue. For one thing, they have to parse five or six questions and figure out which one to respond to. Also, even Ms. Grant’s requests for explanation become constrained. In line 11, she asks them first to explain the process, but then, before they can answer, states the first step, “you took the bottle,” and then asks for the next.

Through such strategies Ms. Grant, and her colleagues, dominated the course of whole class discussions, explicitly working to guide the class to the target response or explanation, with as few detours as possible.

**Research lesson: Creating an initial model**

For their research lesson, Ms. Grant and her team decided to show an elapsed time video of a dead rabbit decomposing on the floor of a florist and ask students to decide which of the things they saw in the video were living or non-living. The intent was to develop a set of criteria to distinguish living, dead, and non-living things. Students watched the video clip and then wrote lists of what they saw that they considered living and non-living.
Then Ms. Grant asked students, “what is the difference between living and non-living?” She said she would write these differences on the board for all to see:

1 Teacher: So I’m just going to write what you guys say what you think is living and nonliving – so can you repeat what you said again, so you said you know when something is living when –

2 S1: It needs oxygen and water food and sun.

3 Teacher: You said oxygen, water, food and sun. okay. Either one – if you guys have anything to share both living and nonliving. Can anybody add on to what S1 said?

4 S2: Habitat?

5 Teacher: For which one.

6 S2: Living.

7 Teacher: Okay, so habitat. What do you mean by habitat?

8 S2: Um, animals need an habitat to live and stay [inaudible].

9 Teacher: Okay and what about nonliving. How do we know what is nonliving?

10 S3: Because it will decompose.

11 Teacher: Okay so you think nonliving is something that decomposes. What else do you know? Say it again?

12 S3: Doesn’t need oxygen.

13 Teacher: Okay so you’re saying it’s the opposite. It does not need oxygen or doesn’t need oxygen. Can anybody else add on?

14 S4: It doesn’t need anything [inaudible]?

15 Teacher: When you say it doesn’t need anything ____ what do you mean by that?

16 S4: Like food.

17 Teacher: So you’re saying it doesn’t need oxygen. It doesn’t need food. Right? Okay what else? Can anybody add onto what did you use, how did you come up with what’s living and what’s nonliving. What was your criteria? So I know some of that is living it needs oxygen, water, sun and has a habitat, and for nonliving it decomposes and it doesn’t need oxygen or food – Marissa, did you want to add on?

For the most part, this is also a highly teacher-directed discussion, although Ms. Grant is not trying to move directly to the “right” answer. For instance, when a student says non-living things decompose, Ms. Grant did not correct him (lines 10 and 11; living things also decompose). She also, during this discussion, asked students sometimes to elaborate on their responses (T3), as in lines 3-8. The discussion continued by having students watch the video clip several more times, each time recording what they saw as living or non-living, and each time discussing the criteria they were using to make those choices.

This is certainly not a student-driven discussion characteristic of productive disciplinary engagement. Similarly to what we saw later in the spring spot observation, Ms. Grant does most of the talking and maintains control of the direction of the discussion in large part by minimizing the amount of talk from students. In contrast to the spot observation, Ms. Grant makes some efforts to elicit elaborated reasoning from students.

Conclusions and implications
The overall patterns of talk we see in our data from this second year of PD is that the teachers we work with struggle to concede control of classroom discourse to their students, thus limiting those students’ opportunities to engage in productive disciplinary discourse. While they made some effort in research lessons to incorporate discourse strategies presented in PD, it seems clear they were not appropriating those strategies as intended.
There are several interacting reasons for this, which we can discuss briefly in relation to the present analyses and earlier ones from this work.

One factor is that most of these teachers did not start with deep understandings of the practices they are trying to get their students to learn (Sandoval et al., 2016). Adding to this, most of these teachers did not seem to believe their students were capable of investigating questions or phenomena without first being told the relevant science concepts (Kawasaki et al., 2017). We were also surprised that many of these teachers did not seem well practiced in writing detailed lesson plans (Sandoval, Cournoyer, Eggleston, Modrek, & Kawasaki, 2017). Consequently, our approach of asking them to revise existing instructional units presented a difficult design and collaboration challenge, as we asked them to work together to revise an existing instructional unit. During this second year, using the storyline tool (Reiser et al., 2015) we provided, they still struggled to produce coherent sequences of instruction, particularly in articulating expansive roles for students to engage in legitimate versions of science practice (Sandoval et al., 2017b).

We draw three conclusions from this, with clear implications for professional development geared toward ambitious science teaching (Windschitl, Thompson, Braaten, & Stroupe, 2012). First, it seems clear that the radical changes to teaching practice required by the NGSS take considerable time to learn. Given that such time is not readily available for working teachers, this is a serious problem. Our own time with them is considerably more than is typical of professional development, but clearly through two years not sufficient. A second conclusion is that asking these teachers to work from their own units and import, as it were, new practices they did not yet understand well is probably asking too much. Instead, it would probably be more helpful to them to provide clear models of instructional units aligned with NGSS and, perhaps, ask them to analyze those units and what they are doing. Indeed, during our current year with them, we have relied heavily on such models and they appear, anecdotally, to be helpful. Our final conclusion is that expanding new forms of teaching practice beyond the highly supported contexts of professional development is clearly difficult. This poses a serious problem for current notions of professional development as something that teachers do, or are given, and then they are done. Our findings suggest that beyond explicit PD offerings or opportunities, teachers need workplace structures to support their ongoing learning. This is a challenge at the systemic level, and one that we, specifically, and the learning sciences generally, have not yet taken up as a problem of research. We suggest this may be a vital line of research for the learning sciences to have sustained impact on teaching practice.

Acknowledgments
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References


Changes in Students’ Use of Epistemic Criteria in Model Evaluation

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Abstract: Scientists collaboratively develop and use epistemic criteria to evaluate the products of their inquiry practices (e.g., models and arguments). Although students are able to engage in many aspects of scientific practices effectively, we know less about students’ ability to develop and use epistemic criteria. In this paper we discuss a model-based inquiry intervention with seventh grade students in which students developed and used epistemic criteria when evaluating models. We explored students’ use of epistemic criteria before and after the intervention. We found that students were able to generate and use a variety of epistemic criteria even before the intervention. Yet they improved in their ability to invoke fit-with-evidence as an epistemic criterion, a central criterion in modeling and argumentation. Our data suggest that students developed in their understanding of which criteria are prioritized in scientific practice—i.e., a meta-epistemic understanding of the utility and importance of epistemic criteria.

Introduction
Scientific inquiry involves understanding and using epistemic criteria to generate and evaluate epistemic products such as models and arguments (Laudan et al., 1986; Longino, 2002; Newton-Smith, 1981). Examples of epistemic criteria for good models include: models are good when they fit with evidence, have an appropriate level of detail, and address the question. The use of epistemic criteria is pervasive in scientific communities and should be included in the learning of science. Educational standards in the United States and elsewhere now advocate for engaging with scientific practices, including an understanding of the underlying epistemic commitments they reflect such as criteria for evaluating epistemic products (NGSS Lead States, 2013; Province of British Columbia, 2016). Through collaborative development and revision of epistemic criteria, students can become enculturated to the epistemologies underlying scientific practices (Berland et al., 2015).

Middle school students are capable of generating epistemic criteria for model quality even before formal instruction on modeling (Pluta, Chinn, & Duncan, 2011). Pluta et al. (2011) found that when students were tasked with comparing pairs of models, deciding which model is better and why, and then generating a list of criteria for good models, student-generated criteria spanned a wide range referring to a variety of model purposes and features, many of which aligned with the epistemic goals of scientists. While this research showed that students can generate criteria, it did not examine whether students could subsequently use these criteria to evaluate epistemic products when engaged in actual modeling and argumentation tasks, and how those criteria change as students gain facility and understanding of them through their inquiry learning experiences.

In this paper, we investigate how middle-school students’ use of criteria changes during the course of a model-based inquiry program spanning 20-22 weeks. We examine change at two levels of epistemic growth: the level of practical performance and the level of meta-epistemic understanding (see Chinn, Duncan, & Rinehart, 2018). Practical performance with epistemic criteria involves the practical application of criteria such as fit with evidence and clarity of presentation to create or evaluate models. Meta-epistemic understanding involves explicitly recognizing that one has selected a model because it meets a core epistemic criterion such as it has better fit with evidence, greater clarity of presentation, and so on. Successful reasoning requires advances at both levels (Barzilai & Chinn, 2017; Chinn et al., 2018; Sandoval, 2005).

There are a number of different learning environments designed to help students engage in scientific practices (see Andriessen, 2006) and to help elucidate students’ implicit understandings of epistemic criteria (e.g., Sandoval, 2003). However, only a handful of these environments have focused on students’ explicit use of epistemic criteria when creating, evaluating, or revising scientific models (e.g., Schwarz & White, 2005; Stewart, Cartier, & Passmore, 2005). Therefore, we still know relatively little about whether and how students use epistemic criteria to guide their engagement in core scientific practices such as modeling. In particular we do not know much about how students’ understanding and use of epistemic criteria changes as a result of inquiry instruction or how understanding at the meta-epistemic level interacts with the practical performance level (actual use of criteria).
Arguably the most central criterion for model quality is fit with evidence—how well the model accounts for the available evidence. The metacognitive understanding of the importance of fit with evidence as a criterion is what we mean by a meta-epistemic understanding of how to evaluate models appropriately. In our prior work we found that while students articulated a variety of epistemic criteria, only about a fifth of the students identified fit with evidence as a criterion (Pluta et al., 2011). Accordingly, in this study we explored in particular how students advanced in their meta-epistemic understanding of evidentiary criteria, as evidenced by both practical application of that criteria (e.g., using more evidence) and meta-epistemic use (explicitly stating that evidentiary criteria were being used) and how this growth was related to the growth in other criteria.

Focusing on explicitly mentioned epistemic criteria, we examined written assessments in which students evaluated competing models based on evidence. The individual assessment was completed before and after engagement in a several-months-long model-based inquiry curriculum in which students collaboratively developed and used public, shared epistemic criteria for evaluating models and evidence. We thus are able to expand on Pluta et al. (2011) to understand students’ use of epistemic criteria and how use changes over time. We wanted to understand:

1. Which model-quality criteria do students apply in their written arguments?
2. How does students’ practical use of epistemic model-quality criteria change before and after instruction?
3. How does students’ meta-epistemic use of epistemic model-quality criteria change before and after instruction?

Theoretical framework
Epistemic norms arise out of collaborative meaning making by communities within the field or culture, often through argumentation (Bang & Medin, 2010; Lund, Rosé, Suthers, & Baker, 2013). In science, epistemic understandings (such as understanding the criteria and the processes used to generate and test models and theories) (Chinn et al., 2018; Ryu & Sandoval, 2012) have been developed, and continue to be evaluated, through discourse within the scientific community (Longino, 2002). These understandings also influence and are influenced by scientific practices (Ryu & Sandoval, 2012), such as creating models of scientific phenomena, and constructing arguments. Given the importance of modeling and argumentation in science and science education, it is important to engage students with these practices in order to help them appreciate how science is done and how scientific knowledge is developed using evidence.

A number of collaborative learning environments have been designed to develop students’ argumentation skills (see, e.g., Andriessen, 2006). Studies have shown that, with proper scaffolding, students improve in their capacity to use more evidence (Suthers, Weiner, Connelly, & Paolucci, 1995), discriminate between evidence and claims (e.g., Reiser et al., 2001; Suthers et al., 1995), develop and elaborate on arguments (e.g., Reiser et al., 2001), and discuss the features of arguments (Munneke, van Amelsvoort, & Andriessen, 2003). Some of these learning environments have also been used by educators and researchers to identify students’ epistemic understandings about science by analyzing students’ implicit or explicit practical use of epistemic criteria when engaging in argumentation. For example, Sandoval and Millwood (2007) found that students discussed the need to warrant scientific claims with evidence, which is an important epistemic understanding in science. Sandoval (2003) also studied the interaction of students’ conceptual and epistemic understandings of science as they used an inquiry learning environment (BGuILE). Sandoval focused on students’ epistemic understanding, which students may not state explicitly but which they use when engaging in scientific practices such as exploring scientific phenomena and using data. He found that students began to develop abilities in using data when theorizing about scientific phenomena. Students were especially able to generate causal mechanisms to explain data, which is a commonly used scientific practice that may help students make connections between evidence and claims (Sandoval, 2003). Overall, students are able to engage in many of the epistemic aspects of argumentation with appropriate scaffolding.

However, students continue to have difficulties with some epistemic aspects of model evaluation and argumentation, particularly with regards to sufficiently privileging fit-with-evidence as a core epistemic criterion (Munneke et al., 2003). For example, students have difficulty adapting their views about the nature of empirical results in science (Sandoval & Morrison, 2003), such as persistently assuming that empirical results are proof rather than evidence for theories, and struggle to attend to alternative interpretations of evidence. Struggling with the purpose of evidence and with attending to alternative interpretations of evidence suggests that students are not yet able to evaluate their knowledge in a sophisticated manner, and is indicative of the need for further development of their epistemic understanding for and of evidence evaluation practices. These difficulties may be due in part to the lack of emphasis on metacognitive epistemic understanding, that is, why
these epistemic criteria matter. Most of these environments did not provide opportunities for students to evaluate their epistemic understandings.

Moreover, assessing students’ metacognitive understanding of epistemic criteria still poses a research challenge; for example, commonly used surveys of epistemic beliefs are decontextualized and are thus not appropriate measures of students’ capacity to understand and use epistemic criteria (Sandoval, 2005). Berland et al. (2015) developed the Epistemologies in Practice framework for analyzing students’ understanding of, and engagement with, scientific practices, arguing that understanding and engaging are intertwined processes. They focused on analyzing student discourse to elucidate the epistemic criteria that students use, often implicitly, when constructing scientific knowledge, and on community development and usage of these products in scientific contexts. This provides a method of examining community use of epistemic criteria to guide knowledge production, but because there is no distinction between implicit and explicit use of epistemic criteria it does not afford the ability to identify students’ metacognitive understanding alongside their practical use.

Through our analysis we aim to address several gaps in existing research. First, we are interested in students’ meta-epistemic use of shared epistemic criteria (i.e., explicitly stating criteria) and how this relates to their use of these criteria at the practical level of using criteria to evaluate models. Given that epistemic criteria were made explicit in the intervention and were assessed (students collectively developed, discussed, and revised public, community epistemic criteria for evaluating models and evidence), we investigated whether students would explicitly reference these criteria in their arguments about models and evidence. Second, we examined the change in students’ use of epistemic criteria before and after an intervention in which they had opportunities to use, discuss, and refine these criteria.

**Intervention**

The middle-school students in this study participated in a life-science model-based inquiry curriculum over the course of several months. The curriculum scaffolded students as they developed, evaluated, and revised models based on evidence. Students also engaged in written and verbal argumentation about the models, evidence, and criteria. The instructional modules were co-designed by the researchers and teachers. Topics included natural selection, genetics, and cell organelles. The curriculum involved individual, group, and class activities. As part of the intervention, students developed, discussed, and revised class criteria lists for what makes good models and used these lists in their creation and evaluation of models. Students were first tasked with developing these criteria after an introductory activity in which they were exposed to several different kinds of models and representations which they were asked to discuss and evaluate in pairs. Students first developed criteria individually, followed by a class discussion in which students collaboratively developed and agreed on a class list. Among their model evaluation criteria students brought up issues of evidentiary support, pertinence to the question at hand, clarity (including using graphs and images), appropriate levels of complexity, and others. These criteria were publically displayed in the classroom and students and teachers referred to them as they engaged in modeling activities. For example, when working on revising a model, students might discuss the areas in which the model might fail to meet the criteria on the list and try to adapt it. The lists were also periodically revised and refined by the class as students developed and refined their understanding of criteria throughout the intervention.

In a typical activity in the unit, the students usually considered two or more competing models explaining the same phenomenon (e.g., model for the function of the nucleus); students evaluated the models and, in some cases, also developed or revised models. Students were given three to six pieces of evidence of varying quality to use in their model evaluation. For example, in the lesson about the cell organelles, students worked with evidence about the number of mitochondria in the muscles of different birds in order to determine the function of mitochondria. They used this evidence in tandem with competing models to determine the function of mitochondria, as well as to learn to evaluate the quality of evidence and models. Evidence was usually presented to groups through computer-based animations and simulations, and also through written reports and hands-on experiments. The evidence was developed to be engaging to students (Chinn et al., 2018) and was used to help visualize complex mechanisms more clearly. In alignment with guidelines from previous research (Rinehart, Duncan, Chinn, Atkins, & DiBenedetti, 2016), evidence varied in complexity, quality, sourcing, presence of data, and relevance to the models. For example, evidence may have been collected by a reliable source using sound methods, or a less reliable source with questionable methods. We planned evidence so that it would problematize students’ evidence evaluation criteria. We have found that this variation helps support richer evidence-quality discussions (Rinehart et al., 2016); in addition, variation is important because it better approximates the range of evidence that people are exposed to in their daily lives.

Activities also included different kinds of prompts including comprehension checks, questions about the quality of pieces of evidence, and questions about the relationship between evidence and the models.
Throughout this process of evaluating evidence and models, students collectively developed and revised criteria lists for model evaluation and practiced using them alone and in groups.

Two main scaffolds supported students in these tasks, in particular evaluating evidence quality and linking evidence to models. First, students used a 0-3 scale to evaluate evidence quality, with zero being very bad evidence so that the conclusions cannot be believed and the evidence should be ignored, and a three meaning that the evidence was of high quality and its conclusions can be believed. A second scaffold was the model-evidence link (MEL) diagram, a chart in which students used arrows to signify the relationship between each piece of evidence and model. Students used five relationship arrows signifying that the evidence highly supports, supports, highly contradicts, contradicts, or is neutral to the model (see Figure 1).

![Figure 1. Model-Evidence Link Diagram.](image)

**Method**

**Research context and participants**

The study included data from 204 seventh grade students in 15 classrooms taught by three teachers in a suburban middle school in a township in the Northeast of the United States. Based on the state report card, 31.2% of the students in the school were Asian, 5.0% Black, 7.2% Hispanic, 56.1% White, and 0.5% other. 14.1% qualified for free or reduced lunch, and the performance of this school was above the state average.

In this paper we report on our analysis of the pre and post modeling and argumentation assessment. We developed two comparable versions of the assessment: one about why we feel muscle pain 48-72 hours after exercise (MP), and the other about why leaves fall off trees in autumn (FL). These were counterbalanced between the pretest and posttest (i.e., some students received MP as a pretest and FL as posttest, whereas others completed the assessments in the opposite order). The assessment introduced students to two competing models. In FL the model better supported by the evidence—which we will call the “correct” model—was Model A. This model proposed that shorter days induced the production of a poisonous chemical that killed cells in the leaf stalk and caused the leaves to fall off, whereas the model less supported by the evidence (the “incorrect” model)—Model B—proposed that below-freezing nights caused ice crystals to form in the leaves, killing leaf cells and causing the leaves to fall (see Figure 2). In MP the incorrect model, Model A, proposed that lactic acid builds up in the cells causing them to swell and push against the nerves resulting in pain, whereas the correct model, Model B, proposed that the muscle fibers are damaged during exercise and the process of repair is painful. Students were provided with five pieces of evidence to help them decide which model is better. The first two pieces of evidence reiterated various aspects of the phenomenon for both FL and MP. The other three pieces of evidence supported, but to different extents, the correct model in both assessment versions. Students
were then prompted to answer: “Which do you think is the better model for the problem? Write at least three (3) detailed reasons for your answer.”

Data analysis
Pluta et al. (2011) developed a coding scheme for model-quality criteria based on the criteria seen in students’ class lists, which we expanded to reflect additional criteria present in students’ essays (see Table 1), as well as further adapted to capture evidence-quality criteria. Model-quality criteria and evidence-quality criteria were the justifications that students gave in support or contradiction of a model or associated piece of evidence which are based on epistemic reasons (general reasons for model or evidence quality, such as “has sufficient details”) rather than empirical reasons (stating specific pieces of evidence or prior knowledge). The criteria included ones relating to empirical considerations (e.g., supported by most of the evidence, includes a sequence of steps), communicative considerations (e.g., clarity of the model, presence of diagrams or charts), pertinence (e.g., model answers a question), and others. We defined the model that students identified as being better as their chosen model. Coding was done by a pair of coders. Disagreements were settled through discussion.

Results and discussion
At the beginning of the model-based inquiry curriculum, students collaboratively developed class lists of criteria for good models that included a range of reasonable criteria. All of the 7th grade classes involved in this study had some form of “fit with evidence” as a criterion on their class criteria lists. Thus, the intervention produced the expected class sets of public criteria generated by students for their own use as a community.

At the practical level of using epistemic criteria on the pretest and posttest, we first note the extent to which students actually used evidence in their arguments on the pretest and posttest. We found that 49% of students included at least one piece of evidence in their arguments on the pretest, which increased to 80% on the posttest (p<.05). The average number of pieces of evidence used on the pretests was 0.94; on the posttests, it was 1.96 (p<.05) (pretest: no evidence: 51%, one piece of evidence: 20%, two: 14%, three-five: 15%; posttest: no evidence: 21%, one: 21%, two: 25%, three-five: 36%).

We also found a significant increase in students’ explicit noting of fit with evidence as a criterion for good models (indicating a meta-epistemic understanding) in their arguments (pre: 15%; post: 35%) (see Table 1), suggesting that students’ meta-epistemic understanding about the importance of evidence as a criterion was improving along with their practical performance (ability to use evidence). The fit-with-evidence criterion included five sub-categories, reflecting the extent to which the evidence set supported/contradicted the models.
Of the five sub-categories, we found a significant increase from pre (5%) to post (22%) in the number of students who specifically noted that more/most evidence supported their chosen model.

Although students also frequently mentioned several other criteria explicitly (Table 1 presents the most frequent categories), only the fit-with-evidence category showed a statistically significant increase in explicit use from pretest to posttest. This suggests that students improved in their understanding of the importance of evidentiary support as a key epistemic criterion for model goodness. Further, they were also able to attend to the proportion of supporting evidence pieces within a set (e.g., noting that most or more of the evidence supported their model), and to the importance of the absence of counterevidence for their chosen model (i.e., that none of the evidence goes against their chosen model). A model supported by more of the evidence and without any counterevidence to contradict it was viewed as a superior model.

Table 1: Categories used by over 10% of students in pre and/or post

<table>
<thead>
<tr>
<th>Category &amp; Definition</th>
<th>Examples</th>
<th>Pre %</th>
<th>Post %</th>
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<tbody>
<tr>
<td><strong>Fit with Evidence</strong></td>
<td>The student refers to the degree to which evidence is included/supports/contradicts a model.</td>
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<td></td>
<td>“I think lactic acid model is better. It supports and has stuff from the evidence.”</td>
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<td></td>
<td>“This is clearly evident as most to all of the evidence supports this reasoning.”</td>
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<td></td>
<td>“The other model has no evidence supporting it.”</td>
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<tr>
<td></td>
<td>“I believe the Poisonous Chemicals is the better model. None of the evidences below seem to go against the model.”</td>
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<td>15</td>
<td>35</td>
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<tr>
<td><strong>Makes Sense</strong></td>
<td>The student refers to the degree to which the model makes sense.</td>
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<td></td>
<td>“It makes sense.”</td>
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<td></td>
<td>“I firmly believe that the lactic acid model is the better. First of all, it makes more sense than the other model.”</td>
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<td></td>
<td>“Explanation 1 doesn't really make a lot of sense.”</td>
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<td>19</td>
<td>19</td>
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<tr>
<td><strong>Explains</strong></td>
<td>Student refers to the extent to which a model explains/has an explanation.</td>
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<td></td>
<td>“I think that the Lactic Acid Model is a lot better because it explains everything.”</td>
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<tr>
<td></td>
<td>“The Ice Crystal model shows how the leaves fall off”</td>
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<td></td>
<td>14</td>
<td>11</td>
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<tr>
<td><strong>Use of Visuals</strong></td>
<td>The student refers to the quality/number of pictures/diagrams/charts in a model.</td>
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<td></td>
<td>“I also think it’s a better because it shows more understandable pictures.”</td>
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<td></td>
<td>“I believe that the Lactic Acid Model is better because it has a before and after picture”</td>
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<tr>
<td></td>
<td>“It has more diagrams than the other model”</td>
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<td>7</td>
<td>10</td>
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<tr>
<td><strong>Realistic</strong></td>
<td>The student refers to the degree to which a model is realistic.</td>
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<td></td>
<td>“Next, the poisonous chemicals is better because it seems more realistic.”</td>
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<tr>
<td></td>
<td>“Ice Crystals may not seem realistic in some areas to lose leaves.”</td>
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In terms of criteria other than fit with evidence, there was not a statistically significant difference in the percent of students who used model-quality criteria as part of the justification for choosing a particular model (pre: 57%; post: 65%). There was also no statistically significant difference in average number of model-quality criteria provided explicitly (pre: 0.59; post: 0.74). Although the students engaged with model-quality criteria throughout the intervention, there was little change on these dimensions overall (both the percent of students mentioning criteria and the average number of criteria mentioned) between pre and post. Thus, the overall picture that emerges is that students initially (at pretest) used a range of epistemic criteria at the meta-epistemic level, but most of these were not evidence-related. The model-based inquiry intervention produced a very specific effect: it increased both practical and meta-epistemic use of fit with evidence as an epistemic criterion.

It is important to note that there are a variety of other aspects of arguments that students learned about, such as the use and description of evidence, explaining connections between evidence and models, and providing reasons that justify the link between the model and its supporting evidence. See Table 2 for an example of good essays with and without model-quality criteria. Given that students learned about all of these different aspects, it is reasonable that many of them decided to focus on aspects other than criteria, such as explaining the conclusions of the evidence or noting whether and how evidence supports or contradicts a model. It is thus encouraging that the number of criteria mentioned remained stable and suggests that students are
developing both their practical use and meta-epistemic understanding of the importance of model-quality criteria. Furthermore, students began the intervention already being able to identify epistemic criteria but using evidence and articulating fit with evidence as a criterion at fairly low rates so this selective change, rather than an overall increase in the usage of all criteria, suggests that students improved in their meta-epistemic understanding of which factors are prioritized in scientific practice.

<table>
<thead>
<tr>
<th>Table 2: Good essays including and not including model-quality criteria: both show practical engagement with the material (e.g., both attended to key pieces of evidence and described their relationship with the model)</th>
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<tbody>
<tr>
<td><strong>With model-quality criteria</strong></td>
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<tr>
<td><strong>Without model-quality criteria</strong></td>
</tr>
</tbody>
</table>

**Conclusion and contribution**

This research indicates that, with curricular scaffolding, students are able to improve in both their practical use of epistemic criteria for model quality and their meta-epistemic understanding of the role of these criteria in model evaluation and argumentation. When students began the intervention, each class developed a list of community epistemic criteria that included many criteria that are used by scientists. On the pretest, they demonstrated that they were also able to use those criteria to justify their arguments. The students continued to use epistemic criteria at similar levels in their posttests. There was a significant increase only in students’ meta-epistemic articulation of fit with evidence as an epistemic criterion. There was a corresponding increase in the practical use of evidence in their argumentation. Scientists use evidence as a primary means to develop, evaluate, and justify models, and yielding to evidence is a central tenet of science knowledge building. Thus, it is crucial that students grow to understand this epistemic cornerstone. The students’ selective increase in using and articulating the need for evidence suggests that, indeed, throughout the intervention students refined their meta-epistemic understanding of criteria, raising the importance of fit with evidence as a core criterion.

Students may have used their meta-epistemic understanding to regulate their practical performance, increasing use of evidence as they came to appreciate fit with evidence as a critical criterion for good models. Students started with a broad awareness of a range of epistemic criteria, but their initial criteria significantly underrated the importance of evidentiary criteria. The model-based learning curriculum produced a highly targeted improvement in both the practical use and meta-epistemic use of evidentiary criteria; given the importance of evidentiary support in scientific practice (e.g., scientists use evidence as a primary means to develop, evaluate, and justify models), the move towards the use of evidence and evidentiary criteria suggests a growth in students’ meta-epistemic understanding of criteria, raising the importance of fit with evidence as a core criterion.

Understanding more about students’ decisions about which epistemic criteria to attend to helps elucidate more about the complex processes governing how students evaluate and use scientific information. This will help teachers, researchers, and others in the education community develop learning environments which will foster the skills needed to aptly engage with science in real-world settings. It is particularly interesting to note that students may come to classrooms with the resources to contribute many of the building blocks needed to engage with scientific practices, such as developing epistemic criteria and using evidence. However, classroom interventions may help them reflect on and refine their knowledge in order to better understand the reasoning that scientists use when they engage in these processes.
References


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Enhancing Reflective Learning Experiences in Museums Through Interactive Installations

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Abstract: In this study we examine the effect that several technological affordances have upon the experiences of children while visiting a museum, focusing upon engagement, discussion and reflection. The museum is the Baba Nyonya Heritage Museum in Malacca, Malaysia. We created a number of public interactive installations designed to facilitate inter-cultural and inter-generational dialogues about cultural identity. The technology employed mixed and augmented reality techniques and gesture recognition to enable visitors to have a multisensory experience with the artefacts on display. Analysis of pre- to post-test knowledge based surveys showed significant learning gains as a result of interacting with the exhibits. Surveys of visitors’ attitudes showed that they felt they had benefitted from the physical interactivity. Qualitative analysis of observational and video data showed that the different interaction techniques provided both benefits and challenges for interaction, which we reflect upon in the paper.

Keywords: cultural learning, reflection, interactive installations, kinaesthetic learning, museum studies

Introduction

Museums have existed for millennia, and throughout their long history their role in society has slowly evolved. They started out as private collections of curiosities, and for a long time their primary role was the cataloguing of artefacts. In more recent times public museums have developed with dual roles as a form of entertainment and vehicles of education (Van Leeuwen et al., 2013). Now they are often viewed as tourist destinations and as such are important contributors to local economies (Van Aalst & Boogaarts, 2002). Modern museums are sophisticated organisations that play a variety of roles in society. Increasingly, they are custodians of community memory and repositories of heritage (Andermann & Arnold-de Simine, 2012). Increasingly also, museums are designed to encourage visitors to create their own meaning by reflecting upon experiences that they have during their visit and relating these to their life outside of the museum. This is why museums have been described as "socially-mediated meaning making environments" (Falk & Dierking, 2000).

The technological revolution has had a major impact upon museums, and many of them make very effective use of a wide variety of interactive technologies. These augment physical artefacts with various types of digital information to increase engagement and facilitate education. There is a widespread belief that many visitors no longer engage with static text, and need to be motivated by interaction (Koleva et al., 2009). However, there is a paradoxical concern that technologies that focus too much on learning goals can distract from the meaning making processes, which are the very things that the technology is trying to promote (Cosley et al., 2008). The key issue is to consider how the technology promotes discussion and reflection in order to facilitate meaning making. Several studies have focused on using technology to encourage visitors to reflect upon their experiences in museum visits. For example, Bampatzia et al. (2016) have used social media to promote discussions between visitors that are designed to stimulate reflection by thinking about the past. A completely different approach is described by Muntean et al. (2017), who have focused upon designing an interactive tangible table-top in a cultural heritage museum in such a way that the tangible interactions support visitors’ experience and understanding of specific cultural values that the museum desires to impart. This type of thinking in museum design is quite new, and there is as yet no received wisdom on how designers should create museum experiences that evoke deep, cultural reflections to help shape community identity.

In this study we examine the effect that several technological affordances have upon the experiences of children while visiting a museum, focusing upon engagement, discussion and reflection. The museum in
question is the Baba Nyonya Heritage Museum in Malacca, Malaysia (http://babanyonyamuseum.com). The Baba Nyonya (also known as Peranakan) is a unique cultural group. The Peranakan people are the descendants of Chinese traders who originally came to the Malay archipelago (an area that now encompasses parts of Malaysia, Singapore, Indonesia and Thailand) between the 15th and 17th centuries (West, 2010). These, invariably male, traders married local women of Malay, Indian, Thai or Portuguese descent. Some of these families became hugely wealthy and they developed their own distinct fusion culture, complete with traditions, food, clothing and many artefacts. The descendants of Peranakans who live in modern Malaysia usually identify themselves as the Baba Nyonya. During the late 19th and early 20th Century (e.g. the British colonial era) the Baba Nyonya families were at the height of their wealth and influence, and so there also came to be a very strong British influence upon this fusion culture. Modern Malaysia is a young country that contains one of the most culturally diverse societies in the world. The population consists of three major ethnic/cultural/religious groups (identified as the Islamic Malays, the Buddhist or Christian Chinese and the Hindu Indians) as well as many smaller groups. Because of the youth of the country and this cultural diversity, many young Malaysians struggle with a sense of national identity. The fusion culture of the Baba Nyonya cuts to the heart of this. Upon visiting the museum, all Malaysians (and indeed many other nationals) do see a lot that is familiar in Baba Nyonya culture.

What we are trying to achieve with this research is to encourage young Malaysians to reflect upon this familiarity, and also the uniqueness of Baba Nyonya culture. We have created several public interactive installations in the museum that are designed to facilitate inter-cultural and inter-generational dialogues about cultural identity. The hope is that these dialogues will help children to consider some important and fundamental questions about what it means to be a Malaysian. In times of increasing ethnic tensions throughout the world, the role of museums as repositories of heritage is ever more important to help people understand cultural similarities and appreciate cultural differences. We are attempting to build upon modern thinking in museum about the use of tangible interfaces to help promote this sort of reflection.

Related work
The use of digital technologies is becoming widespread in museum and other cultural heritage settings. Examples include the use of augmented reality (AR) (Pedersen et al., 2017) and games (Anderson et al., 2010) to support cultural heritage learning and to enhance museum visits. The digitalization of works of art and historical artefacts using modern technologies such as tangible user interfaces (TUI) and Internet of Things (IoT) further allow visitors to interact with either original or copies of cultural heritage artefacts physically, cognitively and emotionally using their senses (Wakkary et al., 2009). For example, in the MeSch project, visitors can use smart replicas – copies of physical artefacts augmented with RFID tags to trigger and play associated multimedia stories about the artefacts (Marshall et al., 2016). The aim of this research is to explore new technological approaches that go beyond supporting cultural heritage learning to evoke deep, cultural reflections as well.

Designing for reflection
Reflection is a key component of successful inquiry based learning (Quintana et al., 2004). There have been several examples of how technology can be used to support reflection in learning and teaching (e.g., Lin et al., 1999; Fleck & Fitzpatrick, 2009). Fleck and Fitzpatrick have synthesized the literature on reflection into a framework consisting of five different levels: ranging from (mere) revisiting of experiences through description, revisiting with explanation, exploring relationships, transformation of earlier perspectives, and critical consideration of wider perspectives (Fleck & Fitzpatrick, 2010). There are many definitions and theories of reflective learning, and we do not set out to synthesise this literature, nor espouse a particular approach. We do, however, take as our starting point the important role of social interaction in supporting reflection on experience (Lin et al., 1999), particularly in young children, and the significant role of the (family) group as the social context for learning in visits to museums and science centres (Falk & Dierking, 2013). Our design approach, therefore, has been to provide visitor experiences that support social interaction within groups of visitors and with exhibits that provoke discussion and reflection.

Designers have demonstrated an increased interest in designing for reflection (Sengers et al., 2005; Baumer, 2015). In the domain of cultural heritage, Skydsgaard et al. (2016) investigated how four design principles (curiosity, challenge, narratives and participation) facilitate reflection and discussion among visitors in a museum exhibition. For example, narratives were found to be effective in facilitating personal reflection, while participation which includes physical interaction with exhibits facilitated the sharing of ideas and feelings between visitors. A reflective design for an art museum focused on under-designed aspects of the visitor experience so as to highlight the presence of unknown others in an ambient way (Boehner et al., 2005).
Giaccardi and Palen (2008) focused on preserving natural heritage by connecting a local community and their land through locative and tangible media. Similar to the present research, CrossCult (http://www.crosscult.eu) is a project that aims to change the way people view history, but using a different platform – that of social networks. Visitors are able to share cultural experiences with social network friends and discuss with each other on museum themes and reflection topics. So far, many of the papers reviewed here have focused on exploring possible approaches to reflective design in cultural settings, but little evidence has been provided so far to suggest their effectiveness in engaging visitors in reflective thoughts (Baumer et al., 2014). In this project, we attempt this by developing three distinctive interactive installations and compare them to understand how best to design for cultural heritage learning as well as reflection.

Context and design of the interactive exhibits
This project is carried out as part of a research collaboration with Baba Nyonya Heritage Museum. It is located in the old district of the World UNESCO area of Malacca town. The project is in line with the museum’s vision of bridging communities to Malaysia’s history through the Baba Nyonya culture. Initial ethnographic studies, information gathering and brainstorming sessions were conducted involving museum curators in a participatory design process over a 6 month period. We found that current personal guided museum tours lack interaction between visitors and museum contents, and fail to cultivate or sustain the cultural learning interest of children. As a huge number of visitors to the museum are school and family groups with children, we decided to design interactive exhibits that could become part of a self-guided tour for families and children.

We were interested in exploring how multisensory and physical interactions facilitate cultural learning and reflection among visitors. Three interactive exhibits were developed, supporting varying levels of multisensory and physical user interactions (from least to most):

1) An interactive mural that allows visitors to listen to and interact with crowdsourced life stories.
2) A goldsmith simulator that allows visitors to simulate the process of making Peranakan jewelry. Early craftsmen would use coins, mainly English sterling and US dollars, incorporated into pendants whose designs were further influenced by local ethnicities (e.g., Indian or Chinese-influenced).
3) An interactive stone grinder (known as ‘Batu Boh’) that allows visitors to engage in the process of ‘kuih’ making. Kuih are bite-sized snacks or cakes and are usually made from rice or glutinous rice. The Batu Boh interactive exhibit highlights the many kuih native to Malay, Indian and Chinese culture that have been improvised by the Baba Nyonyas. Four different kuih recipes could be chosen.

The historical and cultural topics and learning content were chosen to highlight the rich diversity in the Peranakan culture (eastern and western influences, and different Peranakan ethnicities).

Technological approach

- **Interactive mural** - The interactive mural allows visitors to listen and connect to life stories crowdsourced among the Baba Nyonyas. They can submit their audio stories online which are automatically downloaded to the interactive mural. Touch sensitive points, created using conductive paint, were connected to a Raspberry Pi 3 and PiCap adapter. The physical board is complemented with digital projections, allowing background images to be changed based on the selected Peranakan ethnicity (see Figure 1).

- **Goldsmith simulator** – The goldsmith simulator uses Leap Motion, a hand tracking technology to help users understand the jewelry making process by allowing them to take on the role of an early goldsmith. To start, visitors use gestures to select a pendant frame and a coin in the virtual world, made with Unity. In order to solder them together, users need to pump on a physical bellows to start the solder ‘fire’. At the end, visitors have an opportunity to photograph themselves wearing the soldered pendant as a digital souvenir (see Figure 2).

- **Interactive Batu Boh grinder** – The interactive Batu Boh is designed as a replica of an old stone grinder, historically used by Nyonyas to grind and mix spices and other ingredients. By embedding it with sensor technologies, users can insert a tagged ingredient card and turn the handle to simulate the process of kuih making, while at the same time listening to an audio recording of an old chef re-collecting historical and cultural stories associated with the ingredient. The process is repeated until all ingredients have been ground, and a fragrance of the kuih is released along with a physical capsule (containing a sticker of the kuih) as a physical souvenir (see Figure 3).
Method
The user trial was carried out in the Baba Nyonya Heritage Museum on March 19th and 20th, 2017, and involved groups comprising families with children. We employed surveys, user observations and video analyses as the evaluation methods. All participants filled in consent forms agreeing to participate in the study and to be video-recorded. They also completed a pre-test survey to provide their demographic details (e.g., age, gender, education level). The pre- and post-test domain knowledge surveys consisted of 11 items designed to test participants’ knowledge of the Baba Nyonya culture that formed the basis of the culture-related exhibits. Question items were different for the pre- and post-test instruments but tapped the same knowledge content. Learning outcomes were measured using changes in performance from pre- to post-experience. Participants’ attitudes towards the experience were surveyed after the visit, employing a 7-point scale to indicate agreement with the six statements (see results section). Video data were collected by filming every tour and were supplemented by observational notes taken by researchers. A self-guided map was provided to each group. Our prediction was that the visitors would be more engaged in learning and reflection when the interactive exhibit supports more physical and multi-sensory interaction.

Participants
The user trial involved 10 groups, with 32 participants in total. The group size ranged between 3-8 people. All participants were visitors to the museum and from Malaysia. Three groups were residents of Malacca. In the resident group, two groups had visited the museum before. The individual participant age ranged from 9 to 47 years (mean (M) = 19.97 yrs; standard deviation (SD) = 13.33 yrs). There were 23 children under age 18 (M = 11.82 yrs; SD = 2.42 yrs) and 9 adults above the age of 18 (M = 36.8 yrs; SD = 10.46 yrs). A single letter identifier naming approach was adopted for each group (e.g., H), followed by a number for each participant in the group (e.g., H2).

Results
Learning outcomes
The post-test data from the knowledge based survey were positively skewed ($z = 2.202$) and both the pre- and post-test scores deviated significantly from normal (pre: $D (30) = 0.241, p < .001$; post: $D (30) = 0.203, p < .01$). Therefore, a Wilcoxon test was used to compare pre- to post-test scores. Post-test scores were significantly higher at post-test (M = 8.00) than at pre-test (M = 7.00, $T = 355, p < .001, r = 0.52$).
User attitudes

Table 1: Percentage agreement with the statements about the experience (% participants giving a rating of 4-7 on a 7-point scale, from strongly disagree to strongly agree, with a neutral midpoint)

<table>
<thead>
<tr>
<th>Statements</th>
<th>Goldsmith simulator</th>
<th>Batu Boh</th>
<th>Interactive mural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The exhibit provides a good learning experience of the Baba Nyonya culture</td>
<td>73</td>
<td>83</td>
<td>70</td>
</tr>
<tr>
<td>2. The exhibit encourages discussions with others</td>
<td>63</td>
<td>66</td>
<td>50</td>
</tr>
<tr>
<td>3. The exhibit helps me reflect/think more about my own culture</td>
<td>66</td>
<td>75</td>
<td>66</td>
</tr>
<tr>
<td>4. The exhibit made me want to learn more about the Baba Nyonya culture</td>
<td>68</td>
<td>68</td>
<td>58</td>
</tr>
<tr>
<td>5. The physical interaction with the exhibit enhanced my learning experience</td>
<td>72</td>
<td>78</td>
<td>66</td>
</tr>
<tr>
<td>6. I feel that I have gained more knowledge after using the exhibit</td>
<td>77</td>
<td>84</td>
<td>74</td>
</tr>
</tbody>
</table>

Qualitative analysis of sociocultural reflections

Interactive Batu Boh grinder
The design of the interactive Batu Boh exhibit showed some success in encouraging discussion and reflection among family members. Through the video analysis, we observed a boy T1, having finished using the interactive Batu Boh, proceed to examine an original Batu Boh artefact within the exhibit area and engage in conversation with his parents in the background (see Figure 4). There were also instances of historical reflections between participants and other museum visitors who were observing the user interactions. For example, upon seeing a girl (H1) interacting with the interactive Batu Boh, a visitor (A) asked “What’s this?”. The girl’s mother (H2) explained. Then visitor A said “Oh, put [inaudible] to the hole, then...[inaudible]. Let children experience the kind of life in the olden days”. Her father (H3) then remarked, “How long does it need to grind? Maybe grind four more times? Let them experience life”. H2 agreed with H3 by saying, “Yes, experience life”. The use of the interactive Batu Boh also encouraged inter-generational dialogue where a father (Y2) was seen to explain to his child “If you grind this way, the kuih’s flour will come out. You can cook it...I saw this one before...In my grandma’s house”. Another example showed a girl (O1), who was grinding the Batu Boh, ask, “Can it make dim sum?” (see Figure 5). Other group members started to discuss this possibility with her mother (O2) asking, “Is the thing coming out dry stuff or wet like soya bean?” Her father (O3) also began to ask “Can rice flour also be ground?”. In the end, another woman friend (O4) replied, “Yes, you can put the rice flour in there” while pointing at an old Batu Boh. This discussion helped O1 learn that rice flour is an ingredient for making dim sum and can be ground using the Batu Boh.

Goldsmith simulator
With respect to user interactions at the goldsmith exhibit, we observed many occasions where group members worked collaboratively to carry out jewelry making tasks. We found that participants often missed hearing the audio instructions as they concentrated on carrying out the task as it required controlled gestures. Typically, other group members would help repeat the audio instruction to guide the participant through the tasks. In this exhibit, the use of the bellows by participants often triggered discussion about the soldering task. For example, when other members in group C saw how the bellows were used to start the solder fire, C2 (father) said “Emm...This is soldering...You can see it is used to solder things...Did you see him solder the money?”. Then C3 (mother) asked “Are you sure that is money?”, to which C2 replied “That’s a coin...You didn’t see?”.

Interactive mural
In the user observation involving the interactive mural exhibit, most participants did not notice it right away until it was pointed out. Almost instantly, all participants would become curious about the technology, and look behind the board to find out how it works. It was observed that children usually tended to lose interest in the audio stories before they end, suggesting that the current content needs to be modified to suit younger children.

Role of physical and digital souvenirs
Most participants were seen to look pleased to receive a physical capsule as souvenir at the end of their interaction with the Batu Boh. Some children tried to repeat the kuih making to collect all recipe stickers or tried...
to exchange them. For example, when girl A1 finished her turn, she asked girl A2 “Can you give me yours? I want to exchange”. In group F, when the girl F1 received a capsule, she looked at its sticker content and remarked, “I know, this in Chinese is called [kuih’s name in Chinese]”. In comparison, the digital souvenir (digital photo of user wearing virtual pendant) did not solicit much discussion. Some children did not want their photos to be taken, while others kept re-taking photos without focusing much on the pendant they made.

**Role of smell**

As to the use of fragrance of kuih being emitted when the kuih making was completed at the Batu Boh exhibit, many participants would notice the smell and asked “What’s that smell?”, “Do you smell something?”, “Why do we need perfume?” or commented “The smell is nice”.

**Discussion**

The results of the pre- to post-test comparison of tests of knowledge about Baba Nyonya culture showed that there was a significant learning gain as a result of engagement with the exhibits. However, a drawback to this preliminary study is that there was no control group with which to compare any learning gains from visiting without the technology augmentation. Nonetheless, the results are encouraging. Participants also seemed to feel that they gained some knowledge of Baba Nyonya culture as a result of the experience (Q1 and Q6 in Table 1). Whilst they felt that the goldsmith and Batu Boh exhibits encouraged discussion (Q2), there was less agreement about this for the Interactive Mural (the least interactive of the exhibits). This is also reflected in the views about the effects of physical interaction on learning (Q5). Here there was less agreement about the Interactive Mural compared with the other two exhibits.

These experimental installations were designed to provide a range of different levels of physical interaction to evaluate how this kinaesthetic experience influenced engagement, discussion and reflection and ultimately learning. We also included a multisensory experience which included smell, to evaluate whether or not that would trigger discussions. In terms of the kinaesthetics, the interactive mural is the least physical (it has a touch board, but other than that it is a conventional computer interface). The goldsmith simulator is more physical, requiring fine gestures to control the interface and a real bellows to activate the soldering. The Batu Boh is the most physical. There is no screen – the computer-generated output consists entirely of voice and smell, and the user interaction involves inserting a card, turning a handle and collecting a physical souvenir.

With the interactive mural, there was some engagement but not much more than would be expected from a conventional museum exhibit. Some children were curious about the technology (as were some of their parents), but we observed very little reflection about the contents. The goldsmith station was much more physical. The simulation allowed children to select a coin and a frame – using gesture recognition to pick them up, and a real bellows to operate the soldering. The fine motor control required to operate the simulator did cause problems for some younger children, but it also sparked a good deal of interaction and cooperation between children. Sometimes children offered advice to their peers, sometimes they split the physical tasks (for example with one child operating the bellow and another the gestures). There was some discussion about the coins, but little evidence of reflection and certainly no evidence of higher levels of reflection. Any reflection that was observed would fall in the categories of description and explanation (cf. Fleck & Fitzpatrick, 2010). The interactive Batu Boh was by far the most engaging installation. This was a large object that required a lot of physical manipulation. When children first walked in to the room they were often immediately attracted to it. This inspired a good deal of discussion between children, their friends and the parents about the nature of both the artefact and the task. There were also some examples of higher level reflection exploring relationships. A
good example of this was a girl who, unprompted, made a connection with the virtual recipe she was making and modern dim sum.

After the successful completion of the goldsmith and Batu Boh simulations, the children were given souvenirs – digital in the case of the goldsmith and physical in the case of the Batu Boh. In the goldsmith simulator, the children made a virtual pendant and at the end they could photograph themselves “wearing” this. In the Batu Boh simulator, they were given a coloured capsule containing a sticker representing the food they had created. These souvenirs were certainly popular with the children and very engaging, however there was little evidence of them supporting reflection. What discussion there was tended to be more about the souvenir itself than its cultural significance. With the digital souvenir from the goldsmith simulator, the children were far more interested in the photographs of themselves than the pendant they had made. (It should be noted, though, that some children were shy and unwilling to be photographed.) With the stickers produced by the Batu Boh simulator, some children were quite competitive and played the game multiple times to try to get the complete set of stickers. Some traded them with each other – again trying to get a complete set.

The smell produced by the Batu Boh simulator did not in any way seem to facilitate either engagement or reflection. The children certainly noticed it, and sometimes commented upon it but these comments had nothing to do with the simulation or its context – they were along the lines of “what’s the smell?”

This study has provided some evidence to suggest that increasing the kinaesthesic aspects of mixed reality installations can promote reflection. It can certainly promote engagement and is popular with children. It is possible that there is a relationship between the level of kinaesthetic engagement and the level of reflection. However, we don’t have enough data at present to be able to be certain whether this is the case. This is an area in need of further research with larger numbers of children.

Conclusions
The aim of this research was to design and evaluate the effectiveness of mixed reality technologies in augmenting the visitor experience in a museum and cultural heritage context. Our design was based on the potential of interactive installations to enhance the kinaesthetic and multisensory experience of hands-on engagement with artefacts that are normally “hands-off”, in order to promote deeper engagement, discussion and reflection in small groups of visitors, especially children. We have presented some evidence that this was achieved. We have shown that the experience resulted in significant learning gains in terms of knowledge of the content of the exhibits. Visitors liked the experience, and felt that they had learned from it – in particular those aspects involving physical interaction. We also set out in this research to provide a context in which Malaysian visitors (as well as others from an Asian / South East Asian context) might be supported in learning about and reflecting on their (multi)cultural identity. Our qualitative analyses showed instances of how the experiences with the exhibits enhanced discussion and sharing of Peranakan culture within the groups of visitors, especially children. We have presented some evidence that this was achieved. We have shown that the experience resulted in significant learning gains in terms of knowledge of the content of the exhibits. Visitors liked the experience, and felt that they had learned from it – in particular those aspects involving physical interaction. We also set out in this research to provide a context in which Malaysian visitors (as well as others from an Asian / South East Asian context) might be supported in learning about and reflecting on their (multi)cultural identity. Our qualitative analyses showed instances of how the experiences with the exhibits enhanced discussion and sharing of Peranakan culture within the groups of visitors, especially intergenerational exchanges. Finally, the research was an exploration of the affordances of different interaction techniques in supporting reflective learning through intra-group discussions. In comparing between the different interaction techniques, it seems that the goldsmith and Batu Boh exhibits, each of which involved a greater amount of physical engagement, were the more successful in terms of generating moments of reflective learning. These exhibits also afforded more collaborative interactions, where several members of the group could participate at once. These insights have been observed in other studies. However, where we feel we have made an original contribution is in showing how relatively simple interaction techniques can create a rich inter-generational cultural learning experience, embedded in the original museum setting (rather than being separated from it) and that brings to life exhibits that are usually hands-off and experienced at a distance.

References


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Co-Framing Shared Epistemic Objects of Inquiry to Support Knowledge Building Over a Whole School Year

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Abstract: This study explores how fifth graders and their teacher co-constructed shared epistemic objects as collective directions of inquiry to sustain knowledge building about the human body system with Knowledge Forum over a whole school year. Qualitative analyses of observation notes, classroom videos, teacher reflective journal, and student artifacts elaborated the reflective processes and interactive roles of the teacher and her students to co-frame shared directions of inquiry as the knowledge building unfolded. Qualitative and quantitative analysis of students’ survey, interview, research journeys, and online discourse showed how the reflective structuration of epistemic objects helped to sustain and deepen their inquiry over time. These results, together with findings from our previous studies, shed light on agency-driven reflective structuration as a self-sustaining mechanism to guide and sustain principle-based knowledge building practices without extensive pre-scripting.

Introduction
Over the past two decades, major advances have been made to elaborate the socio-cultural and cognitive processes of collaborative inquiry and knowledge building (e.g. Bell & Linn, 2000; Edelson & Reiser, 2006; Hakkarainen, 2003; Hmelo-Silver, 2004; Järvelä & Hadwin, 2013; Roschelle, 1992; Zhang et al., 2007). Despite the conceptual and technological advances, we, as a field, still face the challenge of bringing sustained collaborative inquiry and knowledge building into classrooms to transform educational practices. Underlying this practice gap is a conceptual challenge about how student-driven collaborative inquiry should be organized and supported. This challenge is even more significant for collaborative inquiry programs that require students to enact high-level agency and responsibilities. Research to support collaborative learning and knowledge building has led to a core debate between scripted versus non-scripted approaches (Bereiter et al., 2017) and between procedure-oriented versus principle-based open-ended designs (Zhang et al., 2011). A scripted approach to collaborative inquiry guides and scaffolds learners using carefully designed scripts of collaboration and inquiry for students to use and internalize (Fischer et al., 2013). Such scripts specify, sequence, and distribute various task operations and activity procedures among learners in order to guide them to engage in effective interactions (Kirschner & Erkens, 2013). A non-scripted approach to inquiry, such as the Knowledge Building pedagogy (Scardamalia & Bereiter, 2014), adopts an open-ended, principle-based (as opposed to procedure-based) framework by which teachers and students dynamically co-construct the classroom flow of inquiry as their work proceeds, guided by a set of core principles. At the heart of this debate is an often-polarized tension: At one end is the critical need of guiding structures for inquiry to be effective, and at the other end is the importance of student epistemic agency in creative work and dynamic collaboration.

While the principle-based approach to knowledge building holds promise for enhancing student high-level agency in creative work and collaboration, implementing knowledge building in broad classrooms still faces the challenge of how the fluid, open, and agency-driven processes of inquiry becomes socially organized and pedagogically supported. Reconciling the tension between student agency and structures, we identified reflective structuration as a self-sustaining mechanism through rich analyses of productive knowledge building communities (Zhang, 2013; Tao & Zhang, 2017; Tao et al., 2015; Zhang et al., 2011). Knowledge building communities engage in dual-layer construction: As students engage in deep inquiry and discourse to advance content-focused questions and ideas, they also work with their teacher to generate and adapt collective structures of inquiry to guide and support their collaboration and contribution. These structures provide shared expansive frames—refined using various classroom resources and artifacts—of the unfolding directions of inquiry and ways in which the community should operate. The co-constructed structures are further used by the community to guide individual and collaborative actions, leading to further structural elaboration and adaptation of the inquiry-based practices.

A key aspect of the agency-driven structuration process is to structure what the community should investigate: collective foci, goals, and directions for sustained inquiry. Drawing upon sociologist Knorr-Cetina (2001), we refer to the things of investigation as “epistemic objects,” which “are at the center of a research process and in the process of being materially defined” (p. 181), signifying the lacks, needs, and insufficiencies...
of knowledge that lead to unfolding strands of knowledge practices. Knowledge workers direct and sustain their knowledge practices by continually identifying new epistemic objects and projecting possible epistemic moves upon them. It is a critical challenge to understand the processes by which a community frame shared objects and unfolding directions of inquiry to sustain long-term inquiry, without extensive pre-scripting from their teacher.

Drawing upon our previous studies (Tao & Zhang, in press; Tao et al., 2015), the current study aims to provide a more detailed account of how members of a Grade 5 science classroom (the teacher and her students) worked together to frame/re-frame a connected set of epistemic objects as the focus of knowledge building about human body systems over a whole school year. Our research questions ask: How did the community identify and frame the objects of inquiry to sustain its knowledge building over time? How did students use the structures to support their participation, with what impact on their knowledge building practices?

Method

Classroom contexts
This study was conducted in a Grade 5 classroom at a public elementary school, with 21 students who were around 10-to-11-year old. Students investigated the human body systems as the focal theme of their science curriculum, with two hours’ science lesson each week. The teacher had two years of experience with the knowledge building pedagogy. Instead of following specific inquiry themes, questions or procedures prepared by the teacher, students were expected to work with their teacher’s facilitation to co-identify problems of inquiry and conduct spontaneous actions to address the problems as their inquiry proceeded. The inquiry process unfolded as an open and dynamic process based on student-generated questions, which gave rise to emergent shared directions for further inquiry. Knowledge building in the classroom integrated individual and small group reading, whole class discussions, individual and small group modeling and demonstrations, and student-directed presentations. Major ideas, questions, and findings generated through face to face knowledge building activities were contributed to Knowledge Forum (KF) (Scardamalia & Bereiter, 2014), an online collaborative knowledge creation platform, for continual discourse.

Data sources and analysis

Analyses of classroom observations, videos, and the teacher’s reflective journals
To answer the first research question, we conducted qualitative analyses of rich classroom data. The first author observed each science lesson, took detailed observation notes as well as pictures of important artefacts created by both the students and teacher, and video-recorded major classroom activities over the school year. After scrutinizing the classroom records, we zoomed into the specific episodes when the classroom generated a map of inquiry objects as documented in the classroom artefacts and videos. Videos related to the co-generation of the objects of inquiry were transcribed and analyzed using a narrative approach to video analysis (Derry et al., 2010). This analysis was further supported by the teacher’s weekly reflection journals.

Analyses of students’ survey and interview about their use of the inquiry objects map
To understand how the collective objects map support students’ further inquiry, we conducted a student survey in mid-March and a student interview at the end of the school year. The student survey was made up of two open-ended questions: 1) How did the collective mapping processes help your science inquiry? and 2) In what ways can you use the collective objects map to support your further science learning? The student interview focused on the specific ways that students actually used the map to guide their subsequent inquiry. We conducted qualitative analyses of these two sources of data together using an open coding method (Charmaz, 2006).

Analyses of the students’ research journey reflection and their online knowledge building discourse
To examine the impact of reflective structuration of collective epistemic objects in driving sustained inquiry, we collected the following data from different sources and analyzed them with a content analysis method (Chi, 1997): 1) students’ individual reflection on their research journey aided by the collective objects map about the epistemic objects each of them had investigated and learned from their peers in late April; and 2) students’ online knowledge building discourse in KF. We coded students’ posts over the school year with a five-category coding scheme, which captures productive discourse patterns (1=questioning, 2=theorizing, 3=evidence, 4=referring resources, and 5=connecting and integrating) (Zhang et al., 2011). Two raters independently code 20% of the notes to assess interrater reliability, which was 93.64% (Cronbach’s Alpha = .95). For those posts which were coded as “theorizing”, a further content analysis was conducted to assess scientific sophistication of “theories/explanations” developed by students based on a 4-point scale (1=pre-scientific, 2=hybrid, 3=basic
scientific, and 4=scientific), which was verified in our previous research (Zhang et al., 2007). Two raters independently 20% of the notes labelled as “theorizing”, resulting in an inter-rater agreement of 91.43% (Cronbach’s Alpha = .92).

Results

How did the community identify and frame the objects of inquiry to sustain its knowledge building over time?

Qualitative analysis of rich data identified the reflective processes the community worked together to co-generate shared epistemic objects (see Fig. 1). These include (a) co-formulating collective wonderings (e.g. how does the brain work) based on students’ individual questions; (b) re-framing, adapting and updating existing big wonderings to include new objects of inquiry; (c) deep search, framing, and collective mapping of interrelated epistemic objects as the shared focus of the community’s unfolding inquiry and discourse; (d) individual and small-group reflection and planning for specialized inquiry aided by the collective objects map. Table 1 summarizes the major actions of the teacher and students, and the collective structures co-generated and adapted. Details of the reflective processes as well as the major actions of the teacher and her students are described below.

![Figure 1](image.png)

Figure 1. The reflective structuration processes that the community co-frame shared directions of inquiry.

(a) Co-formulating collective wonderings based on students’ individual questions. Prior to the beginning of the school year, the teacher identified the human body systems as the focal topic of the school based on their school district’s curriculum. The inquiry began with ten out-door games designed by the teacher and another Grade 5 science teacher, aiming to engage students in various activities related to different human body systems. These activities triggered students’ initial interests. When they returned to the classroom, the teacher organized a whole class conversation to share their experiences. After that, each student wrote down the question they were most interested in on a sticky note. They also decided together to “think about their questions and find books that related to their questions to read”. When they met again to share the progress, each student brought one book about their question. The teacher suggested each student to prepare a post-it sticker and write down the following information on it: “Name”, “My question”, and “Body parts (I’m working on)”. Then students pasted the sticky note on the book they chose, searched for the students who were working on related questions about the same body parts. In this way, students were automatically “grouped” into six small groups. These small groups then worked together to co-frame a bigger question to include each member’s question. In late September, the initial six big questions were identified and hanging on the classroom wall. Corresponding separate spaces were set up in KF, too.

Table 1: Processes by which the community co-generated collective objects about what they should investigate
Re-framing, adapting and updating existing big wonderings to include new objects of inquiry. Students continued their inquiry from October to December. The teacher, with support from our research team, designed various reflection templates for individuals and small groups to reflect on where they were in their inquiry, new knowledge gained, and where they should go next. When small groups felt they were done with their research about one topic, they asked their teacher for a time slot to hold a whole class meeting to share their knowledge progress and emergent questions of inquiry with peers. New epistemic objects of inquiry were generated based on new questions from ongoing inquiry. During these three months, initial small groups finished the work on their original focal objects, disbanded and re-formed to work on new unfolding big questions (See Fig. 1b). New emergent groups formed accordingly to continue their research. Corresponding new spaces were set up in KF for their online knowledge building discourse, too. In late January, all students moved onto new objects of inquiry.

Deep search, framing, and collective mapping of interrelated epistemic objects. In February, small groups reflected on knowledge progress in new inquiry areas. As more and more new questions were proposed, the community decided to reflect on all the objects they’d investigated so far. Supported by an incomplete list of epistemic objects identified by the teacher, each student started a review of individual inquiry. Based on this individual reflection, the whole class conducted two collective conversations to identify collective epistemic objects and the connections among them. Meanwhile, emergent objects that were missing in the initial prepared list and new objects that no one in the community had worked on before were identified (see Fig. 1c). The teacher hung the collective objects map on the classroom wall for students to refer to for further inquiry.

Individual and small-group reflection and planning for specialized inquiry aided by the collective objects map. After the co-generation of the collective objects map, students continued their work to prepare for a science symposium as a way to share all their knowledge gain with their peers, parents, and students from other Grade 5 classrooms. As a product for the symposium, each kid wrote an individual journey of thinking about all the objects they investigated and the objects they plan to research soon (see Fig. 1d). Finally, their collective reflection on where to go next led collective inquiry to more specialized objects. Some kids began to work on
the objects that were missing on the collective map, like “kidney”. Some other kids moved onto other objects that was researched by their peer but they had not investigated yet because they wanted to know more about the human body.

While using the collective map of the inquiry objects to guide knowledge building, the community remained open and reflective about new possible directions and connections. A whole classroom conversation was held to review how the various lines of inquiry were connected. Before the collective reflection, the teacher worked with our research team to identify an incomplete list of objects investigated by all students based on their face-to-face and online knowledge building discourse. One student noticed that almost every object of inquiry connected to brain. That led to the whole class discussion with the brain as an object in the center. Other objects were added one by one based on the connections among them proposed by students. During this process, three new major objects (see the pink stars in Fig. 1c) were added/adapted (genetics, immune systems, and 5 senses was promoted); seven new small objects (see green circles in Fig. 1c) were identified (O.C.D., A.D.D., red blood cells, white blood cells, pain, nails, and virus); 25 new connections were made; as well as one “not-yet” object (kidney) was recognized. Below is how they identified the object “kidney” together through the whole class discussion.

T: ...does anybody feel like there are small concept, that green circle missing ...?
S1: Did somebody already say kidneys?
T: What?
S1: Did anybody say kidneys?
T: Did anybody make anything about kidneys? You are studying it? Does anybody study the Kidney?
S2: I did the digestive system.
T: You did the digestive system?
S2: That goes with the digestive system, but...
T: But, but...are the kidneys part of the digestive system?
S2: Actually they are part of the excretory system.
T: But who is studying it? I didn’t see anything about that on Knowledge Forum.
S2: Nobody! But the digestive system is the cause of the excretory system.
T: I will write down Kidney. But I really want this map to represent things we’ve studied and things we know. And I’m going to leave it clipped up until it’s explored...
S1: I will study it!
T: You will study it? That’s awesome!

Nobody in the community studied kidney before. But as students mapped out all the objects related to human body systems, Student 1 (S1) noticed kidney was missing. When she proposed the object, her peer immediately made connections with his previous research. Even though kidney was postponed, this discussion successfully brought it into the community’s attention. And later on in May, when S1 requested for a Kidney space on KF to share her research, it was officially added to the collective map as an object of inquiry.

Before the collective conversations, small groups worked on isolated objects identified by each group as their focus of inquiry, without realizing the connections among them. When kids reviewed their individual research trajectory, they realized there were some connections between the objects in their own inquiry. The collective conversation provided a chance for them to see that even though different groups were working on different objects, they were actually very “connected”. See the excerpt below.

S3: ...okay, the bone connects to the bone marrow. And the bone marrow connects to the blood. [Make connections between epistemic objects of the bone, bone marrow, and the blood]
T: Tell us more...why?
S3: Because the bone marrow is located in the bone. And bone marrow makes...[Inaudible]
T: And the bone marrow does what?
S3: The bone marrow makes blood.
S4: Crazy! It makes blood cells…????!
S3: Yes!
S4: Just blood cells!
T: Okay! Great.

S3 was a member in the bones group that had emerged. During their research, he found the connections among bone, bone marrow, and blood (cells). So he began his research on blood after working on bones. In the above discussion, he shared the connections with peers. S4, who had been working on the heart and blood, was really surprised to know that the work on heart and blood was actually connected to the bone research. Through this collective reflection, all the objects of inquiry investigated were connected. With this connected objects map, it is easier to monitor how different lines of inquiry connect to understand how the human body systems work together.

How did students use the structures to support their participation in knowledge building?
As summarized in Table 2, the students commented that the collective map of inquiry objects supported their science learning in two ways: 1) to position their work; and 2) to understand connections among the different lines of inquiry focusing on different human body systems. For instance, several students commented on the same point: “…there’s a lot I need to learn. I have to catch up…” Almost every student noted the connections among different objects and human body systems: “…basically everything is connected…” Students commented that they planned to use the collective objects map to guide their work and decide where to go next, to add something the community was missing to make the map more complete, and to know whom to interact with to share and connect the new knowledge gained. For example, one student wrote, “…some of the stuffs now are not researched yet…”

Table 2: Qualitative analysis of students’ survey and interview about the collective objects map

<table>
<thead>
<tr>
<th>Students’ survey in March (21 students)</th>
<th>Students’ interview in June (12 students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. How did the individual and collective mapping processes help your inquiry?</td>
<td>Q. How specifically did you use the collective objects map in your science learning?</td>
</tr>
<tr>
<td>• helped to know where I got started, what I learned, what I’m learning, and realize that there are a lot I need to learn about/catch up;</td>
<td>• with the map, it’s clear that all the human body systems work together and all body parts are connected;</td>
</tr>
<tr>
<td>• helped to know how different body parts connect and work together as a system;</td>
<td>• individually, help to position his/her work and make decision about the objects to work on;</td>
</tr>
<tr>
<td>Q2. In what ways can you use the collective map to support your further science learning?</td>
<td>• collectively, use the visualization of the objects map to see what the community has investigated, what the community hasn’t researched yet, and where they should to go next;</td>
</tr>
<tr>
<td>• position my work, look at the map to search for something new to work on next;</td>
<td>• help to know who they should connect with and where to share their knowledge online to help their peers in their research.</td>
</tr>
<tr>
<td>• see everyone’s objects and connections, and reflect on them; work on something the community hasn’t investigated and share them for others to learn;</td>
<td></td>
</tr>
<tr>
<td>• learn the connections among different body parts; give ways to connect with others and share my knowledge with them.</td>
<td></td>
</tr>
</tbody>
</table>

In what ways did the students engaged in productive knowledge building with the support of the collective structure?
The number of epistemic objects each student investigated/learned

In total, there were 50 epistemic objects identified by the community according to the collective epistemic objects co-generated by March. Analysis of students’ individual research journey in which they summarized their overarching process of inquiry revealed that each student investigated about 10 objects (20% of the total objects) and additionally learned about 17 objects from their classmates (34% of the total objects). In total, each student gained knowledge about 27 objects (54% of the total objects) from September to March. The students focused on several specific objects for specialized inquiry with small group members or individually and at the same time developed a reflective sense of the community’s inquiry in other areas for mutual learning and connection.

Content analysis of student online knowledge building discourse

First, we coded the Knowledge Forum notes based on patterns of student contributions (see Table 3). Among all the 607 notes posted by students over the school year, more than one fourth of them (26.85%) involved questions. They also theorized their initial ideas into explanations (46.29%). In the later part of their inquiry, when they identified new objects of inquiry they had little knowledge about, they tended to contributed some relevant information from websites or books about the object first (21.09%), which helped them go deeper in investigating that object.

Table 3: Student contributions in KF over the school year

<table>
<thead>
<tr>
<th>Types</th>
<th>Questioning</th>
<th>Theorizing</th>
<th>Evidence</th>
<th>Reference</th>
<th>Integrating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td>163</td>
<td>281</td>
<td>24</td>
<td>128</td>
<td>11</td>
</tr>
<tr>
<td>Percentage</td>
<td>26.85%</td>
<td>46.29%</td>
<td>3.95%</td>
<td>21.09%</td>
<td>1.82%</td>
</tr>
</tbody>
</table>

The understanding of each focal object were further coded based on scientific sophistication to examine the extent to which students’ explanations align with a scientific framework of human body systems (see Fig. 2). Specifically, the rating of ideas about all the focal objects were between “1 – basically scientific” and “4 - scientific” ($M=3.09; SD=0.52$). Compared with the initial notes they wrote in September and October about various epistemic objects ($M=1.6; SD=0.55$), which was between “1 – pre-scientific” and “2 – hybrid”, students’ knowledge about focal objects of inquiry were deepened significantly.

Discussion

This study investigated the process of reflective structuration to co-frame shared epistemic objects of inquiry as a way to guide and sustain the knowledge building in a Grade 5 science classrooms. First, we documented the reflective processes by which the teacher and students worked together to frame their shared directions of inquiry over time. The collective structures emerged and evolved through several reflective cycles with the interactive input from students and their teacher, including: (a) appropriating existing structures (e.g. curriculum topic) from the school contexts and prior practices and teacher “seeding” of potential directions through inquiry activities and resources; (b) generating and reviewing diverse individual interests and questions to construct an initial list of six overarching questions; (c) using the wondering questions to guide initial personal and group research and expanding the wonderings accordingly, (d) using updated structure to guide further research, and co-reviewing and mapping epistemic objects emerged from the inquiry, and (e) further using the map of epistemic objects to plan and guide specialized inquiry. Analyses of student’ survey and interviews how students used the collective structure to support their science learning with purpose. Content analyses of student survey, interview, and online knowledge discourse revealed how reflective structuration of epistemic objects contributed to students’ sustained deepening knowledge building practices. Deeper analysis of student interview is underway to examine the processes of how small groups and individuals identify each focal epistemic objects of inquiry that contributes to the collective structures of inquiry. These results enrich findings from our previous studies, elaborating reflective structuration as a self-sustaining mechanism to guide and sustain principle-based
knowledge building practices without extensive pre-scripting. Based on the reflective structuration framework, we have created an upgraded design of the Idea Thread Mapper software that works with Knowledge Forum to help knowledge building communities co-structure their inquiry processes over time for connected and sustained knowledge building (Zhang et al., 2018).

References


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Recognizing Competencies vs. Completion vs. Participation: Ideal Roles for Web-Enabled Digital Credentials

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Abstract: Open digital badges are new credentials that can contain specific claims and links to web-enabled evidence and can circulate in networks. Badges are helping facilitate broader shifts away from measuring, accrediting, and credentialing achievement and towards capturing, validating, and recognizing learning. A study of 30 funded efforts to develop badges found that none of the efforts to develop competency badges (for demonstration of specific competencies) resulted in thriving badge-based ecosystems, while four of the five efforts to develop participation badges (for engaged participation in social learning) resulted in thriving ecosystems. The findings were more mixed for the remaining efforts to develop completion badges (for individuals completing projects or investigations) and hybrid badges (for multiple types of learning). This suggests that innovators temper their ambition for capturing and recognizing evidence of individual competencies, and consider exploring more social assessments and informal and crowdsourced recognition.

Keywords: digital badges, metadata, constructivism, participation, recognition.

Over roughly a century, the existing systems for credentialing learning via grades, transcripts, degrees, and certificates emerged alongside modern practices for assessing students, testing achievement, and accrediting schools. Because of this co-evolution, current practices for testing, accrediting, and credentialing remain opaque for many stakeholders, and many of the practices are taken for granted. This leads to problems that obstruct progress, such as the way presumed expectations of external accreditors have discouraged some schools from expanding into online courses (e.g., Parker, 2008; Gallagher, 2016) and discouraged others from allowing students to transfer in credits from courses taken online (Schrock, 2010; AACRAO, 2017).

In addition to being opaque, prevailing practices for testing, accrediting, and credentialing are analog, or have only embraced technology as proxies for analog practices. For example, while tests are increasingly administered online, most still employ the same measurement assumptions from decades ago (Timmis, Broadfoot, Sutherland, & Oldfield, 2016). Likewise, while admissions officers or hiring managers are likely to use email rather than phone calls when seeking information beyond transcripts and resumes, such individualized non-networked communication is still quite laborious. Arguably, these practices represent major obstacles for the broad embrace of the many innovative educational technologies of interest to learning scientists and educational innovators. And while the impact is less obvious, these entrenched practices also obstruct efforts to overcome the inequities that plague contemporary education in most countries (e.g., Bowen & Bok, 2016; Carnoy, 2005).

Open digital badges were introduced in 2012 via the MacArthur Foundation’s Badges for Lifelong Learning initiative. That initiative supported efforts at the Mozilla Foundation to establish the initial metadata standards that made badges interoperable (i.e., function across multiple platforms) and extensible (i.e., function in more advanced platforms in the future). The MacArthur initiative also funded 30 proposals (from over 600 submissions) to design and build open badge systems (with supplemental funding from the Gates Foundation). Together, these events led to broad media coverage in both mainstream venues (e.g., Carey, 2012) and education-related outlets (e.g., Young, 2012). By 2014, multiple systems for issuing and displaying open badges existed.

Expanded open badge metadata standards were released on January 1, 2017 and were adopted by the IMS Global Learning Consortium, the leading standard-setting organization for educational technology. Significantly, these new standards include specifications for third-party endorsements (Everhart, Derryberry, Knight, & Lee, 2016). Proponents believe that these developments will allow these “e-credentials” to eventually transform education in a similar manner as consumer reviews allowed e-commerce to gradually (but inexorably) transform retailing and publishing starting around 2000.
Contrasting different uses of digital badges

Not surprisingly, digital badges have been taken up in a diverse range of educational programs and learning contexts. Some view them as ideal for motivating and recognizing inquiry-oriented and project-based learning (e.g., Cucciara, Giglio, Persico, & Raffaghelli, 2014; Diamond & Gonzalez, 2016). Conversely, proponents of “gamification” have enthusiastically embraced badges (e.g., Mallon, 2013; Metzger, Lubin, Patten, & Whyte, 2016); some have equated open badges with the movement toward competency-based education (e.g., Blackburn, Porto, & Thompson, 2016; Duncan, 2011). Meanwhile, others have argued for “learning recognition networks” consisting of badges and e-portfolios (e.g., Buchem, 2016) that appear more consistent with newer sociocultural theories of learning and motivation that provided much of the theoretical impetus behind MacArthur’s broader initiative (Yowell, 1999, 2014; Brown, 2012). The various chapters in two recent edited volumes confirm the range of this diversity (Ifenthaler, Belin-Mularski, & Mah, 2016; Muilenburg & Berge, 2016).

This diversity of badge uses was represented by the 30 projects funded by MacArthur’s 2012 initiative. An extended study of those 30 efforts provided some initial evidence about the apparent appropriateness of digital badges for different types of educational programs. This paper summarizes some of those findings in the context of a follow-up study that examined which of those 30 efforts succeeded in leaving behind a “thriving” badge-based ecosystem two years after the initial funding was exhausted. As will be shown, one type of badge system appeared particularly successful in this regard, while another category of badge system appeared less successful.

The badge Design Principles Documentation project

The initial study of the 30 digital badge systems was known as the Design Principles Documentation project. This project ran from 2012 to 2014. The project was organized to capture the “practical wisdom” (Halverson, 2004) that emerged as each of the 30 badge design efforts set out to build and implement their proposed badge system. The project first carried out a content analysis of the 30 funded proposals to identify the intended design principles for using digital badges to recognize, assess, motivate, and study learning. Once those projects were well underway in 2013, the DPD project interviewed each of the teams to determine which of the intended design principles had been implemented and explored the factors that supported or thwarted each principle. In late 2014, after each of the efforts had exhausted their funds, a final interview explored which of the design principles had been formalized and whether the badge system had been implemented, partially implemented, or suspended. These findings were synthesized into a set of principles in a widely distributed report entitled Where Badges Work Better. This report included general badge system design principles (8) and more specific principles regarding recognition (12), assessment (7), and motivation (17). Grant (2014) reports additional detailed information about these efforts.

The DPD project report also proposed a framework for organizing research of badge systems. This new framework crosses three dimensions that are relevant to studying badge systems. The first dimension is the purpose of the research (i.e., summative research of badge systems vs. formative research for improving badge systems). The second dimension is sources of evidence (i.e., conventional evidence vs. new forms of evidence provided by the contents of the badges themselves). Crossing these two dimensions results in four categories of badges research. Within each of those four categories was additional dimension of research scope (i.e., specific badges, larger badge systems, and broader badge-based educational ecosystems).

DPD follow-up study

A follow-up study was carried out in 2015-2016, at the request of a project advisor and the program officer. In late 2015, the DPD project followed up with each of the 30 efforts and searched the web and elsewhere for evidence that each system was suspended (i.e., no evidence that the badges were being issued), existing (i.e., badges might be issued but no evidence that they were being earned or shared by actual learners), or thriving (i.e., a functioning badge-based ecosystem where learners were earning, claiming, and sharing badges). Determining the status of the projects proved to be challenging because some of the teams were still trying to implement their badge system or establish a broader ecosystem. Ultimately, consensus was reached among the research team.

The follow-up study then explored whether the success of the various badge systems was associated with the type of badge systems in terms of the forms of learning that the system intended to motivate and recognize. Only a few of the proposals articulated specific theories of learning. Nonetheless, most of the proposals featured activities and assessments that were generally consistent with one of three widely acknowledged "grand theories" of knowing and learning. These three perspectives are rooted in more fundamental philosophies and epistemologies (e.g., Greeno, Collins, and Resnick, 1996) and are widely embraced by many researchers and theorists. Re-analysis of the original proposals and DPD interviews confirmed that most (but not all) of the 30 proposed badge systems were generally consistent with one of these three perspectives. After substantial
deliberation and additional interviews, each of the badge systems were characterized as competency-based, completion-based, participation-based, or hybrid.

Competency-based badge systems

Some of the proposed badge system designs appeared to be most consistent with “associationist” theories. These rather traditional theories (sometimes labeled didactic or empiricist) assume that knowledge consists of a relatively large number of specific associations. These views of knowledge are rooted in the British empiricist philosophy and are most strongly associated with behaviorism and its focus on stimulus-response associations (e.g., Skinner, 1953). However, associationist perspectives are well represented in the work of many cognitive scientists who focus on cognitive “if-then” associations (e.g., Anderson, 2013). Such modern “information processing” perspectives are appealing to instructional designers who worry about "cognitive load" (e.g., Sweller, Van Merrienboer, & Paas, 1998) that results when too much information is presented to learners. The DPD project concluded that badge system designs that were consistent with associationist perspectives would emphasize (a) badges for self-paced individualized mastery of specific competencies, (b) summative assessments of those competencies, and (c) external and extrinsic forms of motivation. It seemed appropriate to characterize these as competency-based badge systems.

Eight of the proposed badge systems were deemed competency-based. This included three proposals that received substantially greater funding as part of the Gates Foundation’s Project Mastery initiative. This initiative supported K-12 efforts to implement “proficiency-based pathways,” which offer “opportunities for students to engage in a learning experience where they can demonstrate mastery of content and skills and earn credit towards a diploma, certificate, or some other meaningful marker” (Gates Foundation, 2012, p. 7). These efforts included (1) Pathways to Global Competence from the Asia Society, (2) LevelUp from EffectiveSC and the Adams 50 School District in Colorado, and (3) the Youth Digital Filmmaker Badge System proposed by YouTopia and the School District of Philadelphia. All three of the Gates-funded projects were also examined in a comprehensive summative evaluation carried out by the RAND Corporation (Steele et al., 2014).

As elaborated in the RAND report and the DPD report, all three of these badge design teams struggled with technology, validity, and personnel issues. The Pathways to Global Competence badge system was never implemented and the other two badge systems were suspended after pilot implementations. In particular, the badge teams struggled to implement and manage the relatively massive demands for summative assessment of specific competencies from student-generated work. This included gathering all the elements of student work and presenting that work to qualified teachers or experts while keeping track of scores and competencies and representing the resulting evidence meaningfully in digital badges.

None of the other efforts to develop competency-based systems resulted in thriving ecosystems around open badges. The (4) Sustainable Agriculture & Food System badge system from Agricultural Sustainability Institute at the University of California-Davis proposed an ambitious degree program featuring sophisticated self-paced e-portfolios and competency badges. This effort stalled in the face of technology challenges, assessment challenges, and personnel changes; a conventional course-based degree was ultimately established. The (5) Young Adult Library Services Association (YALSA) succeeded in implementing an ambitious YALSA Badges system for youth-serving librarians. The group reported that the requirements for independently attaining and gaining expert endorsement numerous specific competencies was too much work considering the modest value of the badge, and the program was suspended. The (6) National Manufacturing Institute succeeded in implementing a single Computer Integrated Manufacturing badge within the widely-used Project Lead the Way STEM curriculum. The badge ultimately languished and became redundant as it only duplicated the effect of course grades. (7) The National Manufacturing Institute also proposed an ambitious badge system organized around the standardized performance assessments from by SkillsUSA for specific industry-defined competencies. However, that effort stalled when the team was unable to secure a formal endorsement for its badges from employers; without formal recognition, the vocational programs were unwilling to purchase and use the SkillsUSA assessments. (8) The startup ScoLab successfully implemented badges within its BuzzMath arithmetic drill and practice website. However, privacy concerns with their young learners precluded the implementation of web-enabled open badges, and their badges simply served as learning tokens within their popular gamified website.

It is worth noting that the DPD project concluded that the challenge that these efforts encountered went well beyond the decision to implement competency-based badges. Nonetheless, these findings suggest that caution is needed when developing competency-based badge systems. In particular, it seems competency-based systems should anticipate the challenges that the DPD project uncovered as well as the tensions in competency-based education (CBE) implementations reported in the separate evaluation of the three Gates’ Project Mastery initiatives (Steele et al., 2014). This includes the challenges of equating evidence from anytime/anywhere learning with conventional criteria; determining who can authorize credit; maintaining a common definition of proficiency;
technical, financial, and logistical barriers to efficiency; and concerns over equity. These bolster the concerns about CBE in a report from the Carnegie Foundation (Silva, White, & Toch, 2015), while also highlighting the challenges that learning management systems present for CBE (cf. Leuba, 2015).

Completion-based badge systems

The largest group of proposed badge systems were generally consistent with “constructivist” theories of learning. This broad class of perspectives is rooted in Piaget’s (1970) genetic epistemology and is associated with modern learning perspectives that emerged in the 1980s. This perspective is widely embraced by many cognitive scientists (e.g., Glaser, 1984), educational psychologists (e.g., Savery and Duffy, 1995), and teacher educators (e.g., Richardson, 2003). Constructivist perspectives embrace a rationalist theory of cognition which assumes that knowledge consists of broader conceptual schema that the human mind constructs when attempting to make sense of (i.e., “rationalize”) new information in the world. Rather than numerous specific stimulus-response or if-then associations, constructivist instruction focuses on fewer “higher-order” competencies and more general competencies such as problem-solving and critical thinking.

The DPD project assumed that badge systems were consistent with constructivist perspectives when they emphasized (a) inquiry-oriented learning, typically via individual completion of projects or investigations, (b) informal formative assessments of that learning via performance and/or portfolio assessment, and (c) more intrinsic forms of motivation associated with curiosity and interest. It seemed appropriate to characterize badge systems that emphasized such features as completion-based.

The project concluded that 12 of the 30 proposals were completion-based. Of these 12, four resulted in badge systems that appeared to be thriving in 2015. (1) NatureBadges were used to extend exhibits at Smithsonian Natural History Museum using computer-based assessments in partnership with Credly. This system was later renamed Q’rriors. (2) Intel and the Society for Science and the Public successfully added open badges into its existing Intel Science Fair curriculum and web technology. (3) The Sweetwater Foundations’ proposed AQUAPONS, an urban aquaponics project that partially implemented a badge system in 2014; after scaling back ambitions portfolio and performance assessment goals, the AQUAPON badge system appeared to be thriving within the Chicago Project LRNG program. (4) The American Social History Project and the Educational Development Center added badges to an existing project-based teacher professional development program known as Who Built America? While the project was unable to implement some ambitious peer/expert performance assessments, the badge system was successfully implemented, and badges were approved for New Your City’s After School Professional Development Program. Thus, of the four completion-based badge systems that were thriving in 2015, one of them (NatureBadges) relied on computer-based assessments while another (Intel) used an extensive network of existing assessment practices associated with its science fairs. The two other teams that succeeded in creating thriving completion-based badge systems both did so after scaling back their assessments.

Four of the proposed completion-based badge systems succeeded in implementing badge systems by 2014, but no evidence of a thriving ecosystem was found in 2015. This included (5) the 4-H/USDA badges, (6) the Starlite Academy Robotics from Project Whitecard Inc and the Center for Educational Technologies at Wheeling Jesuit University, (7) Planet Stewards from 3-D Game Labs, and (8) My Sash is an App from the Girl Scouts of Greater Chicago and Northwest Indiana. The four remaining proposals for completion-based badge systems failed in implementing their badge systems. This included the (9) Wilderness Explorers Badges from Disney/Pixar, the (10) Earthworks Rising badges from The Ohio State University and Digital Watershed, and badge systems for (11) Roadtrip Nation and (12) StoryCorpsU from Corporation for Public Broadcasting.

While the obstacles for the eight completion-based badge systems were varied, they generally struggled to implement ambitious technology-supported performance and portfolio assessments. These assessment systems were different from the competency-based systems in that they aimed to help teachers or outside experts assess completed projects for evidence of relatively high-level student learning outcomes, typically against detailed rubrics. But this is still a time-consuming process that requires specific expertise with both assessment and the domain, and it likely requires extensive refinement. One interesting observation was that several teams reported that badges fostered transparency (and increased scrutiny) that heightened the challenges that prior constructivist assessment reforms have encountered in using performance and portfolio assessments to generate valid evidence of disciplinary problem solving (e.g., Shavelson, Baxter, & Pine, 1992).

Participation-based badge systems

A few of the proposed badge system designs appeared most consistent with sociocultural theories of learning. This perspective is rooted in the early work of the Soviet psychologist Lev Vygotsky (1980) and emerged in its contemporary form in the 1990s (e.g., Lave & Wenger, 1991). One well-known strand of sociocultural perspectives is called situated cognition, which reflects the assumption that knowing is strongly bound (i.e.,
that students were more interested in “pre-professional” badges that focused more on their professional roles. The focus was on discrete skills and accomplishments. However, few earners claimed their badges; interviews revealed that this evidence appeared sufficient to characterize the system as thriving.

In 2015, evidence showed that four of these five systems were thriving. (1) The Supporter to Reporter (S2R) badge system was proposed by MakeWaves in the United Kingdom for its existing youth sports journalism network. S2R had already developed a sophisticated website that included extensive networked peer endorsement and discussion of learner projects (mostly videos). The badges were awarded for completion of projects, and most projects were completed collaboratively by cohorts of students, with particular attention directed at teamwork and cooperation. In 2016, MakeWaves parlayed their success into a standalone open source badge and content management platform known as Open Badge Academy. MakeWaves and the platform were acquired by the Cities and Guilds Group, the leading vocational training and credentialing organization in the UK.

(2) The PBS News Hour Student Reporting Labs (SRL) badge system was similar to S2R in that it layered badges into an existing curriculum and website for secondary students who completed web-based news articles and videos. The program placed particular emphasis on building communities of learners, both within the participating schools as well as across schools via its website. A sophisticated badge system was implemented in 2013, including a feature whereby the high-level badges were ultimately approved by a producer at the local PBS affiliate. The badge system and program were still thriving in 2015, with over 300 SRL Superstar badges issued and the introduction of a new STEM badge, and some badge earners were getting internships at PBS stations.

(3) The badges system at Mouse Inc. was proposed to recognize middle and secondary students learning of network and computer management skills by supporting the technology help desk and network managers at their school. The badges that were layered into its existing web-based program included a Community Win! badge specifically designed to recognize engaged participation in the Mouse network. The program organized cohorts of students known as “Mouse Squads” to complete workshops and projects together. A sophisticated tracking system allowed each squad to keep track of its collective progress. The badge system was successfully implemented in 2013, and there was ample evidence that the program and the badge system were thriving in 2015.

(4) The Cooper-Hewitt Design Prep badge system was proposed by a partnership between the Smithsonian National Design Museum and Cooper-Hewitt School of Design. The teams proposed to layer badges into Cooper-Hewitt’s existing DesignPrep program and website. Their goal was helping students from underserved schools in New York gain design, collaboration, and presentation skills while developing a portfolio of designs for their applications. The initial badge system that was implemented in 2012 consisted of competency badges focused on discrete skills and accomplishments. However, few earners claimed their badges; interviews revealed that students were more interested in "pre-professional" badges that focused more on their professional roles. The badge system was revised to offer participation badges. In 2015, the new badges were featured on the new DesignPrep website and were being offered in ongoing programs. While the badges were not as widely claimed and shared as the three previous projects, this evidence appeared sufficient to characterize the system as thriving.

(5) Design for America (DFA) proposed to add badges to its interdisciplinary network of students in engineering and learning sciences at Northwestern University focused on positive social impact by using the needs of community members to inform the design and implementation of “social impact” projects. They succeeded in implementing its Digital Lofts Badge System in 2013 and were awarded an NSF Cyberlearning Grant to expand badges and other features of the Digital Loft. While DFA and the Digital Loft certainly appeared to be thriving in 2015, no evidence was found that the badges were still being used. The DFA badge system was deemed existing.

Hybrid badge systems

The five remaining badge systems proposed issued two or even three types of badges. Some systems even issued badges that did not fit into any category The research team decided that it was appropriate to characterize them as hybrid systems. (1) The Computer Science Student Network (CS2N) was a collaboration between Carnegie-Mellon University (CMU) and the Defense Advanced Research Projects Agency (DARPA). They intended to
develop educational systems for computer science and other STEM fields for diverse learning groups ranging from middle school students to adult learners and hobbyists. They intended the badge system to serve as a guided pathway for learners to acquire skills in robotics, computer science, and related STEM content areas using ambitious artificial intelligence systems designed to track and develop learners’ progression throughout the program. CS2N included competency badges in robotics and artificial intelligence, completion badges for critical thinking in computer science, engineering, and robotics, and participation badges for some networked social activities. The badge system was only partially implemented in 2014 in the face of challenges associated with automatically awarding competency and completion badges. But further funding and development resulted in a thriving badge-based ecosystem in the Carnegie Mellon CS-STEM network and affiliation with Cities of Learning and Project LRNG.

(2) The Providence After School Alliance (PASA) partnered with after school and extracurricular programs to offer learning experiences to middle and high school students. PASA collaborated with Achievery Inc., a badge-based startup. The effort developed a badge for diverse after-school activities, including self-paced, competency-based activities, cohorted courses, and collaborative projects. A sophisticated attendance tracking and assessment system allowed students to earn course credit for work completed in the after-school programs. As was announced in the national educational media (Ash, 2012), PASA and Achievery successfully implemented its badge system in 2012 and students did indeed begin earning course credit for after school projects. However, the final DPD interview and a detailed ethnography of the program (Davis & Singh, 2015) found that the students felt that awarding of formal credit interfered with and undermined the value of the badges. While the badge system still exists, PASA stopped issuing badges in 2014, and Achievery suspended operations in 2015.

(3) The School District of Philadelphia proposed the Leverage for Digital On-Ramps badge system as part of an ambitious program to prepare urban high school students for entry into college and the workforce. They intended to add badges to the Philadelphia Academy's Post-Secondary and Career Readiness Course, a developmental multi-year course designed to provide 21st century and college readiness skills. The courses and proposed badge system included features that were consistent with all three perspectives, including competency-based programs, individual and group projects, problem solving activities, and face-to-face and networked social interaction. The badge system was partially implemented in 2014 but was soon suspended. This effort laid important groundwork for subsequent participation in Cites of Learning project and Project LRNG.

(4) Microsoft proposed to add open badges to its Partners in Learning Network (PiLN) for educators and school leaders to promote technological competencies and relevant digital networking skills. PiLN aimed to equip educators with the capacity to teach information and communications technology and 21st century skills. The network included self-paced competency-based activities, cohorted workshops, problem solving activities, and extensive social interaction. While an internal badge system was implemented in 2014 and the network appeared to be thriving in 2015, technology constraints with the existing network prevented PiLN from implementing sharable open badges, and their badges served only as internal tokens within the network.

(5) Badges for Vets aimed to connect civilian employers with veterans by translating their skills directly to the workplace. However, veteran organizations and agencies did not cooperate as originally envisioned, preventing the envisioned ecosystem from being established. Rather, the new website took on a social networking function as veterans began to connect with one another. The act of translating military skills to civilian work-ready skills seemed to call on practices that were consistent with multiple perspectives but did not really align with any assumptions about knowing and learning. While a badge system was partly implemented in 2013 and apparently still exists, their badges were never awarded to actual earners.

**Discussion and conclusions**

Many factors were at play in establishing badge systems that continued to thrive after the initial funds were exhausted. But the challenges of assessing individual competencies or completion of projects were clearly a significant factor. The broader conclusion here is that badge systems that emphasized mastery of numerous specific, measured competencies or project completion towards external credit or recognition appeared to overwhelm the assessment capacity of their broader educational and professional contexts. These challenges seemed to be enhanced with self-paced and individualized learning because they eliminate some of informal assessment that occurs naturally with cohorts of learners. As assessment experts like James Popham (e.g., 1997) have long argued, assessing completed artifacts for evidence of specific competencies and/or higher-order problem solving skills can be remarkably difficult. Doing so requires substantial knowledge regarding (a) the targeted disciplinary competencies, (b) how the competencies can be represented in artifacts, and (c) how those artifacts were created.

To summarize, assessment was a major challenge for the seven competency-based systems that failed to thrive, while the one that did thrive issued an automated non-open badge; the four completion-based badge
systems that were thriving either built on existing assessments or significantly scaled back their assessments of completed projects; the one thriving hybrid open badge system used automated computer-based assessments for their competency and completion badges. These findings lead to the conclusion that **badges work better ... where expectations for assessment of individual skills and competencies are modest and manageable.**

To varying degrees, all four types of badge systems included various forms of social interaction among learners. However, those interactions were only emphasized in the participation-based badge systems, and were mostly represented in the other types of badge systems as peer-assessment of individual competencies or projects. The fact that four of the five participation-based badge systems appeared to be thriving and that one led to an entirely new branding platform that is gaining wider use leads to the conclusion that **badges work better ... where learning, recognition, and assessment is primarily social.**

To reiterate, the competency-based and completion-based systems aimed to award badges for evidence of specific competencies or more conceptual understanding. In contrast, the participation-based badge systems awarded badges for successful participation in workshops, apprenticeships, and courses, typically with cohorts of other learners. Importantly, most of these badges did include claims of specific competencies or higher order skills. But, rather than directly assessing those competencies or understanding, these badge systems left it up to educators or experts to make the judgement that someone who completed the particular program, activity, or course had demonstrated those competencies or understanding. This leads to the conclusion that **badges work better ... when awarded for completion of workshops, course, or projects, rather than specific competencies or knowledge.**

Finally, it is important to distinguish between badges awarded for engaged participation in the social practices of learning and badges awarded for mere attendance, which are sometimes inappropriately labeled as “participation badges”. Kyle Bowen of Purdue University coined the term “carpet badges” to refer to such practices, while Serge Ravet (2015) characterized this practice as “spray and pray.” The widespread practice of awarding such badges for attendance at educationally-oriented conferences started around 2013 and seems to have broadly undermined the value of badges for many potential stakeholders.

**References**


Solder and Wire or Needle and Thread: Examining the Effects of Electronic Textile Construction Kits on Girls' Attitudes Towards Computing and Arts

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Abstract: The gender gap in computing has persisted—and grown—over the past 40 years. Prior work has identified a number of contributing factors for the persistence of the divide, including environmental cues, software themes, and course content. More recently, the design of software and hardware tools have been investigated as potentially contributing to the gender gap, and a new class of tools designed with gender in mind have risen to prominence. This study compared one such tool—the Adafruit Flora, an electronic textiles platform—to a comparable platform that was not designed with gender in mind—the Arduino Leonardo. While there were some shifts in self-identification, the most notable result was that the participants’ views of computing and arts became less stereotyped. However, there was no meaningful difference between workshops in this regard. Our results indicate that the relationship between e-textiles and gender may be more complicated than previously thought.

Introduction and background
According to the latest statistics released by the US Department of Education, 55,000 students received a degree in computer science in 2014. Of those students, only 10,000 were women. An article in Newsweek describes the situation: “The gender gap is real and takes many forms… Despite great strides by women in other formerly male fields, such as law and medicine, women are turning away from the computer industry. Men earning computer-science degrees outnumber women 3 to 1 and the gap is growing” (Kantrowitz, 1994).

There are two things that are alarming about this quote. First, the quote is from 1994. This means that the gender gap in computer science has been a problem recognized by popular media for over 20 years. But, even more worrying is the fact that the gender gap in computer science stood at 3 to 1 in 1994, but in 2014 it stood at 4.5 to 1. This means that not only has the gender gap in computing persisted for over 20 years, but it has gotten wider.

Although some argue that concern about the gender gap is blown out of proportion (Cummins, 2015), we are committed to the view that closing the gender gap is of highest priority. Prior research has demonstrated that the gender gap is not the result of girls simply choosing not to study computing, but rather is the result of systematic biases built into the learning environment that suppress women’s participation (e.g., Alvarado & Dodds, 2010). For example, when software contains historically masculine themes like battle and war, girls’ performance relative to boys drops. When the software is modified to be more gender-neutral, the gender difference disappears (J. Cooper, 2006; Joel Cooper, Hall, & Huff, 1990).

If themes are important to consider when designing educational software, it makes sense to consider them when designing other educational toolkits as well. The literature around hardware/electronics construction kits is not nearly as mature as the literature around software, but work in this area seems to indicate that the affordances and design features of construction kits can have similar impacts on youths’ attitudes and behavior. For example, Buchholz et al. found that when using the Lilypad Arduino, a hardware construction kit designed for creating electronic textiles, girls in mixed-gender dyads spent more time engaged in key practices, and had more opportunities to take on leadership roles (Buchholz, Shively, Peppler, & Wohlwend, 2014). The authors argue that the affordances of the Lilypad Arduino are those that “have historically been valued in feminine communities of practice”, and that these cultural affordances “expanded the ways [for girls] into complex electronics and computing content” (p. 18). There is a growing body of literature that both grounds the Lilypad design in theory (Buechley & Eisenberg, 2008; Kafai & Burke, 2014) and explores its impact on children in learning environments (Buchholz et al., 2014; Kafai et al., 2013; Peppler & Glosson, 2013; Qiu, Buechley, Baafi, & Dubow, 2013). This body of research is nearly unanimous in its declaration that the Lilypad opens up a new pathway for girls to become interested and engaged with computing and engineering.

The body of work that has arisen around the Lilypad Arduino provides evidence that providing affordances grounded in feminine communities of practice might be an effective way of increasing girls’ interest in computing. However, most of the studies in this arena to date have been observational, and the underlying
mechanism responsible for the shift in attitudes is unclear. What is still missing is a direct comparison of how kits with similar functionality but different affordances affect girls’ attitudes. This study made such a comparison. We used an experimental design with two experimental groups—one using an e-textiles kit, and the other using the original Arduino interface of pins and wires—and a control group to better tease out the effects of the design of the construction kit on attitudes.

Methods

Participants

N=49 6th and 8th grade girls were recruited from an all-girls middle school in Silicon Valley (N=46 6th graders, N=3 8th graders). The school is notable in that computer science is one of the core subjects, so all of the students had some prior programming experience with Scratch.

Design

The study took place in a Silicon Valley all-girls middle school during a week-long intersession. During this intersession all classes were suspended and the 6th and 8th grade girls chose from a number of different week-long workshop opportunities. We offered two different workshops during the intersession. In the first workshop, called Electric Fashion, we introduced the students to programming microcontrollers with electronic textiles. The students in this workshop worked exclusively with the Adafruit Flora—a sewable Arduino microcontroller—and a variety of sewable LEDs and sensors. This group of girls is referred to as the SEW group (Sewing and Electronics Workshop) in this paper. The second workshop, called Light Up Your Life, covered the same conceptual content as the first workshop, but used a different programmable microcontroller. Instead of a microcontroller designed for e-textiles, this group used a microcontroller called the Arduino Leonardo. And instead of using conductive thread to connect the sensors and LEDs, the students in Light Up Your Life used wires, solder, and breadboards. This group of girls is referred to as the WIRE group (Workshop Involving leonaRdo and Electronics) in this paper. The third group—the control group—was composed of girls who took part in other workshops offered by the school (Table 1). Choices included workshops in stop animation, outdoor survival, learning about and drinking tea, set design, quilting, sailing, and others. Ours were the only workshops where students worked with electronics and computer programming.

Table 1: Full study design

<table>
<thead>
<tr>
<th>Participants</th>
<th>Pre-Surveys (30 min)</th>
<th>Treatment</th>
<th>Post-Surveys (30 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEW Group (N=10)</td>
<td>Implicit and Explicit Attitudes</td>
<td>Electric Fashion: create fashion projects with electronic textiles</td>
<td>Implicit and Explicit Attitudes</td>
</tr>
<tr>
<td>WIRE Group (N=10)</td>
<td>Implicit and Explicit Attitudes</td>
<td>Light Up Your Life: Make everyday objects interactive</td>
<td>Implicit and Explicit Attitudes</td>
</tr>
<tr>
<td>Control Group (N=29)</td>
<td>Implicit and Explicit Attitudes</td>
<td>None</td>
<td>Implicit and Explicit Attitudes</td>
</tr>
</tbody>
</table>

Out of the 49 students who took part in our study, N=20 were selected by the school administration to take part in our workshops and N=29 were selected to be in the control group. The administration stated that the assignments were random, however we were not part of the randomization or selection process. Students in the control group took part in a variety of different workshops unrelated to electronics and programming, but still took the pre- and post-surveys. N=10 (9 6th graders) students were assigned to the Electric Fashion workshop, and the other N=10 (8 6th graders) were assigned to the Light Up Your Life workshop.

The girls in the SEW and WIRE groups used the same software to program their projects and were taught using the same materials (with slight changes to account for the differences in the hardware). The girls in both workshops had access to the same crafting and construction materials, and we did not make suggestions about the kinds of projects they might choose to make. Every attempt was made to control the software and instructional content between the two workshops so that the effects of the hardware design on the girls’ attitudes could be isolated. The surveys were administered once at the start of the week and once at the end of the week.

Hardware and software

Students in the SEW group learned to program the Adafruit Flora, a microcontroller that can be sewn into fabric and other soft materials (Figure 1, left). The Flora is compatible with a number of sewable sensors (e.g., a light sensor, a motion sensor) and actuators (e.g., sewable LEDs). These components can be connected by sewing them together using stainless steel conductive thread to complete a complete, responsive, programmable system.
Students in the WIRE group learned to program the Arduino Leonardo (Figure 1, right). Both the Flora and Micro use the same microcontroller, the ATmega 32u4. This means that a program written for the Flora can be downloaded to the Micro and the functionality will be identical. However, the Arduino Leonardo is not designed to be sewn into soft materials using conductive thread. Instead, the Leonardo is the latest in a long line of hobbyist microcontrollers (stretching back to the BASIC Stamp, released in 1992) to use wire, breadboards, and soldering as the primary connection method. The full list of sensors and actuators provided for each group is reported in Table 2 below.

Figure 1. On the left are materials that were used in the SEW group, and on the right are materials that were used in the WIRE group.

Table 2: Comparison of microcontrollers and electronics used in each workshop

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>SEW Group</th>
<th>WIRE Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adafruit Flora</td>
<td>Arduino Leonardo</td>
</tr>
<tr>
<td>Actuators (Outputs)</td>
<td>Sewable LEDs, LED Strip</td>
<td>LED Strip</td>
</tr>
<tr>
<td>Miscellaneous Items</td>
<td>Conductive Fabric, Conductive Thread, Alligator Clips</td>
<td>Breadboard, Wires, Solder and Soldering Iron, Wire Strippers</td>
</tr>
</tbody>
</table>

While the Arduino programming environment does simplify many of the difficult parts of physical computing, it may not be the ideal environment for middle-school students’ first exposure to physical computing (Sadler, Shluzas, & Blikstein, 2016). Because the participants were all learning the Scratch programming language (Resnick et al., 2009) as part of their core curriculum, a member of our research team (Proctor) created a set of tools that allowed the girls to use the Scratch programming language to program their microcontrollers. Using a Scratch extension and a connected helper application, we created a hardware simulator that provided a way to light up virtual LEDs, read input from virtual sensors, and connect the virtual sensors and virtual LEDs using block-based code. Both workshops used the same simulator, whose graphic interface consisted of a row of circles to represent LEDs and several bars to represent sensor values. The helper application translated participants’ code to the Arduino language and logged versions of participants’ programs. More details on the software and an analysis of this code will be published in future work.

Instruments
In order to understand the girls’ changes in self-identification and their shifts in gender perception a set of instruments was administered before and after the workshop. We analyzed these data to understand the girls’ attitudes before the workshops and to measure how their attitudes changed as a result of being in either the SEW, WIRE, or control groups. We included instruments to measure both explicit and implicit attitudes.

We were interested in the following attitudes: personal identification with computer science, personal identification with arts, gender perceptions of computer science, and gender perceptions of arts. Our hope was to gain a more nuanced understanding of how gender perceptions and personal identity were related, and how gender perceptions and personal identity might change as a result of being in the different workshops.

Traditionally, self-report measures have been used to assess students’ attitudes towards computing and gender. However, explicit responses can be influenced by social or personal pressure (self-presentation) (Greenwald & Breckler, 1986). For this reason, implicit measures of attitudes were included in the study. The implicit tests measured the subset of explicit attitudes that were most vulnerable to self-presentation bias: gender perceptions and self-identification with computing and arts.
Explicit attitudes: Identity and gender semantic differentials

We designed two 36-item, 11-point semantic differentials (Osgood, 1952), one for measuring identity and the other for measuring gender perceptions of computer science and the arts. The surveys were created on the Qualtrics platform and administered online. The Gender Semantic Differential was designed to measure the girls’ explicit gender perceptions on computing and arts, while the Identity Semantic Differential Scale was designed to measure the girls’ explicit self-identification on those same categories. In a semantic differential scale, participants are presented with a set of attitude objects and asked to rate each of them along a bipolar adjective scale. On the Gender Semantic Differential Scale, participants rated words from 0 (masculine) to 10 (feminine) (Figure 2). On the Identity Semantic Differential Scale, they rated the same words from 0 (Not My Kind of Thing) to 10 (My Kind of Thing or Could Be My Kind of Thing). The same 36 items were presented in both scales. The order of the questions was randomized at the participant level.

Figure 2. Two example items from the semantic differential measure of explicit attitudes.

We originally designed each scale to measure the following categories: computing, electronics, arts, crafts, and stereotypically feminine. We evaluated each of the categories using Cronbach’s alpha and found that they were not consistent. To remedy this, we broke the original categories into sub-categories (a priori) and recomputed Cronbach’s alpha for each new category. These new groupings proved to be more consistent (alpha > 0.7). The final list of categories, along with the individual items in each category and Cronbach’s alpha, can be found in Table 3.

Table 3: Categories and corresponding individual items for the explicit attitudes semantic differential

<table>
<thead>
<tr>
<th>Category</th>
<th>Individual Items</th>
<th>Cronbach’s Alpha (Gender)</th>
<th>Cronbach’s alpha (Identity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS Actions</td>
<td>Debugging a broken program, Programming robots, Computer hacking, Programming projects with computers, Writing code, Solving problems with software</td>
<td>0.85</td>
<td>0.92</td>
</tr>
<tr>
<td>Electronics Actions</td>
<td>Troubleshooting electronics, Building electronics projects</td>
<td>0.84</td>
<td>0.74</td>
</tr>
<tr>
<td>Arts</td>
<td>Drawing, Sketching, Painting, Making art, Art class</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>Stereotypically Feminine</td>
<td>Me, Makeup, Nail polish, Fashion, Working on fashion projects, Sewing</td>
<td>0.80</td>
<td>0.88</td>
</tr>
</tbody>
</table>

In addition to analyzing these categories, we also hand-picked a subset of questions to analyze individually. These items were chosen because of their theoretical importance to answering our research questions. We chose these items before analysis to reduce the risk of Type 1 error. The following items were chosen for individual analysis: Conductive thread, Arduino, Troubleshooting electronics, Building electronics projects, Scratch, Working on crafts projects, Me, Sewing, Working on fashion projects, Soldering, and Computer programming.

Implicit attitudes: Identity and Gender Go/No-Go Association tasks

The Go/No-Go Association Test (GNAT) assesses the strength of an association between a target category (e.g., computing) and two poles of an attribute dimension (e.g., male-female) (Nosek & Banaji, 2001). During the GNAT procedure, stimuli from the target category and from one pole of the attribute dimension are the signal or go items, while stimuli that do not match the target category or the target pole of the attribute dimension serve as noise or no-go items. A correct response on a go trial requires pressing the space bar on a computer keyboard to correctly identify the stimulus as belonging to the target attribute or attribute dimension.

For example, a participant might be asked to correctly identify stimuli that are either related to computing (the target category) or feminine (the attribute dimension). On the first trial, the word “Internet” appears on the screen and the participant hits the space button—a correct response—and sees a green circle. On the next trial, the word “Boy” appears on the screen and the participant hits the space bar—an incorrect
response—and sees a red check mark. Finally, the word “Sewing” appears on the screen and the participant does not hit the space bar. After 833 milliseconds, a green check mark appears on the screen (see Figure 3 for an example trial).

Figure 3. Example GNAT. On the top-left is the target concept (Arts) and on the top-right is the target attribute (masculine). When stimuli that match either of these signal categories are presented, a correct response is to hit the spacebar before the deadline.

We designed two GNATs to measure the strengths of eight different associations. The Gender GNAT measured the associations between female and computing, male and computing, female and arts, and male and arts (Table 4). The Identity GNAT measured the associations between self and computing, other and computing, self and arts, and other and arts (Table 4). Both GNATs were created on the Inquisit Millisecond platform and administered online using the Inquisit Millisecond Web Player (Draine, 1998). As recommended by the creators of the GNAT, d-prime was used as a measure of the strength of the participants’ association between the two target concepts (Nosek & Banaji, 2001). The higher the d-prime, the easier it was for the participant to associate the target concept and attribute. d-prime values of zero indicate that the participant was unable to identify the signal at all. d-prime values below zero indicate that the participant was better at selecting the noise than the signal in that trial and most likely confused. In accordance with the advice of the GNAT designers, all values of d-prime below zero were removed before analysis. Due to low test-retest reliability, we were not able to compare pre-workshop scores to post-workshop scores. However, we were able to combine and analyze all of the pre-workshop data from the students to compare explicit and implicit attitudes.

Table 4: Gender GNAT targets, attributes, and stimuli

<table>
<thead>
<tr>
<th>Category</th>
<th>Gender Stimuli</th>
<th>Identity Stimuli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target A</td>
<td>Computing</td>
<td>Artificial intelligence, programming, computers, robotics, coding, Arduino, algorithms, debugging, electronics, Scratch</td>
</tr>
<tr>
<td></td>
<td>Artificial intelligence, programming, computers, robotics, coding, Arduino, algorithms, debugging, electronics, Scratch</td>
<td></td>
</tr>
<tr>
<td>Target B</td>
<td>Arts</td>
<td>Pottery, sewing, drawing, sketching, arts, stencils, quilting, painting, crafts, knitting, jewelry</td>
</tr>
<tr>
<td></td>
<td>Pottery, sewing, drawing, sketching, arts, stencils, quilting, painting, crafts, knitting, jewelry</td>
<td></td>
</tr>
<tr>
<td>Attribute A</td>
<td>Female</td>
<td>Myself, me, mine, I, self, my</td>
</tr>
<tr>
<td></td>
<td>Female, feminine, girl, woman, her, she, hers</td>
<td></td>
</tr>
<tr>
<td>Attribute B</td>
<td>Male</td>
<td>Someone else, them, other, not me, they</td>
</tr>
<tr>
<td></td>
<td>Male, masculine, boy, man, him, he, his</td>
<td></td>
</tr>
</tbody>
</table>

Results

Two distinct types of analysis were performed in the study. The first analysis is a comparison of implicit and explicit attitudes measured before the workshops, and the second is an analysis of changes in identity and gender perceptions as a result of taking part in the workshops. The first analysis was performed on the pooled pre-survey data collected from all of the experimental groups (N=49). The two goals of this analysis were to gain a better understanding of the girls’ attitudes before the intervention and to compare their implicit and explicit attitudes. The second analysis was performed to better understand how taking part in either the SEW, WIRE, or control group changed the participants’ identities and gender perceptions.

A comparison of implicit and explicit attitudes

An analysis of the pooled data from the pre-survey responses on the Gender GNAT (Figure 4, left), the girls were more likely to associate computing with male (mean=1.41, sd=0.88) than with female (mean =1.08,
sd=0.82); t(43) = 2.26, p < 0.03. In other words, the girls’ automatic associations were in line with common stereotypes about computing, arts, and gender.

An analysis of the Identity GNAT (Figure 4, right) showed that the girls were more likely to associate arts with self (mean=1.00, sd=0.97) than with other (mean=0.73, sd=0.77); t(43) = 2.26, p < 0.03. However, no significant difference was detected between the mean d-prime values for self and computing (mean=0.86, sd=0.76) and other and computing (mean=0.86, sd=0.76); t(43) = 0.98, p < 0.34.

Figure 4. Implicit attitudes of the entire sample (N=49) before the workshop. Higher d-prime values indicate a stronger association between the two items. Error bars show standard error.

In order to compare the girls’ explicit attitudes to their implicit attitudes, we matched items from the Semantic Differential to items presented in the GNAT and created two categories: Computing and Arts. On the gender semantic differential, a paired t-test showed that the girls were more likely to rate the computing items as more masculine (mean=6.23, sd=1.06) than the arts items (mean=4.79, sd=0.46); t(31)=-6.434, p < 10^{-5}. On the identity semantic differential, a paired t-test showed that the girls were more likely to rate the arts questions as more “My Kind of Thing” (mean=7.06, sd=1.80) than the computing questions (mean=5.97, sd=1.99); t(21)=-2.53, p < 0.02.

Figure 5. Explicit attitudes for the entire sample (N=49) before the workshop. Error bars show standard error.

In summary, the girls’ implicit and explicit attitudes were in agreement. Both implicitly and explicitly, they held stereotypical views of computing and arts: they were more likely to view computing as masculine and arts as feminine. In addition, the girls identified with arts both implicitly and explicitly, but were more indifferent towards computing.

Changes in identity and gender perceptions

We used a regression analysis to measure the changes in attitudes for participants in each workshop. We compared the SEW group to the control group, the WIRE group to the control group, and the SEW group to the WIRE group. In this analysis, the independent variable, workshop, involved three levels: SEW, WIRE, or
Control. The dependent variable was the mean of all the post-workshop questions in the category or item of interest, and the covariate was the mean of the pre-workshop questions from the same category or question. In other words, this analysis allowed us to compare post-workshop scores for participants in each workshop while controlling for pre-workshop scores.

**Changes in identity**
The participants’ attitudes shifted in two out of four categories on the self-identification semantic differential: Electronics Actions and Arts. There was a significant positive shift in self-identification with Electronics Actions for the SEW group (p=0.03), and there was a marginal difference between the experimental groups (p=0.11) with the SEW group showing a more positive change than the WIRE group. In addition, there was a marginally significant negative shift in self-identification with Arts for the SEW group (p=0.10) when compared to control. On this category, there was no significant difference between the experimental groups.

On the individual items, there were two significant changes. First, there was a significant shift in self-identification with Arduino for each experimental group when compared to control (p=0.009 for WIRE, p=0.04 for SEW). There was no difference between the experimental groups. Second, there was a significant increase in self-identification with troubleshooting electronics for the SEW group when compared to control (p=0.03). There was a marginally significant difference between experimental groups (p=0.10), with the SEW group showing a more positive change than the WIRE group.

**Changes in gender perceptions**
The participants’ attitudes did not shift in any of the four categories on the gender semantic differential. However, there were a number of notable shifts on individual items. There were significant or marginally significant increases in the perceived femininity of the following items: Conductive Thread (p=0.08 for SEW, p=0.11 for WIRE), Arduino (p=0.10 for SEW, p=0.01 for WIRE), and Scratch (p=0.07 for WIRE). There were significant increases in the perceived masculinity of the following items: Working on Crafts Projects (p=0.08 for WIRE, p=0.10 for SEW), and Working on Fashion Projects (p=0.09 for SEW). There were no significant differences between the SEW and WIRE groups for any of these items.

**Discussion**
In this paper we dug deeper into the claim that e-textiles may appeal to girls because of the alignment between the affordances of the kit (e.g., sewing) and historically feminine practices. Operating under this assumption, we expected to see differences between the two workshops. In particular, we expected that the SEW group would show more positive changes in self-identification with computing practices and a stronger reduction in gender stereotypes about computing when compared to both the WIRE group and the control group.

However, instead of seeing larger changes for the SEW group when compared to the WIRE group, we found that in nearly all cases, the two groups moved together. The girls in both groups experienced strong positive shifts in their self-identification with the Arduino. Their gender perceptions of a number of items became less stereotyped as well. Working with the traditional electronics kit appeared to be as effective at shifting girls’ gender perceptions and identity as working with the e-textiles kit.

We see two possible ways of reconciling our findings with prior work. First, no prior work that we are aware of has directly compared an e-textiles kit like the Adafruit Flora to a functionally identical, but more traditional kit like the Arduino. The results of the present study indicate that in some cases, the results reported in those studies might have also been obtained with a more traditional Arduino. Second, it is possible that the effects previously reported only emerge in mixed-gender environments. If this is the case, then the explanation for why we did not see any differences could be that the participants’ identities as girls were never activated, or that barriers to girls’ participation are more likely to emerge in mixed-gender learning environments.

**Conclusion**
There is still much left to learn about how the design and affordances of the tools we use interact with our perceptions of gender, our attitudes, and our identities. Future work would include repeating this study with mixed-gender dyads and looking for activation of gender identities and corresponding changes in attitudes, replicating earlier work with a comparison group using an Arduino Leonardo to see if the same effects can be achieved with the more traditional platform, and exploring how historically-gendered tools might give rise to or disarm stereotype threat. Although our study shows that the picture is less simple than we thought, we hope our work has identified promising future pathways that may lead to closing the gender gap for good.
References


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Do Alternative Instructional Approaches Result in Different Learning Progressions?

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Abstract: Learning progressions (LPs) are the hypothetical pathways that students may take as they learn about core ideas in a domain. LPs take a developmental approach to learning and assume that there are constraints that drive the learning paths. The question then is: how strong are the constraints of the learning process? We report on a comparison of two distinct instructional interventions informed by the same genetics progression that were implemented with introductory biology students (10th and 11th grades). The interventions targeted the ideas in the LP but differ in the: (1) sequencing of instruction, (2) focus phenomena, and (3) activities. To determine the learning paths for each instructional intervention we used causal model search and path analyses to explore relationships within and between these ideas. Our findings may indicate that the two instructional contexts result in maps that have both differences and similarities providing further evidence about the strengths of conjectures in LPs.

Introduction

Learning progressions (LPs) are hypothetical pathways that students may take as they develop more sophisticated ways of reasoning about important ideas and practices in a domain (Alonzo and Gotwals, 2012; Duncan & Hmelo-Silver, 2009). LPs begin with a consideration of students’ prior knowledge and initial understandings to define the lowest level (lower anchor) of the LP. The uppermost level of the LP explicates target understandings (upper anchor) in the domain and is based on analyses of the domain and societal expectations (what students should know by the end of a specific grade or grade band). Between the lower and upper anchors of the LP are descriptions of intermediate levels of growing sophistication. The intermediate levels are derived from research on student thinking and learning in the domain. Movement along the progression depends on carefully designed instruction (Corcoran, Mosher and Rogat, 2009).

In essence, LPs take a developmental approach to learning with the underlying assumption that there are developmental constraints and affordances that drive the learning path. We use “developmental” in the sense that the acquisition of new knowledge depends on existing knowledge (Wiser, Smith, & Doubler, 2012); the developmental constraints in this sense are not necessarily related to age. From a cognitive perspective, the question is: how strong are the constraints of the learning process? It may be that constraints are relatively loose and many different learning paths exist between the same start and end points. Theories of learning that take a more situated, knowledge-in-pieces, perspective (diSessa, 1988; Lave & Wenger, 1991) suggest that this may be the case. Alternatively, it may be that the constraints are strong and that there are very few possible paths that are most effective and efficient in promoting learning. Research on second language acquisition has shown that learning of certain grammatical features follows a “natural order” (Krashen, 1981, p. 10) suggesting that, at least in some domains, there are strong constraints on learning and a predictable path. If the developmental constraints are strong, then LP scholarship can help us identify such constraints and inform curriculum and instruction. However, the constraints are weak, and there are numerous possible paths, it is not clear whether LPs can contribute to the development of a best-practice instructional approach. Understanding the nature of the constraints on learning and how these impact learning paths is a currently unresolved issue of interest in LP research (Duncan & Gotwals, 2015; Sevian & Talanquer, 2014).

One way to explore this issue is to develop different instructional interventions informed by the same progression; that is, both interventions target the same core ideas but differ in how and when (sequence) they are taught. If the developmental constraints are strong one would expect that learning will follow the same path regardless of the specific instructional intervention. However, learning may be less efficient with an instructional intervention that is not well aligned with the hypothesized trajectory (levels of the progression). Learning under the conditions of an intervention that is better aligned with the LP will be more efficient. This is akin to building a complex Lego structure using one of two sets of instructions. One set, the “aligned” set provides instructions that call for the pieces in the “right” order; the other “non-aligned” set calls for the same pieces but in an order that is not ideal. In both cases the Lego structures will eventually be built, but it will be a much more troubled and cumbersome process with the non-aligned instructions. Note that both sets of instructions involve the same
building blocks and the final structure is the same, but the order of assembling the blocks is different. A radically different conceptualization is the assumption that the learning constraints are very soft or non-existent, and in that case the two instructional interventions will lead to very different outcomes. In our analogy this means that the despite having the same building blocks the final Lego structures themselves will be entirely different. Therefore, having an experimental design with two different instructional approaches can potentially provide evidence that can differentially support one of the two hypotheses (strong versus weak constraints).

Here we report on such a comparison in the context of two distinct instructional interventions informed by the same genetic progression that was developed and revised by the authors (Shea & Duncan, 2013; Duncan, Rogat & Yarden, 2009; Todd & Kenyon, 2015). Both interventions were implemented with students learning introductory biology at the high school level (10th and 11th grades). The interventions targeted the same core ideas in the LP but the order of addressing these ideas, the focus phenomena, and the specific instructional activities were different. Students learning in both instructional conditions were assessed with written assessments that used ordered multiple-choice items (Briggs & Alonzo, 2009; Briggs et al., 2006).

To determine the learning paths in each condition we used causal model search and path analysis to explore relationships within and between these ideas, and how the modeled relationships fit with the data. The following two research questions guided our analyses: 1) How do two different instructional interventions developed using the same progression influence high school students’ core ideas and the connections between ideas in an LP? 2) What do the progression maps suggest about the nature of the constraints on learning? We next describe the genetics learning progression that informed the design of the instructional interventions in the two conditions and then describe the two interventions.

Theoretical framework: The genetics LP

The genetics progression was developed using the framework of genetics literacy by Stewart, Cartier and Passmore (2005) to identify core genetics ideas. The framework for genetics literacy depicts three interrelated conceptual models: (a) the inheritance model, which explains the probabilistic patterns of correlation between genes and traits; (b) the meiotic model, which explains the cellular processes that allow for the transfer of genetic information from one generation to the next; and (c) the molecular model, which explains the cellular and molecular mechanisms by which genes bring about their physical effects within an individual. The genetics LP describes learning for grades 5-10 and includes eight core ideas, or constructs, grounded in the three conceptual models described above (Duncan et al., 2009). In this paper we focused our analyses on two constructs that capture ideas from the molecular model—constructs B and C; and two constructs that capture ideas from the inheritance and meiotic models—constructs E and F, respectively.

To simplify matters, we refer to constructs B and C as the molecular genetics constructs. Construct B is about the nature of the genetic information. It embodies the idea that genes are instructions that encode the structure of proteins. Construct C, in turn, deals with the roles of proteins in genetic phenomena. Proteins are essentially the mediating mechanism between genes and traits; they carry out a variety biological functions such as: channels, structural support, sending messages within the cell, etc. Protein function impacts the structure and function of cells and those in turn impact the structure and functions of tissues and organs. When proteins malfunction (due to a mutation in the genetic instructions for them) this may alter the function of the cells, tissue, organ, and whole organism.

We refer to constructs E and F as the classical genetics constructs. Construct E describes how genes are passed from one generation to the next through sex cells (sperm and egg). It involves understanding the equal contribution of genetic material from both parents, the random distribution of genes in sex cells, and the process of meiosis. Construct F involves the patterns of correlations between the gene variants (alleles) and the physical characteristics (traits). Examples of these patterns include: recessive, dominant, sex linked, etc. Individuals have two alleles for each gene (one from each parent) that can vary in terms of their DNA sequence. The higher levels of construct F also involve understanding patterns of inheritance at the molecular level.

While we anticipate that the constructs are all related to each other, both within and across the genetics models, the progression as developed (Duncan et al., 2009) did not include any conjectures about how the constructs relate to each other. There was simply not enough research to merit making such assertions. Later work using data from empirical studies of the progression has begun to characterize relationships between constructs (Shea & Duncan, 2013; Todd & Romine, 2017). The analyses we conducted for this paper also provide valuable information about potential dependencies and relationships between constructs and how these relationships develop under different instructional conditions.

Methods
Study contexts and instructional interventions
We report data from two research groups that developed instructional materials using the same genetics LP. The instructional interventions developed were implemented with HS students. In the next section we discuss each implementation context and the different instructional interventions.

Research Group 1 context
The Research Group 1 implementation study was carried out with 285 students in the classes of five 11th grade biology teachers in a suburban eastern United States high school. The school’s students come from diverse backgrounds: 47% African-American, 23.7% Caucasian, 17% Hispanic and 12% Asian with 44% of the students considered economically disadvantaged. In collaboration with the participating teachers we developed a 10-week instructional unit in genetics that consisted of three modules focusing on concepts in molecular (4 weeks), classical genetics (4 weeks), and a bridging unit (1 week) that connected ideas in molecular and classical genetics. The molecular module addressed constructs B and C of the progression while the classical genetics module addressed constructs E and F (Duncan et al., 2017). The bridging module connected the molecular and classical genetics models by helping students develop molecular-based explanations of inheritance patterns.

For the purposes of a larger project we had two instructional conditions. About half of the students learned with the molecular genetics module first followed by the classical genetics module and then the bridging module- this is the MC condition. The other half of the students learned with the classical genetics module first followed by the molecular module- this is the CM condition. Each teacher taught classes in both conditions (within teacher assignment). Thus even within Research Group 1 we have two instructional interventions that vary in sequence, but not in content. Table 1 illustrates the MC condition in the first column.

All modules focused on model-based inquiry and students developed and evaluated models of genetic mechanisms using evidence. The modeling activities were followed by benchmark lessons that synthesized what was learned in the modeling activities, introduced relevant terminology, and provided opportunities to practice using the newly learned ideas. More information can be found in: Todd, Romine, and Cook-Whitt, 2017 (See Table 1).

Table 1: Instructional interventions

<table>
<thead>
<tr>
<th>Research Group 1 Instructional Design</th>
<th>Research Group 2 Instructional Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecular Module (M)</strong></td>
<td><strong>Molecular and Classical Modules</strong></td>
</tr>
<tr>
<td>Does HIV resistance exist? (1 week, modeling)</td>
<td>How Do Cells Become Cancerous (2.5 weeks, intervention lesson set, problem-based)</td>
</tr>
<tr>
<td>What is the link between genes and proteins in genetic disorders? (1.5 week, modeling)</td>
<td>Why Are Siamese Cats Colored The Way They Are? (2.5 weeks, intervention lesson set, problem-based)</td>
</tr>
<tr>
<td>Genetically Modified Organisms: (1.5 week, modeling)</td>
<td>How Can Hyla c. chrysoscelis, A Native Frog, Tolerate Being Frozen? (1.5 weeks, problem-based)</td>
</tr>
<tr>
<td>Introduction to Pedigrees and Punnet squares (1.5 weeks, modeling)</td>
<td>How Can We Reduce the Risk of Obesity in Our Community? (2.5 weeks, problem-based)</td>
</tr>
<tr>
<td>How is hair texture inherited? and Why is colorblindness more common in males? (2.5 weeks, modeling)</td>
<td>How Can There Be A Case of Disputed Maternity? (2.5 weeks, intervention lesson set, problem-based)</td>
</tr>
<tr>
<td>Classical Module (C)</td>
<td>Can We Genetically Engineer a Superhuman? (2.5 weeks, intervention lesson set, problem-based)</td>
</tr>
</tbody>
</table>
Co-dominance and sex-linked traits. Revise models of inheritance. Constructs addressed: F

Observed traits explained by patterns of inheritance. Constructs addressed: B, C, E, F

**Bridge Module (B)**

**How Can We Diagnose and Develop a Treatment Plan for a Simulated Patient?** (2 weeks, problem-based) Examine symptoms, proteins, mutations, propose genetic treatment. Constructs addressed: B, C, E, F

**What is the link between genes, proteins and the phenotype in a genetic disorder?** (1 week, modeling)

Students developed models of the molecular basis of inheritance patterns in the following contexts: blood types, cancer, CF, Sickle Cell and Dwarfism. Constructs addressed: B, C, E, F

### Research Group 2 context

The Research Group 2 implementation study involved sixty-five students within a 10th grade introductory biology class at a Midwestern United States suburban public grade 6-12 STEM school. Student demographics represent the region with white/non-Hispanic students making up 69.9% of the school population, 12.5% black non-Hispanic, 9.6% multiracial, 5% Asian/Pacific Islander, and 3.4% Hispanic; 24.5% of the school’s population is considered economically disadvantaged.

All 10th grade students in this school received the same instruction, designed predominantly by the biology teacher but containing four instructional intervention lesson sets targeted to the upper levels of the constructs of the LP. Consistent with the school’s mission to utilize project-based learning and inquiry activities, the intervention lesson sets and other teacher-developed genetics lesson sets were all problem-based and centered on a driving question (see Table 1). The students began the instructional period focused on the molecular constructs (i.e. molecular first), learning about structure/function relationships of proteins and cells, cellular differentiation, and protein denaturation. These lesson sets focused on constructs B and C, among others not discussed in this paper. For example, at the end of the second lesson set, students were able to explain how enzyme denaturation in different parts of a Siamese cat’s body leads to the coat pattern seen. Students then learned about the classical constructs, examining DNA structure, chromosomes, karyotypes, meiosis, and patterns of inheritance. Throughout the classical genetics lesson sets, instruction also focused on integrating the molecular model (constructs B and C) with the classical models (E, and F). For example, in the sixth lesson set, students used colored pencils to illustrate how an individual with an allele coding for a light blue pigment and an allele coding for a dark brown pigment would have brown eyes because the darker pigment masks the lighter pigment, although both are expressed. More details about the instruction can be found in Todd, Romine, & Cook-Whitt, 2017 (see Table 1 second column).

### Data collection

The assessments used for this study included ordered multiple-choice items (OMC). OMC items are developed to map onto the levels described by the genetics LP (Briggs, 2016). Rather than giving right or wrong scoring to each item response, OMC items allow for giving partial credit to each response. This is helpful for allowing researchers to obtain more information about students’ level of reasoning about a particular construct using the same item and reduces the number of items needed in an assessment.

Research Group 1: The assessment instrument (described in Duncan et al., 2017) consisted of 56 ordered multiple-choice (OMC) items. These items were selected from a pool of 85 OMC items that we developed, piloted and validated in previous research (Duncan et al., 2017). The 56 items were selected included about 4–5 items per construct and each item included response options that mapped onto 2-4 levels of the relevant construct.

Research Group 2: The assessment instrument is a previously validated Learning Progression-based Assessment of Modern Genetics (LPA-MG, Todd, Romine, & Cook-Whitt, 2017; Todd & Romine, 2017). The LPA-MG also consists of OMC items mapping on to the levels described in our modified version of the genetics LP (Todd, Romine, & Cook-Whitt, 2017). The 36-item LPA-MG assesses all progression levels with each construct containing three items; the item response options mapped onto the 4-6 levels of the relevant construct.

### Data analysis

**Coding of the data**

Both research groups used a Guttman coding scheme to translate students’ responses into a location along each construct, using the assumption that if students’ understandings corresponded to a higher level of the construct
good fitting model (Hu & Bentler, 1995). An RMSEA of 0.06 or below indicates a good-fitting model (Hu & Bentler, 1995). The Tucker-Lewis Index (TLI), and the Root Mean Square Error of Approximation (RMSEA). Values of 0.9 or above for the CFI and TLI indices exceed accepted criteria for good model fit (Hu & Bentler, 1995).

Model search
Relational structure in the data was sought using the fast greedy search (FGS) algorithm implemented in TETRAD (Glymour et al. 2016). This score-based algorithm was implemented in previous work with genetics learning progressions (Todd, Romine, & Correa-Menendez, 2017), and is described in detail in Madigan and Raftery (1994). Briefly, score-based algorithms like FGS search the data for probable relationships and then combine these relationships into a more complex structure in a way which maximizes the likelihood of the model given the data (Raftery, 1995). We used the Bayesian Information Criterion (BIC) approximation to this likelihood, which carries with it the prior assumption that in the absence of data, all models are equally probable (Raftery, 1995).

After searching the space of probable models, a model is selected which minimizes the BIC score as it is specified by Raftery. In order to constrain the model search space, which is hyperexponential with an increasing number of parameters (Madigan & Raftery, 1994) and given the extensive research on validation of these progressions (Todd & Romine, 2017), we added the constraint that the progression levels within each construct were related and sequential, and required those links to exist in the model before searching for additional links.

We applied the above process to three datasets: (1) Research Group 1, MC Intervention, (2) Research Group 1, CM Intervention, and (3) Research Group 2 MC Intervention. This resulted in a best-fitting directed acyclic graph (DAG) describing links within individual constructs as well as links between related constructs. Fit of these graphical structures with the data were then confirmed using path analysis.

A model being the “best model” does not mean it actually explains the data as all models in the set may be poor-fitting (Link & Barker, 2006). Fit of the resultant relational structure derived from the model search process with the data was confirmed using path analysis. We evaluated fit of each construct with the data from which it was derived using Mplus7 by comparing the covariance matrix inferred by the model to the actual covariance structure in the data. We used three fit indices: the comparative fit index (CFI), the Tucker-Lewis Index (TLI), and the Root Mean Square Error of Approximation (RMSEA). Values of 0.9 or above for the CFI and TLI indices indicate a good-fitting model (Hu & Bentler, 1995). An RMSEA of 0.06 or below indicates a good fitting model (Hu & Bentler, 1995).

Results
We compared three instructional interventions developed with the genetics LP to determine the role of instruction. The progress maps suggest more similarities than differences across the instructional interventions. We first provide evidence for fit of the path models with the data and then discuss the patterns we noticed across the implementations.

Fit indices derived from path analysis indicate that all models uncovered by the FGS algorithm fit the data well. The CM model from Research Group 1 had an RMSEA = of 0.058, a CFI of 0.95, and a TLI of 0.93. The MC model from Research Group 1 had an RMSEA of 0.059, a CFI of 0.95, and a TLI of 0.93. The MC model from Research Group 2 had an RMSEA of 0.029, and values of 0.99 for the CFI and TLI. All of these indices exceed accepted criteria for good model fit (Hu & Bentler, 1995).

Comparison between Research Group 1’s two instructional conditions
We first compared the path analyses of Research Group 1’s two respective instructional sequences molecular-then-classical (MC) and classical-then-molecular (CM). In this comparison the students are from the same research context and the intervention activities are identical except for the sequencing of the classical and molecular modules (see Table 1). The path models in the form of progression maps are shown in Figure 1. The nodes represent levels of the progression for each construct, i.e. B1, B2, and B3 nodes are three successive levels of the B construct (gene code for proteins). The constructs are color coded with darker shades indicating more sophisticated levels understanding. Constructs E and F are in shaded in green and blue. The molecular constructs B and C (proteins do the work of the cell) are shaded in orange and yellow. The arrows indicate connections between levels within and between constructs. The red arrows denote connections between constructs and the strength of the connection is reflected in the arrow width. Note that arrows are directional. A connection between F2 and E2 (classical constructs: inheritance patterns and meiosis, with an arrow from F to E) means that students...
who achieved a level 2 understanding on construct E usually had already attained a level 2 understanding on the F construct. Knowing F at a level 2 affords learning of E at a level 2.

Figure 1 illustrates these connections, both across constructs in the same genetic model (between E and F or B and C) and between the classical and molecular constructs (between F and C, F and B). The F1 nodes in both maps have the greatest number of connections. This means that F1 functions as a central idea in both conditions. Interestingly, construct E is connected only to construct F in both conditions. Students’ understandings of construct E (meiotic model) do not bootstrap the learning of other constructs; however, understanding the ideas embodied in construct E is afforded by understanding construct F (patterns of inheritance). This is not surprising, as students often know more about inheritance patterns compared to meiosis, as these concepts are often part of the middle school curriculum. The understanding that each individual has two alleles (one from each parent) can bootstrap understandings that sex cells have half the genetic content and that alleles are randomly distributed in sex cells.

In comparing the two progression maps we can see that the (red) arrows in the MC condition are mostly originating from construct F towards other constructs (B, C and E); thus construct F seems to be a bootstrapping construct in this condition. Progressing along construct F affords learning ideas in other constructs. This was a bit surprising to us since in the MC condition students learned molecular ideas first and yet it seems that students may not have fully understood ideas in other constructs before they had a strong grasp of construct F. The opposite seems to be true in the CM condition. In that progression map for construct B levels B2 and B4 seem to point to construct F. This suggests that understanding construct B (genes are instructions for proteins) affords learning ideas about patterns of inheritance. This makes sense given the nature of the higher levels of construct F (levels 2-4), which involve understanding the molecular basis of inheritance patterns (e.g. mutations in genes can result in recessive alleles). However, we find it odd that these connections are present in the CM condition, in which students learned about classical genetics first and yet these connections are present. One potential explanation that may account for these seemingly unexpected patterns has to do with the bridging module. It may be that when students in the MC condition, who had just completed the classical module, learned about the connection between the molecular and inheritance models (bridge) they developed deeper understanding of the molecular constructs. That is the bridge helped make the more recently learned construct a scaffold for deepening understandings of the molecular constructs, which were revisited in the bridge module. The opposite is true for the CM condition. These students had just completed the molecular module before starting the bridge module. In the bridge module their understandings of the molecular construct B scaffolded the deeper understanding of the revisited classical constructs.

Comparison between Research Group 1 and Research Group 2 interventions

Below we show a comparison of the progression maps from the MC condition from Research Group 1 and the instructional intervention of Research Group 2. Both of these interventions were of the molecular-first ilk but involved different phenomena. Further, whereas Group 1’s unit was model-based, Group 2’s unit was project-based. In both cases students were guided by driving questions and strived to explain a variety of genetic phenomena. The best-fitting path models are shown in Figure 2. There are several points to note here. First, we wish to point out that the two progressions have different numbers of levels. This is because Group 2’s progression is a revision of the progression used by Group 1 and it has more levels for all constructs. To help in comparing these we color-coded the levels using similar shades. Thus for construct F, Group 2 has an extra level not included...
construct $F$ from Group 1. However, in construct $C$, the terminal levels are the same; $C5$ (Grp 2) is equivalent to $C4$ (Grp 1), and levels $C1-3$ in Group 2 are all part of level $C1$ for Group 1. While this is somewhat confusing, the extra levels in Group 2 do not change the overall pattern of findings.

Second, there are more connections in Group 1’s map, in particular from construct $F$ to the other constructs. This suggests that $F$ is a central construct and progressing in understanding of this construct afforded the learning of ideas in other constructs. We suspect that the bridge module may have contributed to this phenomenon as it afforded students with additional opportunities to revisit constructs $B$ and $C$ in the context of discussing inheritance patterns ($F$) right after they learned about classical genetics. It may be that learning about the molecular mechanisms underlying inheritance patterns allowed students to develop more sophisticated understandings of the molecular constructs in and of themselves (resulting in a bootstrapping effect between $F$ and the molecular constructs).

Third, in both progression maps the constructs grow in sophistication meaning the arrows within a construct all originate from prior levels to subsequent levels and the values are all positive. Moreover, the initial and terminal nodes are very similar. Initial nodes are those that only have arrows originating with them, in both maps the initial nodes $E1$ and $F1$ belong to the classical genetics constructs; whereas $C1$ is initial only in the Group 1 map, and $B1$ is initial only in the Group 2 map. The terminal nodes, those that have only arrows pointing to them, are also similar with $F4/F5$, $B4/B6$, and $E4/E5$ respectively, whereas $C4$ is terminal only in Group 1 map.

We discuss our interpretation of the similarities and differences between these maps and their implications next.

![Figure 2](image-url)  
**Figure 2.** Path models (progression maps) of MC conditions for Research Group 1 (left) and Research Group 2 (right).

**Discussion and instructional implications**

As noted above, all three the progression maps (the MC, CM maps for Group 1 and the MC Group 2 map) show noticeable similarities and differences. In terms of commonalities, the similar initial and terminal nodes suggest that students ground their understanding of genetics in ideas from the classical genetics constructs $E$ and $F$ since these serve as initial nodes in both maps. Students begin with classical genetics ideas and then use these to develop understandings of molecular genetics. The order of introduction of classical versus molecular genetics does not seem to matter much in terms of initial and terminal ideas (Figure 1). Students seem to have similar start and end points. However, the order of instruction does seem to matter in terms of which constructs bootstrap the learning, and here our findings are somewhat counterintuitive. Beginning with the molecular module does not mean that the molecular constructs will facilitate learning of the classical constructs, and the reverse is also true—classical constructs do not bootstrap learning in the classical first condition. We believe that the odd patterns we identified in the Group 1 progression maps may be due to the role of the bridging module in revisiting constructs that were introduced first and deepening them at this later stage.

Differences mostly comprised the connections between constructs. There were more connections in the Group 1 maps in comparison to the Group 2 map. This plurality of connections suggests that the instructional intervention of Group 1 may have afforded multiple paths (while resulting in similar end points). Again, it may be that the bridging module, by focusing on connections between ideas, allowed students to deepen their understandings of different ideas and to forge new paths through the terrain of these constructs.

To conclude, we wish to return to our question: What do the progression maps suggest about the nature of the constraints on learning? Our findings do not provide the clear and conclusive answer we had hoped for. Overall, we see both strong similarities and important differences between the maps across the three conditions.
Certain instructional opportunities and foci may impact some learning paths more than others. Overall, our findings do not support the existence of strong constraints on learning; however, they do imply some weaker constraints given the similarities in initial and terminal nodes and the progression within constructs. We also point out that the differing study contexts (e.g. schools, students) and measures may have exaggerated some of the differences between the two MC instructional contexts. We hope that in future collaboration between our groups we can develop more elegant and streamlined designs that can provide stronger evidence and help us better understand students’ learning trajectories and the impacts of instruction on these trajectories.

References

Acknowledgments
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Encouraging Revision of Scientific Ideas with Critique in an Online Genetics Unit

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Abstract: Encouraging students to revise their scientific ideas after encountering new evidence is essential to science learning, but has proven challenging. We investigated the merit of critique in promoting revision. 315 students participated in an online genetics unit where we investigated how critique affects the nature and frequency of revisions made to student essays. Students in the critique condition explain what is wrong or missing from several common non-normative student ideas regarding difficult topics in genetics. We compare this to a method used in the past to encourage students to add new ideas to their essays; students in the revisit condition are directed back to relevant information and interactive models rather than practicing critique. Students in the critique condition were more likely to revise their essays at all, especially students with low prior knowledge. Students that practiced critique were also significantly more likely to add new ideas to their revisions.

Keywords: science, genetics, critique, revision, technology, knowledge integration

Introduction
This research investigates how two types of guidance influence student revision of their scientific explanations. Revision of scientific explanations and arguments is an essential practice in learning and communicating science (Brownell et al., 2013). Revision is also stressed prominently by the NGSS. The NGSS were developed around the idea that students continually build on and revise their knowledge (NGSS, 2013). The NGSS science practices constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information describe an iterative process of incorporating new ideas and evidence into continually constructed scientific knowledge. Although revision is a necessary skill for gaining the integrated understanding called for by the NGSS, there are limited opportunities for students to revise in a typical science classroom (Berland & Reiser, 2011). Furthermore, students are challenged by NGSS to make productive revisions. Bridwell (1980) analyzed 12th grade students’ English essay revisions for changes in surface features, words, phrases, clauses, sentences, multiple sentences, and text. All students revised, but most revisions occurred at the word (31.2%) or surface level (24.8%). Students revised primarily by improving word choice and by correcting mechanical errors. Crawford et al. (2008) reported similar findings for 5th and 8th grade students, who focused on revising words and punctuation.

Previous studies suggest that encouraging revision is indispensable to student learning, and promoting revision in any form can be beneficial for students. For example, Tansomboon et al. (2017) revealed that students who attempted to revise their science explanations made significantly greater gains from pre to posttest than those who made no revisions at all, even if the revisions made were incorrect. In addition, students that made relevant revisions gained a more integrated understanding of the science material (Gerard et al., 2015; Linn et al., 2014). Previously, in an online unit on plate tectonics, we developed a rubric to categorize the types of revisions that students made on embedded essays. We found that students who made integrated revisions demonstrated greater gains on a posttest essay item, as compared to students that did not revise at all or simply added disconnected ideas.

This study investigates how engaging students in critique can promote productive revision of student written explanations. We conducted the study in the context of a Web-based Inquiry Science Environment (WISE) unit on the topic of genetics and simple inheritance at the middle school level. We compare critique activities to having students revisit relevant material and interactive models to gain new ideas. Both strategies promote knowledge integration by encouraging students to look for concepts that are missing from their explanations and incorporate them into their existing ideas. This unit was designed according to the Knowledge Integration (KI) framework, which encourages making valid and coherent connections between scientific concepts as well as using evidence and reasoning (Linn and Eylon, 2011). This framework elicits students’ prior knowledge in order to build on their ideas, and promotes adding and distinguishing ideas, and finally reflecting on newly constructed knowledge (Linn and Eylon, 2006). These steps make this framework ideal for supporting
students in revising their scientific ideas. Supporting students through challenging practices, such as critique and revision, can be difficult in the context of new and demanding disciplinary content (Scheuer et al. 2009); technology in the WISE platform is ideal for supporting these two tasks simultaneously.

Based upon the NGSS practices and a review of the literature, we decided to test the benefit of critique for encouraging students to make productive revisions to their explanations and arguments for several reasons. Critique in this context is a detailed analysis and assessment of a claim or theory; it is necessary for the process of evaluating scientific information and evidence, as well as constructing and revising explanations. Argument-based interventions have become popular, given its propensity to foster scientific literacy (Cavagnetto, 2010). However, Henderson et al. (2015) purports that argumentation without critique limits opportunities for students to engage in authentic scientific reasoning in the classroom. The construction of knowledge involves a continuous cycle of construction and critique (Ford and Forman, 2006). Critique is not simply an exercise, it is fundamental for epistemic vigilance and critical thinking (Henderson et al., 2015). Written arguments and explanations depend heavily on content knowledge, but explicitly supporting students in skills such as critique has been shown to increase the complexity of written explanations despite new and challenging content material (Berland and McNeill, 2010). This has been demonstrated repeatedly in the context of genetics (Jimenez-Aleixandre and Duschl, 1999; Zohar and Nemet, 2001), making our WISE Genetics unit an ideal context for this study. This unit covers content contained in the science standards, while also delving into aspects of genetics pertinent to general scientific literacy. Due to the growing presence of genetics in media and the public interest, developing and continually refining and evaluating one’s knowledge of genetics and the mechanism of inheritance is of increasing importance.

We designed two randomly assigned conditions that student groups participated in to assess the value of critique versus revisiting. The revisit condition reintroduced a relevant interactive model and prompted them to answer new sets of questions designed to elicit new ideas that may not have initially been ascertained from the model. The goal of this condition was to allow students to directly test their explanations after writing them, and was modeled after past guidance used in WISE units that direct students back to relevant material to gain new insights (Donnelly et al., 2015). The critique condition prompted students to explain what was incorrect or missing from several non-normative statements rather than revisiting the interactive model. These non-normative statements were developed from ideas that students generally found to be the most challenging. The goal of this activity was to encourage students to consider flaws in their own reasoning, explicate them, and then incorporate these newly distinguished ideas into their own revisions. The activity was designed to help students unpack the complexity of constructing and revising scientific ideas by focusing explicitly on the practice of critique. Throughout the two-week-long unit, students encountered their assigned activity, critique or revisit (see Table 1 for outline of conditions), while the rest of the unit was identical for all students.

Table 1: Outline of a sample sequence of critique and revisit conditions

<table>
<thead>
<tr>
<th>Critique</th>
<th>Revisit/ Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Essay Prompt</strong>: Explain how you would use a Punnett square to figure out the probability of getting a certain genotype.</td>
<td></td>
</tr>
<tr>
<td><strong>Critique</strong></td>
<td><strong>Revisit</strong></td>
</tr>
<tr>
<td><strong>Example Critique</strong>:</td>
<td></td>
</tr>
<tr>
<td><strong>Student 1</strong>: &quot;Their 4th child will have attached earlobes.&quot;</td>
<td></td>
</tr>
<tr>
<td>Explain how this statement is incorrect or too vague, and how to make it more accurate.</td>
<td>Use the Punnett square model again to answer the questions below. (Model is embedded on the next page, along with the questions)</td>
</tr>
<tr>
<td><strong>Example Question</strong>: When both parents have the genotype EE, what is the probability of having a child with attached earlobes? Explain.</td>
<td></td>
</tr>
<tr>
<td><strong>Revise</strong>: Now that you've learned a bit more about Punnett squares and probability, take some time to revise or improve your answer to this question from earlier.</td>
<td></td>
</tr>
<tr>
<td>What is a method you would use to calculate probability of getting a certain genotype using a Punnett square? (Students’ original responses are imported automatically)</td>
<td></td>
</tr>
</tbody>
</table>

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Methods

Participants and procedures
Three teachers from two middle schools participated in this study, with a total of 13 classes of 8th grade students (372 students, 198 student workgroups). Teacher 1 taught 4 classes (120 students) at the first school (49% non-white, 32% free/reduced lunch, 7% ELL). Teachers 2 and 3 taught at the second school (62% non-white, 22% free/reduced lunch, 12% ELL). Teacher 2 taught 4 classes (111 students), and Teacher 3 taught 5 classes (141 students). Students completed the 8 day Genetics WISE unit during 50 minute class periods. Students worked in collaborative workgroups assigned by their teachers, mostly pairs with a few students working individually or in groups of 3. Students completed the pretest one day before beginning the unit, and the posttest one day after completing the unit. Both pre and posttest were completed individually. Of the total students, 315 completed both the pre and posttest, as well as (most of) the Genetics unit. Workgroups were randomly assigned to one of the two conditions (critique or revisit) by the computer based on their WISE Workgroup ID.

Curricular materials
This study builds on a Web-based Inquiry Science Environment (WISE) unit on genetics and simple inheritance. The unit features “critique” and “revisit” activities. It is framed around 4 essential questions related to genetics: (a) Why do we look the way we do? (b) How can we predict disease? (c) How do mutations affect DNA? (d) How do we control our world with genetics? To address these essential questions, it is important to understand both the mechanism of simple inheritance and that inheritance is rarely simple. This unit does this by employing manipulatable computer models and various interactive question types to help students understand the complexity of genetics while simplifying situations into solvable problems. Throughout the unit, learning goals include independent assortment of alleles, dominance and recessivity, probability of inheriting certain traits depending on parental genotypes, tracking of alleles through several generations using a pedigree, the relationship of DNA to phenotypic expression, and how the environment and human influence leads to change in genetic expression and inheritance. The WISE platform is able to track and save student work from various assessments embedded throughout the unit.

The unit features an interactive punnett square model to help students see the effects of allele combinations on specific phenotypes (Figure 1). It also includes drag and drop questions to help students sort evidence and receive immediate feedback, and interactive graphing tools to allow students to construct visualizations of data illustrating connections between different genotype crosses. Activities were added that focus on genetic modification, both through artificial selection and engineering, as well as common mutations and their effects.

![Interactive Punnett Square](image)

**Figure 1.** Screenshots of the interactive Punnett Square model; students drag different alleles to populate the boxes and test different combinations.

Assessments
The pretest and posttest were used as measures of student knowledge integration, looking at students’ prior knowledge and relative improvement. Items generally asked students for a written explanation that required
synthesis of several genetics concepts. For example, one pretest question (SiblingsPrePost) prompted: “Siblings look similar, but not exactly the same unless they are identical twins. If they inherited their DNA from the same parents, why don’t siblings look exactly the same? Explain.” A critique question was also included on the pre and posttest: Students were given a completed punnett square showing two parents heterozygous for brown/blue eyes and were asked to predict the probability of having a child with blue eyes. The follow up critique question (CritPrePost) prompted: “Another student said: ‘From the Punnett square, you can tell that the couple’s 4th child will have blue eyes.’ Do you agree or disagree with this statement? Explain.”

We scored students’ initial and revised explanations using KI rubrics to measure the value of critique versus revisit guidance. Specifically, we looked at the types of revisions students made on two embedded KI synthesis essay questions. The first question was identical to the first pre/post question regarding the mechanism of inheritance: Why do siblings from the same parents look similar but not exactly the same? (Siblings). The second question focused on the use of a punnett square to determine the probability of getting a certain genotype in various cases (PunnettSquare): “What is a method you would use to calculate probability of getting a certain genotype using a Punnett square?”

Analysis approach
Student essay responses on the pre and posttest, as well as embedded essay items, were scored using a 5-point Knowledge Integration (KI) scale (See Table 2 for sample rubric). KI scoring is designed to reward students for making connections between ideas, thereby integrating new information with their prior knowledge (Linn & Eylon, 2011; Liu et al, 2008). The rubric for the Siblings question demonstrates how links are scored (Table 2).

Table 2: KI Rubric Example: Why do siblings from the same parents look similar but not exactly the same?

<table>
<thead>
<tr>
<th>KI Score</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Answer</td>
<td>“I don’t know”</td>
</tr>
<tr>
<td>2</td>
<td>Non-normative/irrelevant: Token mechanism only (&quot;skips a generation&quot;) with no elaboration. Incorrect ideas: “you get different amounts of DNA from each parent”</td>
<td>Because you and your sibling have close genes but they are not the same genes. You inherit similar amounts of the same traits from the same parents at slightly different amounts. Because it's not exactly the same, you look a little different.</td>
</tr>
<tr>
<td>3</td>
<td>Partial link (one correct statement, but not connected to other scientific ideas, or student does not elaborate)</td>
<td>They get different parts of dna from their parents. You get a different set of genes then your sibling.</td>
</tr>
<tr>
<td>4</td>
<td>One full link between normative scientific ideas</td>
<td>Because you get half of your parents DNA but it does not specify which half you will inherit from them. This means that the half that you might get will not be the same that your sibling will get.</td>
</tr>
<tr>
<td>5</td>
<td>At least two full links</td>
<td>Siblings do not look exactly the same because they have slightly different alleles. Each child has a chance of receiving a different allele from its parents than its sibling because of probability.</td>
</tr>
</tbody>
</table>

Qualitative revision codes were also given to the embedded essay revisions based on how a student revised. A code was given for whether students made connected (C) or disconnected (D) revisions. Another code was given for whether students added new (N) ideas in their revision or expanded existing (E) ideas that were already present in their initial response (see Table 3 for examples of each code combination).

Table 3: Rubric and examples for embedded essay revisions (Student revisions underlined)
You would use the method of counting by 25's. Each square is a 25% chance.

You would use the method of counting by quarters. The two letters from each parent would represent a quarter of the genotype and all the quarters combined would show what phenotype would be dominant over the other.

A method I would use is that I would choose the number of squares that have a certain genotype and find out what percent of the squares have that genotype.

A method I would use to calculate the probability of getting a certain genotype is that I would choose the number of squares that have a certain genotype and find out what percent of the squares have that genotype.

You would put the alleles of each parent on the outside of the square and the possible alleles for their children would be in the square.

You can find the dominant and recessive traits to calculate the probability out of four.

The figure shows how many possible genotypes that children can have.

The figure shows how many possible genotypes that children can have. D means dimples and d means no dimples.

## Results

All teachers implemented the unit as planned, during 50 minute class periods over the course of two weeks. Teachers intermittently reminded students of guidelines for productive collaboration with their partners throughout the project.

### Pre/posttest analysis

#### Learning gains

Students began the unit with moderately low genetics knowledge, with an average pretest KI score of 2.47 (SE=0.04). Students in the critique and revisit conditions were at similar levels at the beginning of the unit [Critique: Pre: M=2.50 SE=0.05; Revisit: Pre: M=2.44, SE=0.07].

All students achieved learning gains in genetics by the posttest (SiblingPrePost and CritPrePost) [Post: M=3.19, SE=0.05]. These items were chosen for analysis because they require the synthesis of various genetics concepts. The item SiblingPrePost involves independent assortment of alleles, leading to offspring from the same parents receiving different combinations of alleles, and different genotypes resulting in different phenotypes. The item CritPrePost asks students to explain how the probability of a certain trait can be predicted using a punnett square, and involves a critique component. There was no difference in gain between conditions from pre to posttest on these items [Critique: t(148)=8.42, Post: M=3.13 SE=0.07, p<0.001; Revisit: t(119)=9.80, Post: M=3.28, SE=0.08, p<0.001].

#### Interactions with prior knowledge

A regression analysis revealed an interaction between condition and prior knowledge on pre/post gain. We separated students into high or low prior knowledge groups based on their pretest score on each of the two items; those that scored a 1-2 were considered low, and those that scored 3-5 were considered high prior knowledge. We chose this cutoff because students must include at least one normative scientific idea to achieve a score of 3. Our analysis revealed that students with low prior knowledge scored an estimated average of 0.36 points lower in posttest gain in the critique condition (p<0.05) compared to students with high prior knowledge.
This suggests that high prior knowledge students are more likely to benefit from critique activities in terms of pre/post gains. This may be because success at critique depends on understanding the content material.

Revision on embedded assessments

**Nature of student revisions and learning gains**

Overall we found that critique motivated adding more new ideas to essay revisions than did revisiting relevant material.

For revisions on the *siblings* embedded essay question, students in the *critique* condition added new ideas an estimated 1.84 times as often as students in the *revisit* condition, on average ($z(198)=2.05, p<0.05$). Condition had no effect on KI score gain from initial to revised response for this item. However, students that did revise on this item scored, on average, 0.41 points higher on their revised essay than students who kept their original answer (did not revise) ($t(196)=3.40, p<0.001$). This suggests that students that revised made productive changes to their essays on this item.

For the *PunnettSquare* embedded essay, students in the *critique* condition were 2.74 times as likely, on average, to add new ideas to their revisions compared to students in the *revisit* condition ($z(198)=2.72, p<0.01$). In addition, students in the *critique* condition scored an estimated 0.20 points higher on this item than students in the *revisit* condition from initial to revised response ($t(196)=2.54, p<0.05$). This is likely due to the addition of new relevant science ideas in their revisions.

For both embedded essay questions, we found no effect of condition on students making connected revisions.

**Frequency of revision**

Critique condition students were overall more likely to revise their essays, compared to students in the revisit condition. Students in the *critique* condition were 2.75 times as likely to revise at least one of the two embedded essays as compared to students in the *revisit* condition ($z(198)=3.25, p<0.001$).

Prior knowledge was a significant factor in deciding to revise as well; students with high prior knowledge were 2.28 times as likely to revise at least one of the two embedded essays compared to students with low prior knowledge ($z(195)=2.13, p<0.05$). In order to examine the effect of prior knowledge further, we separated students again into high and low prior knowledge groups. High prior knowledge students in the *critique* condition were 2.22 times as likely to revise at least one of the essays compared to high prior knowledge students in the *revisit* condition ($z(159)=2.26, p<0.05$). Students with low prior knowledge in the *critique* condition were 5.2 times as likely to revise compared to low prior knowledge students in the *revisit* condition ($z(36)=2.27, p<0.05$). Therefore, not only did the *critique* condition promote revision more often, it especially encouraged students with low prior knowledge (an initial essay score of 1 or 2) to revise more often.

**Qualitative critique analysis**

These results suggest that both conditions were effective in promoting student understanding of genetics and simple inheritance from pre to posttest. While low prior knowledge students in the critique condition gained slightly less than high prior knowledge students, the critique activities still encouraged them to revise their responses more often than the revisit condition. For revisions, critique was helpful for adding new scientific ideas, but these ideas were not necessarily connected to their previous responses. We present examples of revisions that students in the critique condition made in order to see how ideas were being added (see Table 4).

Table 4: Revisions from students in the critique condition (revisions in bold)

<table>
<thead>
<tr>
<th>Initial Response</th>
<th>Revision after Critique</th>
</tr>
</thead>
<tbody>
<tr>
<td>His grandparents passed it to his parents, but the disease skipped a generation</td>
<td>His grandparents passed down one recessive and one dominant gene to his parents and then they both gave him their recessive genes so he would have cystic fibrosis.</td>
</tr>
<tr>
<td>Eric inherited cystic fibrosis because his grandparent had it and it could very possibly skip a generation. Eric's mother most likely recieved the dominant gene which was not</td>
<td>Eric inherited cystic fibrosis because his grandparent had it and [ ] it skipped their generation. Eric's mother most likely recieved the dominant gene from her mother and a recessive gene from her father which was hidden and</td>
</tr>
</tbody>
</table>
Eric might have inherited cystic fibrosis by his grandpa's genes skipping over his parents and going straight to him.

We think that siblings look similar to each other but not exactly the same because the traits of the parents are different and each child gets different traits from each parent.

These examples illustrate how students in the critique condition distinguished their ideas. Rather than keeping their vague answers (ex. “each child gets different traits”), they revised to include more specific scientific vocabulary and more nuanced definitions of phenomena (such as “a hetrozygous genotype which could give Eric a 25% chance”). Distinguishing vague ideas to give more detailed scientific explanations is an important part of the KI framework. In this study, the critique condition showed promise in helping students achieve this difficult task.

Conclusions and implications

Revising ideas after encountering new information is an essential scientific literacy skill. This study shows the benefit of critique activities in promoting revision of scientific ideas.

Both conditions in our study were effective in helping all students achieve learning goals in genetics and simple inheritance. Further analysis revealed advantages for critique regarding motivating revision more frequently. This is likely because these students were exposed to flaws in their own thinking by analyzing common incorrect ideas, motivating them to rethink and clarify their original responses. Students in the critique condition also regularly added more new ideas to their essay revisions. This is likely because students had to consider their logic more carefully while critiquing, encouraging them to distinguish between ideas, whereas the models revisited in the other condition did not explicitly encourage students to think about the mechanisms of inheritance, such as that of allele movement. While we hope to create guidance and activities that encourage students to make more integrated revisions, studies have found that even attempts at revision have been shown to result in greater learning gains (Tansomboon et al., 2017). Our critique activity was successful at motivating students to at least attempt to revise their ideas more often, especially those students with low prior knowledge in the content area.

Overall, revisions that students made in this unit were highly relevant, and attempted to add value to their responses in the form of new or better-clarified ideas. This is in distinct contrast to studies, including Bridwell (1980) and Crawford et al. (2008), that found most student revisions were occurring at the word or surface level. This again promotes the practice of critique in encouraging students to revise their scientific ideas rather than just their grammar.

Future studies will look into ways to refine our critique activity to further support students with low prior knowledge in making greater gains. Improvement of our interactive models can also be made to more clearly depict the mechanism of inheritance. We will also investigate further the mechanism for critique motivating students to revise more often, and ways to encourage students to make more connected, integrated revisions of their scientific ideas.

References


Abstract: College readiness, particularly with regard to academic writing, has become central to education policy. While this transition seems a natural point where college professors and secondary teachers might build the mutual understandings that “readiness” suggests, little contact occurs. This tendency is unfortunate, because both groups contribute expertise and insight about students’ writing needs. In order to build grounded knowledge about college writers and transitions, we invited a group of secondary English teachers and college writing instructors to a series of School-University Dialogues. This paper reports on the successes and challenges of this affinity-space-based collaboration, examining its emergent design features over time, as well as evidence of its ability to effect change in teachers’ practices and roles.

Introduction
College readiness, particularly with regard to academic writing, has become central to federal and state-level education policies. National foundations, standards consortia, and state-level education agencies have worked to develop assessments and standards aimed at college and career readiness for all students. Too often, teachers sit on the sidelines of these conversations about college readiness and writing across high school and college levels. Even while the transition between high school and college seems a natural point where college and secondary teachers might collaborate to build the mutual understandings that “readiness” suggests, little contact occurs (Alsup, 2001; Alsup, Bush, Brockman, & Letcher, 2011). When contact does occur, professors and policy-makers often blame secondary teachers for students’ poor writing and preparation (e.g. Goldstein, 2017; Sanoff, 2006).

Secondary teachers, however, possess valuable knowledge about student writing even if the standardized assessments to which their teaching often responds do not line up well with disciplinary models of college writing. Similarly, college professors understand the demands of the extended, theoretical, researched writing that students must complete in college (Fanetti, Bushrow, & DeWeese, 2010). We wondered if bringing representatives of these groups together to build local knowledge about first-year college writers and college transitions would produce more grounded understandings. We invited a group of local English teachers and college writing instructors to a series of School-University Dialogues. Rather than one-time, top-down, expert-led professional development, we designed the Dialogues to respect the expertise of all teachers and to reflect a wide swath of teaching experiences.

Literature review: Models for professional development and learning
In secondary schools, “professional learning communities” (PLCs) have become widespread models for teacher learning (e.g. DuFour, 2007; Vescio, Ross, & Adams, 2008). PLCs, often organized in reaction to traditional, top-down professional development, build teacher learning “communities of practice” (Lave & Wenger, 1991). The results of implementing such structures, however, are diverse and can be equally restrictive for teacher participants (DuFour, 2007; Lock 2006). For instance, many PLCs are school- or team-wide and devised to study a topic considered important by administration leaders. As early as 2001, Grossman, Wineburg, and Woolworth cautioned that “community,” as applied to school structures like classrooms and teacher organizations, “has lost its meaning” (p. 943). These structures, in other words, may or may not be open to equitable participation.

In contrast, learning scientists have embraced the concept of researchers working alongside of practitioners and administrators to design professional development and learning interventions. Rather than a top-down model, Penuel, Roschelle, and Shechtman’s (2007) articulation of co-design positions teachers as centrally important designers of research solutions to instructional problems. Similarly, Spillane, Halverson, & Diamond (2004) have considered principles of distributed leadership in which school leaders actively collaborate in order to accomplish diffused tasks like professional development, instructional (re)design, and reform. Broader concepts of design-based implementation research (Penuel, Fishman, Cheng, & Sabelli, 2011) argue that in order to successfully implement educational interventions (particularly at scale), collaborative work that draws on the practical expertise of researchers, administrators, and practitioners is necessary, even though such negotiation is often challenging due to the disparate experiences and worldviews of various members (see also Penuel, Roschelle, & Shechtman, 2007).

More recently, school districts have paired with research organizations in research-practice partnerships (RPPs) where stakeholders investigate questions, design interventions, and gather data together (Coburn, Penuel,
RPs are often large, grouping diverse colleagues including teachers, administrators, policymakers, and researchers. This work typically examines common features of such models: place-based, long-term inquiry; focus on instructional problems; and the production of findings that might not be possible without diverse partners. RPs bring together multiple values, cultures, and complex collaborations, though research suggests teachers’ input is sometimes marginalized in such partnerships.

Existing research on professional or design partnerships in the area of writing and college readiness among college writing faculty, English education, and secondary teachers, however, has been limited. Formal and informal interaction, collaboration, and research across high schools and colleges is rare, and the divide between college writing programs and secondary teacher education has been clearly documented (Alsup, 2001; Alsup, et al., 2011). When collaborative conversations between high school and college teachers do occur, they are often short-term (Strachan, 2002; Donahue, 2007; Crank, 2012). In other words, in the realm of ELA/writing teaching, such initiatives have so far failed to build extended research-practice partnerships (Coburn, Penuel, & Geil, 2013) that might create sustainable programs that ease high school students’ transitions to college.

The design of dialogues
As we began to plan the first meeting of the School-University Dialogues, one story echoed. Years before we’d even considered starting the discussion, several colleagues had been asked to talk with high school teachers about college preparation. They’d arrived in an auditorium and were appalled when they were seated on the stage, literally above the high school teachers, and, as representatives of “higher education,” asked to answer questions about what schools could do better. Avoiding such situations and metaphors became our guiding principle.

Our model, shown in Figure 1, is explicitly dialogic and focuses on teaching writing across the high school–college divide. We wanted the resulting professional learning to respect the expertise of all of the teachers in the room. As such, though we did want to engage in active exploration and honor the various institutional and sociocultural contexts from which members come, we rejected the idea of working from a communities of practice framework (Lave & Wenger, 1991). Communities of practice are simply too intertwined with individual learning trajectories that develop from novice to expert. Rather, in our network of teachers, everyone was simultaneously an expert teacher in her own institutional context and a novice teacher in the other institutional context, and would likely make both legitimate peripheral moves and central ones depending on the current topic of discussion. We thus turned to Gee’s (2004, 2017) idea of affinity spaces to provide more equitable grounding. This work explicitly reconceptualizes learning as residing in spaces, not in individuals—an important shift towards understanding how the development of expertise is necessarily dispersed and distributed in collaborative networks.

Affinity spaces are sites of informal learning where groups with diverse expertise interact around a “common endeavor” (Gee, 2004, p. 85). We use this concept to place writing teachers’ and researchers’ interests on the same level, to disrupt traditional boundaries, to examine expertise as distributed across people and institutions, and to build “dialogues” around a joint interest. While many scholars have theorized affinity spaces primarily as online entities (e.g. Lammers, Curwood, & Magnifico, 2012), we see this terminology as useful for describing and designing ongoing interactions among otherwise-disconnected teachers. Whereas high school and college writing teachers have historically talked about each others’ institutions in conversations about “college-readiness,” they have rarely connected in person (Strachan, 2002). Conceptualizing this group as an affinity space focuses our activity on cultivating lateral, non-hierarchical discussions across institutions and individuals.

Methods
Rationale and research questions
By conceptualizing Dialogues as an affinity space and viewing professional learning as equitable, collaborative, and distributed, we made a commitment as leaders to revise its structures over time, adjusting to the needs of the group. In other words, we knew that this design would remain emergent and contingent; thus it became important to employ practitioner-based action research methods (e.g. Chiseri-Strater & Sunstein, 2006) to capture changes and learning over time. Similar to Cole and Packer’s (2016) study of the 5th Dimension, sustainability was more important to us than maintaining a particular design or structure, and the input of Dialogues members in the ongoing design of the space and our collaborative research has been vital. As such, we cannot document learning in Dialogues merely by describing members’ work in meetings or analyzing the various products and presentations that participants have made over time. Here, we follow the work that Cole and Packer (2016), Curwood (2013), Fields and Kafai (2009), and Lammers (2016) have done to examine the evolution of learning practices, group structures, and overall designs over time. We adapt the analysis of “key moments” in participants’ learning (Halverson & Gibbons, 2009) to the necessary shifts that we made to the design of Dialogues in collaboration with our members, and we ask the following research questions: (1) What evidence do we have that this space mattered to participants’ teaching practices? (2) What evidence do we have that the Dialogues design was able to create new roles, structures, relationships, or knowledge? How do we know that design adaptations were effective?

In asking these questions, we aim to articulate the adaptive design structures of Dialogues and consider when similar “key moments” or key shifts might become necessary in the life of similar groups and partnerships.

Participants
While 22 college professors and high school teachers have participated in Dialogues meetings over the years, here we focus on the 13 members who have sustained participation through all of the group’s phases and have been consistent attendees. (All names are pseudonyms except ours, and we plan to eventually look more closely at members who have ceased participation. They, too, are important in affinity spaces.) The members listed below in Table 1 represent the teams who have developed each of the four current cross-institutional research projects:

Table 1: Teams who have developed each of the four current cross-institutional research projects

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Role</th>
<th>Attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alecia</td>
<td>Co-director of Dialogues, English Teacher Educator</td>
<td>2014-current</td>
</tr>
<tr>
<td>Christina</td>
<td>Co-director of Dialogues, Director of Composition</td>
<td>2014-current</td>
</tr>
<tr>
<td>Kasey</td>
<td>High school English teacher</td>
<td>2014-current</td>
</tr>
<tr>
<td>Marie</td>
<td>High school English teacher</td>
<td>2015-current</td>
</tr>
<tr>
<td>Ellen</td>
<td>High school English teacher</td>
<td>2014-current</td>
</tr>
<tr>
<td>Natalie</td>
<td>High school English teacher</td>
<td>2014-current</td>
</tr>
<tr>
<td>Colleen</td>
<td>High school librarian, at-risk English teacher</td>
<td>2014-current</td>
</tr>
<tr>
<td>Lara</td>
<td>High school ESL teacher</td>
<td>2015-current</td>
</tr>
<tr>
<td>Janet</td>
<td>College composition teacher</td>
<td>2014-7/2017</td>
</tr>
<tr>
<td>Melissa</td>
<td>College composition teacher</td>
<td>2014-current</td>
</tr>
<tr>
<td>Lindsay</td>
<td>College composition teacher, English teacher educator</td>
<td>2014-current</td>
</tr>
<tr>
<td>Sam</td>
<td>College composition teacher, graduate student, project assistant</td>
<td>2015-current</td>
</tr>
<tr>
<td>Caitlin</td>
<td>College ESL composition teacher, graduate student</td>
<td>2015-current</td>
</tr>
</tbody>
</table>

Data
Analyses were conducted using multiple artifacts including: field notes, meeting agendas, meeting transcripts, lpost-meeting debriefs, post-event surveys, and participant-created presentations, chapters, and narratives. For the purposes of this analysis, we were interested in macro-level shifts and structures of Dialogues, and how we adapted the activity over time to sustain participation. We engaged in open-ended thematic analysis (e.g. Boyatzis, 1998) of observational data and field notes on Dialogues meetings, as well as the artifacts listed above. From this analysis, three “key moments” where reorganizations of activity became necessary to respond to members learning and research interests emerged. These phases describe macro-level evolutions over time, whereas we plan to engage in further micro-level analyses in the future to further tease out these themes and findings.

Findings
The findings we present here focus first on the long narrative arc and macro-level results of this partnership. To provide context for readers, we first show the overall progression of “common endeavors” in which we have
engaged, and how members of the partnership have used their participation in the collaboration to begin projects in their own classrooms and school buildings. We then analyze three “key moments,” or phases, in the design of Dialogues, to show how we made design changes to respond to the interests and the needs of the participants.

The overall picture: Building common and research-driven endeavors

Our first agenda included questions to foster a collaborative, distributed discussion: “What do we share? What are common concerns? What are some experiences/ideas about writing that we all value as writing teachers? What are the questions that are still on the table?” (April, 2014). We wanted every teacher’s expertise to be valued.

In the participants’ reactions and field notes from this initial meeting, we learned that everyone wanted to keep talking. One high school teacher noted surprise: “I assumed it would be… more of a lecture from the college profs. This was so much more than what I expected.” Another high school teacher asked “could we hear from current [college] students at some point?” A college teacher noted that she was thinking about “how we have the same challenges across the board… and so much to learn from one another” about teaching writing. In the April, 2014 meeting, we began a list of topics for future discussions, centering ideas for learning from each other.

Beginning in October, 2014, we designed a system for high school teachers and college professors to learn from each other: Over two meetings, we brainstormed research topics and questions about writing teaching. Then, as leaders, we created a “speed dating” activity, asking participants to rotate to a variety of topics and discuss which ones they were interested in taking forward into a larger project. Topics included “revision and editing,” “creating motivation to write,” “workshop writing or peer conferencing,” and a space for further ideas (October 2014). By Spring 2015, four topic groups of high school and college teachers had emerged and coalesced:

1. **Revision** (two high school teachers, one Composition instructor, Alecia)
2. **Second-language writers** (one high school teacher, one ESL Composition instructor, Christina)
3. **Students’ attitudes towards research** (one high school teacher, one Composition instructor, one Composition graduate student and instructor)
4. **Digital and multimodal writing** (two high school teachers, one Composition instructor)

During the next two years, members of these research collaborations worked together to visit each other’s classrooms, design action research studies, collect data (including surveys, interviews, and artifacts), analyze these data, and present this work in public, first at a University-level colloquium and later at the National Convention of Teachers of English (NCTE) conference. All four of these initial teams (representing 13 participants altogether, including Alecia and Christina) successfully completed cross-institutional, action research studies. Each group has since completed a full draft of a chapter detailing these findings, and together, we are writing a book proposal to highlight the Dialogues partnership. In the following sections, we detail the phases of the partnership, showing the deliberate and emergent design choices and the ways in which participants responded to evolutions over time.

Phase 1: Brokering access and building curiosity through visceral experience

Dialogues began with building curiosity and brokering access to a range of students and teaching experiences. Bringing college professors and secondary teachers together for lunch and conversation was the centerpiece of this phase, but from the beginning, we wanted to open the institutional doors. At first, we used Dialogues meetings to host panels on college transitions and writing with first-year college students and experienced professionals. In each meeting, we included time for open discussions, for listening to a variety of experiences, and for considering teaching and learning practices across the settings. This curiosity building became our first common endeavor.

Brokering access to students

Field notes and transcripts demonstrate that participants used the cross-institutional conversations to see and think beyond their own settings. In this excerpt from December, 2014, high school teachers asked questions of first-year college students to project forward and understand the writing preparation that their own students need, and college professors considered how to tease out and understand their students’ prior knowledge from high schools:

_**Janet:**_ We try to do a questionnaire at the beginning of [Composition] to try to learn where students are coming from with writing. What are the best questions to ask [students] about their writing background?

_**Student 1:**_ What was the most meaningful writing assignment you did in HS? And why? What was the least valuable writing assignment you did in HS?

_**Student 2:**_ Those are good. What kinds of writing make you feel comfortable or uncomfortable? What do you want to learn about writing?
Ellen: What do you wish your HS teachers would have taught you?

Student 3: Revision. I only did one paper in HS where there were revisions.

Student 2: Talking about writing. More discussion about why are you writing what you’re writing.

(12/12/2014 Field Notes)

Because the first year students had been high school students recently, conversations with them made the college transition—and a number of elements that are typically obscured from college professors’ and high school teachers’ vision—very tangible. Such experiences helped to motivate the necessity of cross-institutional learning.

**Brokering access to classrooms across settings**

In addition to building curiosity, direct social contact allowed us to broker access to members’ classrooms and students to extend the discussion. We opened up university Composition classrooms to Dialogues secondary teachers, and we encouraged secondary teachers to likewise welcome Dialogues professors. To normalize these visits, we visited classrooms ourselves when invited. Long before we planned research projects, these cross-institutional visits enabled learning about college and secondary writing with observation and visceral experience.

For example, Sam, a graduate student and Composition instructor, reflected on differences across settings and how “being back in a high school after a decade or so makes everything feel foreign to me” (Sam, narrative). Two ESL teachers, one secondary and one college, learned about the deep differences in their students and settings by visiting each others’ classrooms, and subsequently decided to introduce their students to each other:

Lara’s students were in her classroom for one period each day, but for the rest of the day, they… interacted with mainstream students […] Many had been in the U.S. for enough time and with enough purpose to feel that this country was their home. […] In my classroom (Intensive English), the students were only enrolled in English language classes […] They identified as citizens of their home countries and temporary residents of the U.S. (Caitlin, narrative).

Overall, in-person access to multiple teaching settings and practices effected curiosity. In these initial meetings and classroom visits, Dialogues participants began to think across each others’ settings, and to articulate ideas about their writing students. Their expertise as writing teachers, and as teacher-learners, began to grow as they realized how much their institution’s norms and practices colored the ways in which they understood teaching.

**Phase 2: Building research questions and doing action research**

In Phase 2 of Dialogues, we began to encourage all of the members to follow their emerging interests and questions in order to craft small cross-institutional action research projects. Rather than considering answers through open discussions, we settled on articulating honest questions and active areas of interest and inquiry in the fields of Composition and English Education. These questions began to lead into research.

**Cross-institutional action research: Opportunities and tensions**

Initially, in October 2014, we “speed dated” during a meeting as a way to articulate interests and surface questions. As questions coalesced around several topics, we suggested a new common endeavor—cross-institutional research—to continue learning from each other and move our work forward. We wrote an internal grant to fund Dialogues meetings and a local research colloquium, and hoped that our intuition about research was correct. We took up teacher research in our April, 2015 Dialogues meeting with a short writing prompt: “[T]hink about what you know. Think about things that bother you. Think about things that work for you. Think about changes you’d like to make to your own practice… or base it on the observation you did this morning…” (4/3/2015 Field Notes).

Field notes and transcripts show that these discussions built curiosity around research, which Alecia and Christina led by offering practitioner-friendly texts (e.g. Chiseri-Strater & Sunstein, 2006) and sharing our own research projects, methods, and journeys. In subsequent meetings, we included time for research groups to meet, asked secondary teachers to share their Masters-level qualitative projects (a requirement at our university), and solicited experiences with IRBs and methods from college professors and graduate students.

From Fall 2015 through Summer 2016, Dialogues teams developed questions, designed research, and collected data. Teachers at both levels consulted with us as they identified, tried, and adopted a variety of research practices including observations, surveys, interviews, and artifact analyses. This process was rarely straightforward, however. College and high school teachers are busy, and everyone struggled with finding time to visit each others’ classrooms. Ellen, a high school teacher, experienced this tension acutely. She was deeply committed to her group’s work on digital and multimodal writing, but her family’s health and responsibilities at
school forced her to miss two Dialogues meetings and delay active data collection. She confessed to Christina that she was “nervous” to attend because she felt that “she no longer had a role to play, and she’d let the group down” (5/13/2016 Debrief Memo). She did choose to attend the meeting, though, and her presence enabled her to reconnect with her group and pull the project towards successful completion. Ellen’s story, along with numerous other moments of guilt and difficulty (from leaders and participants alike), suggests the challenge of sustaining a space in which all participants play central roles and bring vital expertise to the discussions.

Reflections on cross-institutional action research: Changes in teaching practice
Looking beyond participants’ research experiences, their reflections reveal that they began to think differently about teaching practices as a result of their research. Marie noted that her group’s revision study helped her adopt colleagues’ practices “I use the revision activities my group came up with in my teaching now. I intend to explore the possibilities of digital essays, which I learned about from [another group]” (Marie, 10/12/2016 Survey).

Similarly, Janet, a college instructor, shifted the way in which she introduced the research paper in her first-year writing class in response to her group’s interviews with students about research practices and techniques:

I realized that while I encouraged inquiry, I didn’t include safeguards in my assignments […] I began sharing results from our team’s transfer studies with my classes: ‘If you like your project,’ I would say, ‘you’re not only more likely to do well on your paper, but to remember it. Research demonstrates it. If you don’t like your research question, switch it now’ (Janet, narrative).

Overall, designing action research had far-reaching consequences. Dialogues participants evaluated and applied widely accepted, professional tools of qualitative research. They learned about research ethics, submitted IRB proposals, developed data collection and analytical methods, negotiated cross-institutional research, and interacted with students from multiple institutions in person and through research artifacts. These experiences led them to reflect on their work in complex ways, building confidence in each others’ practices and their own conclusions.

Phase 3: Becoming writers and presenters for a broad audience
In May 2016, the research teams had persevered through challenges to plan and execute their projects, and we knew from one-on-one conversations that many members were worried about their progress. We decided, instead of dwelling on delays, to celebrate the team, as well as the recent funding of our local colloquium grant and our roundtable symposium acceptance to the NCTE conference. We brought cake, decorations, and Dialogues t-shirts to the meeting; asked everyone to share their plans or progress; took stock of challenges and what we’d learned; and began to consider how to address these local and national audiences. We reasoned that in order to continue to develop members’ identities as researchers and developing experts in their topic areas (particularly after difficult winter logistics), Dialogues members needed to shift towards, and celebrate, this emerging common endeavor.

External audience as professional validation
An external audience proved important in Dialogues members’ confidence and identity as researchers. After our September, 2016 local research colloquium, we surveyed the group about presenting to colleagues, mentors, and administrators, all of whom had been invited. Many seemed surprised by the interest, including Lindsay, a college instructor: “I enjoyed seeing the big turnout, realizing that people are interested in our research” (9/2016 Survey). Ellen noted that she was “glad” she hadn’t walked away after the winter’s setbacks: “The audience was receptive [and] the questions they asked were helpful in giving us ideas as to where to go from here” (9/2016 Survey).

Exciting, too, were members’ positive responses to each others’ presentations, which most had experienced in final form for the first time at the colloquium. Lara, for instance, noted that “it was great to share research [and] methodologies and learn from colleagues from multiple levels of education as well as different areas among the state” (9/2016 Survey). While we knew that all of the teachers enjoyed socializing at Dialogues meetings, presenting as professionals increased their respect for each other, too. As Janet put it, “[I want] to take more opportunities to learn from my high school peers… The others’ presentations reminded me of how much more I can learn from them” (9/2016 Survey). This mutual professional respect only got stronger when we reprised our research findings in an NCTE symposium, and several members told us afterwards that they very much wanted to write chapters for a book about our findings and experiences (now in progress).

Writing as real practice and as empathy
We suspected that Dialogues members would see themselves differently as a result of conducting research, writing and giving presentations, and composing book chapters. We didn’t anticipate that members would share the experience of becoming teacher-researchers and writers with their students. Engaging in teacher-writing provided
ways for college professors and high school teachers to discuss real-world writing practices with students, and to empathize with their composition struggles. Casting back to a Winter, 2017 Dialogues meeting where we began to draft reflective narratives, Kasey remembered her excitement at Alecia’s decision to include mentor texts in our writing. She recalled bursting into her classroom the next day, saying “‘You’ll never believe what happened yesterday!’ [...] I couldn’t wait to show [my students] that real people use mentor texts...” (Kasey, narrative).

After the writing retreat that we hosted in August 2017, in preparation for assembling our now-in-process book manuscript, we asked members to consider whether they would tell their students about their experiences. The responses described several helpful practices to student writers, including Caitlin’s suggestion to “create a place where we can focus on our task and leave other concerns out of that space” (8/2017 Survey). Several teachers, including Lindsay, Marie, and Kasey, who worked together on their research chapter, spoke to the importance of collaboration and “working with a writing group to help motivate you” (Kasey, 8/2017 Survey). Colleen spoke directly to empathy with students for whom writing doesn’t come easily: “It really helps them to know that learning never stops and that everyone struggles with written expression” (Colleen, 8/2017 Survey).

**Discussion and significance**

Overall, the Dialogues have been successful: they have led to partnerships among high school teachers and college professors, partnerships among four secondary schools and our university, local cross-institutional knowledge about college transitions and college readiness in English Language Arts, and the generation of research-based findings about student writing and college readiness that have been presented in local and national venues.

Learning Sciences literature notes that context and perspective are critical features of instructional situations. Penuel, Roschelle, and Shechtman’s (2007) co-design suggests teachers should be active partners in educational research design, while Spillane, Halverson and Diamond’s (2004) work shows that school leaders benefit from working with a network of partners to implement change. Dialogues shows us that these findings are not confined to situations where instructional reform or new design are being developed; rather, the need for respecting context and noting perspective extends to the ordinary practice of fields like writing and college readiness. In short, the difficulties of preparing students look very different for high school teachers and college composition instructors. Neither of these views are correct; rather, each is incomplete. They inform each other.

A space like Dialogues—one that deliberately draws on the expertise of teachers across institutions and levels—reveals this partiality clearly, and it has encouraged members to visit each others’ spaces and learn from each others’ students and findings. When college professors like Janet and secondary teachers like Marie discuss the ways in which they have revised their classroom practices in response to their own research, it becomes easy to understand how Coburn, Penuel, and Geil’s (2013) conception of a research practice *partnership* creates real change in educational institutions. When we enable teachers to work together and learn from each other, students and colleagues at both levels benefit. High school students see their teachers’ cross-institutional expertise as they begin applying to college. First year college students get the benefit of a professor who understands that their prior knowledge of high school writing is critical to their future success. One limitation here is that we are not (yet) aware of students who came through the high school classes of a Dialogues member into first-year writing at our university, but we are eager to learn about how these perceived benefits to students play out.

Along with this broadened view of student writers during college transitions, Dialogues has enabled new writerly roles for teachers. Over time, and through research design and writing experiences, college professors and high school teachers have begun to talk about themselves as not just teachers, but actively working researchers and writers who have observed a range of learning settings. In their research groups, Dialogues teachers have considered not only data that they’ve collected, but how their teaching practices might respond. Some groups have even extended their work into bringing their students into dialogue (in the case of Lara and Caitlin’s ESL students). This attention to, and empathy for, students’ experiences as writers helps teachers tune into the communicative—not just evaluative—nature of writing, and may help students write for real settings beyond the classroom walls.

In short, while changeable and contingent, the emergent nature of this design has enabled us to respond to participants’ needs and continually reinvent our Dialogues space to suit the changing needs and phases of the group. In turn, that responsiveness has enabled Dialogues members to follow their interests, adapt their practices, and create new knowledge across institutions about college readiness in the increasingly-central field of writing. If we had initially aimed to create a community of practice (Lave & Wenger, 1991), or a professional learning community (DuFour, 2007) in which we taught secondary teachers and college composition instructors about qualitative research, Dialogues might well have ceased when we reached the end of the initial static design. Instead, the emergent nature of a designed affinity space (Gee, 2004, 2017) has pushed us to teach, listen to, and sustain each other over time. The diverse expertise that has grown through our ongoing conversation is far more diverse, respectful, interesting, and useful to secondary and college educators than we had initially imagined.
References


Power in the Digital Age: A Critical Revision to Productive Disciplinary Engagement (PDE)

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Tesha Sengupta-Irving, Vanderbilt University, tesha.sengupta-irving@vanderbilt.edu

Abstract: Engle and Conant’s (2002) articulation of productive disciplinary engagement (PDE) highlights problematizing, resources, intellectual authority and accountability as important principles for designing learning environments. Yet, in the years since their writing, the field has advanced significantly in its articulation of power in relation to learning. Students’ disciplinary engagement is not only dependent on how they author, share or convince others of their ideas, but also how such practices invoke issues of power. This suggests a need to revise the framework to engage specifically with what are now readily understood as racialized, classed, and gendered dimensions of learning. In this paper, we bring the issues of power to the forefront to explore the equity potential of the PDE framework. This preliminary move – which centers on the promise of positioning as a principle – is a starting point for the field in working toward a more integrated understanding of power and disciplinary learning.

Introduction

Years of research (National Council of Teachers of Mathematics [NCTM], 2014) have unveiled key features of productive mathematics learning environments that highlight the importance of instructional tasks (Smith & Stein, 1998), meaningful mathematical interactions (Cobb, Yackel, & Wood, 1992), and student authority and accountability (Engle & Conant, 2002). While for many the design of mathematically productive learning environments is the same as designing equitable environments, current research provides compelling evidence of how even well-designed learning environments may still fail to engage non-dominant students at various levels (Esmonde, 2009b; Langer-Osuna, 2011, 2016; Philip, Olivarres-Pasillas, & Rocha, 2016) in classrooms with or without technology. Thus, this analysis problematizes the easy equivalence of productivity and equity by asking: What is mathematically productive about equitable engagement and what is equitable about mathematically productive engagement? In this conceptual review and through analysis of empirical examples from the literature, we seek to determine characteristics of a learning environment that promote both productive and equitable mathematical engagement for students. We begin by focusing on inequities resulting from power-laden micro-interactions that shape and are shaped by larger social structures of power. We use this to inform a reinterpretation of Productive Disciplinary Engagement (PDE) as a framework (Engle & Conant, 2002) of principles for designing effective learning environments. The benefits of PDE have been well documented in various analyses of students’ disciplinary learning (e.g. Barron & Darling-Hammond, 2008; Kumpulainen, 2014; National Research Council, 2009; Schoenfeld, 2013). The PDE framework has also been adapted and appropriated to think about other types of learning environments such as knowledge forums (Zhang, Scardamalia, Reeve, & Messina, 2009), technology-rich classrooms (Rasmussen, Krange, & Ludvigsen, 2003), and online learning courses (e.g., Hickey & Rehak, 2013). We submit, however, that this framework requires elaboration to sufficiently address issues of power that arise in-situ, with or without technology, to better reflect principles of productive disciplinary engagement and equitable engagement. This paper therefore contributes to expanding the use of PDE to address the sociopolitical dimensions of learning (Gutierrez, 2013) necessary for thick democracy (Apple, 2006).

Broadening PDE to PEDE (productive and equitable disciplinary engagement)

First, we briefly describe the PDE framework and its four principles: problematizing, authority, accountability and resources. Then, we summarize the literature on positioning, a construct we will argue as central to articulating principles of productive and equitable disciplinary engagement (PEDE). We then elaborate our broadened framework of PEDE in the context of an empirical example taken from the literature (note: in the interests of space we present only one of multiple empirical examples in the full paper).

PDE framework and its four principles

Engle and Conant (2002), in their framework on productive disciplinary engagement (PDE), defined student engagement as evidenced by contributions to the topic made in coordination with each other rather than
independently as assessed by their alignment of eye gaze, body positioning, and their emotional displays expressing passionate involvement. Engagement is explicitly linked with disciplinary practices: “there is some contact between what students are doing and the issues and practices of a discipline’s discourse” (p. 402). In mathematics, for instance, students are expected to reason and justify their thinking as they solve mathematical tasks, build on each other’s ideas, and revise their explanations in light of new information or critiques (Common Core State Standards Initiative, 2010). As such, it is expected that a productive engagement will not only bring about a change in the learner’s knowledge, but also in her beliefs about disciplinary norms of participation (Yackel & Cobb, 1996).

The PDE framework is also accompanied by four principles, i.e., the features of a learning environment that help foster student engagement: problematizing, authority, accountability and resources. Table 1 (except the last column) explains each of these principles in more detail. Problematizing encourages exploration of mathematical content by students in personally meaningful ways. Student authority allows learners to take active roles in the construction of their knowledge, and accountability ensures that authority to share ideas comes with a justification that is open for critique. Resources, as a principle, function at a different level, as shown, in the sense that it also supports the realization of the other principles.

Table 1: Principles of productive and equitable disciplinary engagement (PEDE) framework

<table>
<thead>
<tr>
<th>Problematizing</th>
<th>Authority</th>
<th>Accountability</th>
<th>5th principle: Social Repositioning</th>
</tr>
</thead>
</table>
| "individual or collective action encouraging disciplinary uncertainties to be taken up by students."
| Giving students active role to act on the disciplinary uncertainties and resolve them. Four kinds of intellectual authority:
| A norm where students are held responsible to justify their contributions in light of other’s ideas and responses.
| Monitor and address students’ positioning of each other, w.r.t. math competence and socially-constructed identities. |

<table>
<thead>
<tr>
<th>Resources (time, tools, artifacts, technology, co-constructed concepts &amp; ideas, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problematizing:</td>
</tr>
<tr>
<td>Learners “authorized” to share what they really think.</td>
</tr>
<tr>
<td>Become recognized as “authors” of those ideas.</td>
</tr>
<tr>
<td>Become “contributors” to the ideas of others.</td>
</tr>
<tr>
<td>Gradually develop into local “authorities” about something.</td>
</tr>
<tr>
<td>Competing claims (how to reason alternatives).</td>
</tr>
<tr>
<td>Authority:</td>
</tr>
<tr>
<td>Inside-out accountability: Learners account for the sense-making of their ideas to oneself.</td>
</tr>
<tr>
<td>Safer peers.</td>
</tr>
<tr>
<td>Challenging peers.</td>
</tr>
<tr>
<td>Internal authorities.</td>
</tr>
<tr>
<td>External authorities.</td>
</tr>
<tr>
<td>Accountability:</td>
</tr>
<tr>
<td>Problems can be about:</td>
</tr>
<tr>
<td>Unknown path (how to begin or proceed).</td>
</tr>
<tr>
<td>Uncertain arguments (how to justify).</td>
</tr>
<tr>
<td>Questionable conclusions (how and what to conclude).</td>
</tr>
<tr>
<td>Competing claims (how to reason alternatives).</td>
</tr>
<tr>
<td>5th principle: Social Repositioning:</td>
</tr>
<tr>
<td>Teachers reposition low-status students using multi-ability and multi-framing treatment:</td>
</tr>
<tr>
<td>Pay explicit attention to the emerging racial and cultural discourses.</td>
</tr>
<tr>
<td>Attend to them rather than ignore them.</td>
</tr>
<tr>
<td>Utilize them to draw connections between the disciplinary concepts and cultural meanings embedded within them.</td>
</tr>
</tbody>
</table>

Research elaborating the PDE framework

Further investigations are continuing to provide explanations and extend definitions of the PDE principles in order to (re)conceptualize them for different types of learning environments and for classrooms with diverse student population. For instance, Venturini and Amade-Escot (2009) highlight that co-constructed micro-ideas by students and teacher during classroom conversations are powerful resources for fostering deeper engagement. Studies also highlight the role of material artefacts, cultural tools, and technology as resources in supporting disciplinary problematizing by diverse students (Furberg & Arneseth, 2009; Krange, 2007). Two technology-rich learning environments were studied by Rasmussen, Krange, and Ludvigsen (2003). They found that the process of achieving joint understanding of tasks and problematizing the use of resources through negotiating authority relations were the main challenges in collaborative work within both the learning environments.
In contrast, several investigations also highlight the issues of equity that arise in spite of the learning environment being well-structured and productive. For example, Philip, Olivares-Pasillas, and Rocha (2016) provided evidence that certain forms of problematizing and resources, like student-generated ideas linking their racial or gendered experiences with mathematical concepts and challenging dominant ways of understanding certain academic concepts are fraught with challenges. Minoritized student contributions may get ignored, contested or positioned as less preferable by peers and teachers, leading to unproductive political controversies and student disengagement. Similarly, Langer-Osuna (2016) found that unbalanced authority structures arise if the intellectual contributions and critiques of non-dominant students are undervalued/subdued by social authority of other students (like popularity of high-status students). We therefore argue for an understanding of the sociocultural and sociopolitical environment and argue the importance of theorizing processes and principles that address both. To this end, we offer the principle of positioning and discuss its theoretical and empirical base in the next section.

Positioning

We see positioning as a discursive process whereby people dynamically create narratives about others and themselves mediated by their own subjective histories in the social world around them (Davies & Harré, 1990). How children position themselves and others, and get positioned with respect to academic competence and socially-constructed identities has been found to be linked to children’s classroom engagement (e.g., Kim & Viesca, 2016; Leiva, 2011; Martin-Beltran, 2013; Wood, 2013). Esmonde (2009a) determined positioning as one of the key four processes that has implications for students’ opportunity to participate and learn. Students positioning on the basis of physical characteristics, abilities, and teacher perceptions also influence the kinds of roles (e.g., explainer vs. listener) and work practices (e.g. individualistic vs. collaborative vs. instructive) students assume or are given during collaborative work (e.g., Esmonde, 2009b; Sawyer, Frey & Brown, 2013; Wood, 2013). Further, studies show girls, racially minoritized students, and emerging multilingual students are often positioned out of ongoing disciplinary discussions by peers and teachers (Bang, Warren, Rosebery, & Medin, 2012; Martin, 2000; Moschovich, 1999; Philip, Olivares-Pasillas, & Rocha, 2016). Further, students irrespective of race or gender may get positioned as slow, incompetent, or learning-disabled based on their prior performances (Ben-yehuda, Lavy, Linchevski, & Sfard, 2015; Lambert, 2015), or as disruptive if their behaviors do not align with what is considered appropriate in the dominant culture (Langer-Osuna, 2016; Wortham, 2004).

The aforementioned studies demonstrate how micro-interactional acts of positioning structure learning. We thus locate the importance of positioning for engagement and propose a consequential fifth principle to the current PDE framework: (Re-)Positioning. We assert that with explicit attention to the mechanisms of positioning we shift PDE toward PEDE toward direct engagement with power.

Re-positioning as the fifth principle

The core idea behind repositioning is that teachers pay explicit attention to the issues of power and positioning arising in the classroom interactions, and reposition students perceived as low-status in order to provide and maintain their access to mathematical discourse and participation (See Table 1, last column). For this, we build on (a) Cohen & Lotan’s (1997, 2004) multi-ability treatment with its specific focus on students’ behaviors, emotions, and expressions, and (b) Hand, Penuel, & Gutierrez’s (2013) multi-framing treatment to emphasize teacher moves. We consider the principle of repositioning as a dance of teacher authority where teacher dynamically moves in and out of different teaching frames to support all students’ needs, to recognize student mathematical discourses as intricately linked to their racial and cultural identities, and publicly emphasize that connecting emotionally or culturally to the topic is a sign of engagement. However, we acknowledge that with the addition of repositioning as a possible principle, there also comes a necessary revision to the original four principles—what are considered as valuable resources, what it means to problematize, become intellectual authority, and be accountable. As such, problematizing is about encouraging disciplinary uncertainties to be taken up by learners as linked to political, cultural and social realities. Learners are authorized to share what they really think about the disciplinary concepts, and also about political, cultural and social issues in relation with those concepts. Learners are responsible to justify their contributions that are open for critique vis-à-vis politically, culturally, and socially lived experiences of people. Culturally-relevant resources are used in conjunction with their political, cultural, and social meanings that are embedded within them to advance disciplinary learning. We will describe these extensions further in the context of an example below. Furthermore, it is also important to ensure that repositioning does not come at the expense of disciplinary rigorouss. We have conceptualized connections between Repositioning and the other principles of PDE in Table 2. The best way to recommend our proposal is to demonstrate it using an example as we do below.
Table 2: Illustrating affordances and limitations of PDE for equity and how repositioning addresses those limitations.

<table>
<thead>
<tr>
<th>PDE Principles</th>
<th>Affordances for Equity</th>
<th>Limitations for Equity</th>
<th>Connections with ‘Repositioning’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problematizing</td>
<td>Allows for personally and culturally meaningful exploration of content.</td>
<td>Challenging ‘dominant ways of knowing’ may lead to racialized controversies.</td>
<td>Repositioning supports uptake of sociopolitical uncertainties (racial, gendered, dominant ways of knowing) using disciplinary concepts and practices.</td>
</tr>
<tr>
<td>Authority</td>
<td>Students are given active role in the construction of their own knowledge.</td>
<td>Utilitarian/dominant beliefs may hinder uptake of controversial/political issues.</td>
<td>Repositioning allows students to discuss controversial racial, gendered and cultural issues using disciplinary concepts and practices.</td>
</tr>
<tr>
<td>Accountability</td>
<td>Accountability ensures that authority to share ideas comes with a justification that is open for critique.</td>
<td>Authority to share and justify one’s ideas is easier than maintaining accountability to critique and revise ideas.</td>
<td>Repositioning ensures disciplinary accountability and accountability to others as students explore sociopolitical uncertainties and controversies.</td>
</tr>
<tr>
<td>Resources</td>
<td>Culturally relevant resources has potential to tap into students’ interest.</td>
<td>Students may fail to connect disciplinary concepts with the racial/cultural meanings embedded within such resources.</td>
<td>Repositioning allows co-constructed micro-ideas on sociopolitical uncertainties and social controversies generated by students to be used as resources for disciplinary exploration.</td>
</tr>
</tbody>
</table>

Example from the literature

After conducting an extensive review of the mathematics and science education literature, we carefully chose a few rich empirical examples to illustrate how PDE principles might get renegotiated in-the-moment as a result of emergent power dynamics, leading to sabotaged work of engaged students and committed teachers. We present here one especially rich example of several examples we chose and re-analyzed. This example (Philip, Olivares-Pasillas, & Rocha, 2016) that we present below was originally analyzed by the authors to draw attention to the racial contestations that occurred in the classroom as a result of the racial context that the activity was embedded in. We repurpose their data to analyze student engagement, with the content and with each other (i.e., peers and teacher), to highlight mechanisms that afforded productive disciplinary engagement but limited student equitable participation.

Philip, Olivares-Pasillas, & Rocha (2016) investigated interactions of students involved in the data visualization activity in an urban high school computer science classroom, which was designed to be culturally relevant for the youth of color. The students were given graphics representing geographical rental patterns of two movies in the Los Angeles area: a popular, mainstream movie “The curious case of Benjamin Button” and a niche, independent, Black movie “Not easily broken”. Using this example, we first identify how it exemplifies productive disciplinary engagement (which was not the original article’s focus, but is important for the current investigation) despite particular students being adversely positioned during classroom interactions. We then show how the use of PEDE would necessarily illuminate for the designers and analyst (researcher, teacher) issues of power that must be mitigated in order for this to also reflect equitable disciplinary engagement.

Events evidencing productive disciplinary engagement

The given activity was open-ended, group-worthy, and culturally relevant. Students immediately became passionately involved in the discussion and had authority to share their ideas while using the given resources (data visualization graphs). For instance, a couple of students recognized the neighborhoods in the given graphs where the first mainstream movie did not do well saying “Because they Black” and “ghetto” (we will refer back to this moment in the next section). William, an African-American student, noticed that in those same neighborhoods, however, the other Black movie did better. He explained that since it is a Black movie, more African-Americans watched it. The teacher publicly recognized William’s hypothesis and labelled him as the author of the idea. At the same time, the teacher also held him accountable for his explanation by offering an alternative explanation of how movies get marketed differently irrespective of race. William, however, felt...
strongly about his black solidarity hypothesis and stuck with it. For our purposes, we notice that William problematized the data visualization from a racial point of view, which was more meaningful to him. Later in the discussion, the teacher and other students pursued the teacher’s marketing explanation more rigorously. At this time, another black female student, Jessica contributed to William’s idea by utilizing the given graphs on other states like Atlanta and Boston to critically justify his argument about black solidarity over marketing.

To summarize, we noticed students’ productive disciplinary engagement through the enactment of PDE principles, namely, problematizing, authority, accountability, and resources. In the next set of episodes, we will highlight those classroom interactions which we cannot possibly explain by just using the PDE framework.

Events leading towards inequitable disciplinary engagement
Philip, Olivares-Pasillas, & Rocha (2016) highlighted in the article how students’ implicit positioning of African-Americans (and thus of William and Jessica) as “ghetto”, arguably a term loaded with negative connotations for Black population, initiated events of “microaggression” in the classroom. Students kept mocking and ridiculing William throughout the lesson using racial slurs. However, William and Jessica continued to support their hypothesis using evidence-based argumentation even when they continued getting mocked by the other students and their argument disregarded by the teacher. The discussion that started on a productive note soon turned into a commotion. It ended with William asking to move on to the next assignment in frustration. William and Jessica remained silent and disengaged for the rest of the session.

Additionally, we note that by pressing for his marketing argument over William’s black solidarity argument, the teacher unwantedly subdued an important act of problematizing, and positioned William’s argument as inconsequential. Teacher’s exclusive focus on the content and predetermined explanations, ostensibly, overpowered the student needs to understand the racial context and its implications for their disciplinary argumentation.

How repositioning might foster productive equitable disciplinary engagement?
We use the revised PEDE framework to argue that if students’ acts of racial positioning were monitored and addressed by the teacher, the important resources in the form of ideas that were being co-constructed in the moment by the students, rather than going unnoticed, could be utilized towards building a productive and equitable learning community.

Utilizing co-constructed political ideas as resources through multi-framing treatment
The racialized context that was arising in the classroom was also in fact allowing students to co-construct important ideas. We highlight two instances where student-generated ideas could be explored (and racial slurs curbed) with the support of the teacher to explicitly reposition the Black students and their contributions as meaningful. First, by shifting to a coaching frame, rather than giving students authority to negotiate or construct racial meanings by themselves, the teacher could curb students’ initial negative positioning of African American students as “ghetto”. Second, by shifting to a cultural frame, the teacher could redirect students’ attention to the racial/ cultural relevance for understanding movie popularity rankings, therefore offering a more connected explanation of the black solidarity and marketing hypotheses. Furthermore, by utilizing student-constructed ideas as resources, the teacher could have also helped other non-black students gain racial understanding and appreciation about what it means to be black. Authors refer to this as fostering “data literacy about race”.

Repositioning students using multi-ability treatment
William productively drew on his cultural knowledge to make sense of the data; William’s expertise illustrated, in authors’ words, his “racial literacy about data”. The teacher could publicly recognize William’s expertise in the class. This could reposition William as an expert, while highlighting to the students other perspectives necessary to competently explore and analyze data. Similarly, by publicly and explicitly recognizing how Jessica employed the data creatively to present evidence in support of the black solidarity argument, she could be repositioned as an expert on employing disciplinary practices of evidence-based argumentation and contributing to other’s ideas. This could present to students other models of successful data exploration, and also help divert their demeaning racial language towards practices aligned with the discipline.

Conclusion
In this paper, we suggested expanding the PDE framework to PEDE (Productive and Equitable Disciplinary Engagement) by positing positioning as one way to press the framework in its engagement with issues of power. Re-positioning describes ways in which researchers can analyze and teachers can address students’ racial/ gendered/ cultural positioning of each other, which often times create imbalances in student participation and
uptake of opportunities. We submit that such a focus forces a more specific articulation of the possibilities and promises of public education (and in particular, mathematics education) as a social and political good that advances democracy. However, we still need more work to demystify social processes embedded within these principles and clarify how they negotiate hierarchies of relational power and positioning. During our presentation, we will also discuss implications of our work for teacher preparation and professional development programs, and for learning environments with or without technology.

References


Design Matters: The Impact of Technology Design on Students’ Inquiry Behaviors

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Abstract: Recent curricular frameworks consider science inquiry as an intertwined set of practices revolving around data, models and theory. This poses major challenges on the design of tools to support science inquiry. We developed a novel hybrid technology for biology classrooms that combines remote laboratories with modeling tools. How to design such systems is of fundamental importance because the design influences students’ learning processes (deJong, Linn & Zacharia, 2013). We examined the impact of the design of the modeling interface on learning, using two designs that differ in the type of visual feedback and the degrees of freedom for exploration. We found that neither of the designs was categorically better; rather, they were conducive to different forms of engagement in the inquiry activity, each offering distinct affordances for learning. This suggests that designers of technology for science inquiry need to be explicit about desired learning goals and forms of engagement.

Keywords: science inquiry, remote laboratories, inquiry strategy, modeling, interactive biology

Introduction

A central goal for science education is to help students become “critical observers” (Hodson, 1986), i.e. participants of scientific conversations that use evidence from real-world data to critically review and evaluate scientific claims. Essential to being a critical observer is the capability to coordinate scientific ideas with real data into evidence-based explanations and arguments (Duschl & Grandy, 2008).

Main attempts to facilitate science learning engage students in practices of science inquiry (Duschl & Grandy, 2008). However, there are many challenges to successfully integrating scientific practices into K-12 classrooms (Abd-El-Khalick et al., 2004; Chinn & Malhotra, 2002). Research has predominantly dealt with these challenges by focusing on scientific practices in isolation (Berland et al., 2016). While these reductive approaches helped students improve in the respective practices (Zimmerman, 2000), they have yet to prove successful in fostering critical observation (Berland et al., 2016; Chinn & Malhotra, 2002). This is not surprising, as coordinating scientific ideas with real data interweaves multiple practices at once. The bifocal modeling framework provides an approach to integrate practices instead of isolating them, by bringing scientific models and data into the same representational space for real-time comparison (Blikstein, 2014).

Inquiry-based learning activities hinge in large parts on the available technologies (Sandoval & Reiser, 2004). We argue that there is a shortage of technologies that facilitate more integrative approaches: Many technologies such as physical laboratories or interactive computer simulations generally focus on experimentation and interaction with the scientific phenomenon (de Jong, Linn, & Zacharia, 2013); they are not yet designed to facilitate more model-based inquiry practices (Blikstein, 2014). Technologies for scientific modeling on the other hand generally lack affordances for experimentation or interaction with real data (see VanLehn (2013)). Thus, if a science teacher wants to engage students in the core practices of coordinating scientific ideas with real data, she has to pick different technologies for each practice, and bring them together through the design of the learning activity. This is challenging given the range of logistical requirements, data formats, designs, etc.

A technology can be more conducive to integrative approaches if it provides affordances for various scientific practices within one system, while being easy to use and robust against the constraints of a classroom. In this paper, we present a new technology prototype for science inquiry in biology that integrates scientific models with real-world data into one system, drawing on the bifocal modeling framework. Biology is particularly interesting for such hybrid systems for the following reasons: First, recent technological developments gave rise to interactive biology, i.e. interaction with real living cells through various stimuli both remotely and in real-time (eg. Kim et al., 2016; Lee et al., 2015); second, biological phenomena are inherently noisy and complex processes that no model can fully account for, which necessitates explicit coordination of data and models.

There are many possible ways to implement such a technology design, using different visualizations, affordances and scaffolds, each of which is conducive to different science learning. Tools for the same scientific phenomena that differ in their affordances emphasize different aspects of the phenomena, are conducive to different ways of reasoning about them, and hence influence how students learn with them (Bumbacher et al.,...
It is not well understood though what dimensions of a technology design impact learning processes, and how (Bumbacher et al., 2017). Furthermore, there are multiple ways by which the effectiveness of a technology design can be assessed. A common approach is to look at learning outcomes alone. Other approaches incorporate measures of the inquiry process, for example of students’ experimentations or parameter exploration strategies (e.g. Bumbacher et al., 2017). A third possibility is to assess the cognitively alignment of actual and intended technology use, i.e. the similarity of actual and intended cognitive and discursive processes of students as they work with the technology (Sandoval & Reiser, 2004). The choice of measurement can affect the evaluation of effectiveness of the technology (e.g. Bumbacher et al., 2017): For example, based on learning outcomes alone, one might conclude that affordance of quick variable manipulations is beneficial for learning (learners get exposed to more examples in the same amount of time; Zacharla & de Jong (2014)); however, examination of inquiry processes might suggest the opposite (quick manipulation can encourage learners to carry out play-like, undeliberated interactions; Renken & Nunez (2013)).

We employed our technology in middle school biology classrooms, using an inquiry unit that engages students in experimentation with the remote lab, and in modeling. In this paper, we will only talk about the modeling part, in order to address the question of how the design of technology impacts learning. We designed two different versions of the modeling interface and analyzed their influence on learning outcomes, exploration strategies and cognitive alignment.

**Description of technology**

We developed an interactive hybrid system that integrates a modeling interface with a remote laboratory, where students interact remotely with real living cells. The phenomenon under study is the phototactic behavior of *Euglena gracilis*, i.e. their movement in response to light stimuli. The remote lab is detailed in (Hossain et al., 2016) and was also incorporated in a MOOC (Hossain et al. 2017), but in short: Students can remotely control in real-time four different LEDs placed around the edge of the microscope plate holding the Euglena. Euglena sense light via a single photoreceptor, that can sample the entire space as the microorganism spins about its own body axis. The net result is that that the creature swims away from the LED light (negative phototaxis). This behavior is noticeable within a few seconds already, which makes it particularly well-suited for inquiry activities in class.

We implemented a model of the microorganism with only three parameters: a) *Speed* of the forward movement; b) *Coupling* – the direction and strength of the reaction to light; positive coupling leads to movement towards the light and negative coupling to movement away from the light; the magnitude determines the strength of coupling; c) *Roll* – the rotational speed about the body axis. In the model exploration interface (Figure 1), each of the three parameters is controlled by a slider. The parameters can take on only a discrete set of values. The model will never perfectly match the behavior of the real microorganism; there is no unique solution, but a subset of six optimal parameter values. The coupling parameter ranges from positive to negative values, which allows students to create both positive and negative phototaxis. Once the parameters have been configured, the system visualizes one three-dimensional model of the microorganism and simulates its behavior in reaction to the light sequence it is exposed to. Each simulation lasts about 30 seconds. Students can run as many simulations as they want.

**Experimental conditions and research question**

We created two designs of the model exploration interface that differed in the types of interactive affordances and types of feedback of the model exploration interface (Figure 1): The *Simultaneous (SIM)* condition is very much in line with the traditional bifocal modeling framework; students can see both model and real organism move at the same time, being exposed to the same, pre-programmed light sequence. The real data consisted of a recording of a real experiment with the given sequence of light directions. The *Light (LIGHT)* condition is more aligned with the remote lab interface in terms of how the light sequences were generated: Students could change in real-time the direction of light (by means of the joystick) during the simulation. However, they could only see the model organism and not the real one. Thus, students in the LIGHT condition could not directly compare the model and the real organisms, but in turn do real-time changes to the light intensity and direction for the model.

In sum, the SIM condition has a smaller degree of freedom of manipulation (parameters-only) than the LIGHT condition (light+parameter), and a richer type of visual feedback (model+real vs model-only). In this paper, we examine how the two conditions compare in terms of students’ (i) learning outcomes, (ii) parameter exploration strategies and (iii) cognitive engagement with the behavior of model and real Euglena.

The rationale for these two designs was to create designs that were likely to elicit differences in inquiry processes, to get a better sense of the variation in inquiry processes and their interplay with the technology design. It was not to explore the impact of specific design dimensions – degrees of freedom or visual feedback – on student’ inquiry processes and learning. Such a targeted study would be premature for this novel technology that
has not been implemented in a classroom before. We selected two design dimensions that play an important role in how technology facilitates inquiry-based learning (Ainsworth & VanLabeke, 2004; Renken & Nunez, 2013) and that we could manipulate in our technology.

By keeping the light sequence constant, and providing a direct juxtaposition of real and model, we expected the SIM condition to foster more reflection on the interplay between model parameters and model behavior; we hypothesized that this would get manifested in two ways: 1. a more systematic exploration of parameters; 2. more comparisons the behaviors of model and real organisms. In contrast, by focusing on the model only, but introducing the degree of freedom of light, we expected students in the LIGHT condition to engage more in reflection on the dynamics of the model behavior, and on the interaction of light and model structure in the model behavior.

Methods and materials

Student and school sample
The study took place in 7th and 8th grade classes of a private K-12 school in the San Francisco Bay Area. Each class has 50 minutes of lab per week; classes are split in half for the lab session. Over the course of multiple weeks, the researcher team taught 6 sessions of about 8-12 students each, with a total of 59 students. The first two sessions were used to test and adjust the technology and lesson plan. The final study consists of the last four sessions, with 41 students (21 girls, 20 boys). Students worked in groups of 2 to 3, with an overall of 20 groups.

Model exploration activity
In both conditions, the goal of the activity was to discover the mechanism of how Euglena react to light; students were prompted to “understand the three parameters to find out what makes the organism see light from all directions. Find the values for the three different parameters that make the model follow the path of the real organism as closely as possible”. In order to stress the discovery aspect, we labeled only the speed parameter explicitly, and left the other parameters unlabeled so students could come up with their own names for them. We added a traced path of a real organism in reaction to the pre-programmed light sequence of the real data used in the SIM condition (Figure 1). In both conditions, the model organism’s initial position was at the beginning of that path. Students in the SIM condition could directly compare the model to the real organism that followed this path.

Study design and procedure
The four lab sessions were split equally between the two experimental conditions. The teacher guided the class through the lesson, but minimally engaged with the students during the activities. In the first part (10 minutes), the whole class explored the phenomenon with the remote laboratory; the microscope view of the system was projected onto the wall in front of the class, and one student controlled the light while others told this student what to do. In the second part (5 minutes), student groups examined experiment videos to evaluate and eventually confirm the hypothesis that the organisms move away from strong light. This was followed by a teacher-led classroom discussion (10 min) about the possible mechanisms of the organism behavior. Students came up with ideas about i) how the organism sensed the light (e.g., heat, electricity, vision, etc.) and ii) the potential mechanism. The teacher eventually resolved the first question by showing a microscope view of the single eye-like organelle
of the organism. In the third part (~12 minutes), students engaged in the Model Exploration Phase: After the activity, students individually completed the test of learning outcomes (10 min).

**Data collection**

**Assessment:** We assessed learning outcomes by means of a 5-question post-test. We did not give a pre-test because students had not learned about Euglena phototaxis. The light question asked students to infer from a given organism path what light sequence it must have been exposed to. The sequence consists of five direction changes, and every direction was worth 1.0 point. The parameter questions were three questions that provided different scenarios of how a model path differed from a real path and asked students to identify what parameter needed to be changed, and how, in order to align the paths of the model and real organism. Each question was given 0.5 points for a partially correct answer, and 1.0 point for a complete answer. **Interaction logs:** We assessed model exploration strategies based on students’ interaction logs. Every time students ran the simulation, we logged the current parameter configuration. We also recorded any string students entered in the textboxes for the two parameters. Additionally, for the LIGHT condition, we collected the light sequence of a simulation every time it reached the maximal duration of 30 seconds. **Video data:** In order to examine the cognitive engagement in the inquiry activity, we used video and audio recordings of each student group during the Model Exploration Phase, with the camera pointed towards the computer. This gives us a total of 20 videos of about 12 minutes.

**Analysis**

Learning outcomes were analyzed on the individual level, and strategy use and student discussions during the experimentation were analyzed on the group level. We found no significant intra-class correlations (less than 5%) in the analysis of student performance by means of two-level mixed models with students nested in groups. Thus, we employed fixed effects MANOVA and ANOVA models, as well as t-tests.

**Model exploration strategy**

We characterize model exploration strategies by the types of manipulations of any of the three parameters, and the time between manipulations: 1. Manipulations of only one parameter at a time (CTRL); 2. Manipulations of more than one parameter at a time (MIX); 3. Repetitions of preceding parameter configurations (REP); 4. Short experiments (BURST). This characterization builds on previous work on productive exploration strategies (Bumbacher et al., 2017), where we found that short durations between runs (BURST) and confounded parameter manipulations (MIX) were less productive for learning. For each student group, we calculated a 4-dimensional strategy vector with the manipulation types, coding each as percentage of total simulation runs per group. We calculated the proportion of bursts based on the between-manipulation times, as specified in Bumbacher et al. (2017).

**Cognitive engagement with real and model Euglena**

In order to evaluate cognitive engagement with the phenomenon, we extracted from the audio data simple frequency measures of three codes: 1. Reflections on the functionality of the parameter, and on model characteristics; 2. Comparisons between real and model behavior; 3. Comments about the purpose of the task, i.e. matching the model to the given path. We chose those dimensions because they are reflective of the coordination of scientific ideas with data within a simple inquiry task. We chunked each conversation into short segments of 1 – 3 conversation turns, by topic of conversation, and coded each segment as either “Reflection”, “Comparison”, “Path-Matching”, or “Other” (see Table 1 for examples).

<table>
<thead>
<tr>
<th>“Reflection”</th>
<th>Student1: he needs to take longer to see it, smart huh? Cause it is going to take him longer for him to notice that there is light over there. Right?</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Comparison”</td>
<td>Student1: So, I see the regular one (real Euglena), I think it has to be a bit slower</td>
</tr>
<tr>
<td>“Path-Matching”</td>
<td>Student2: Really close, we have the right speed, maybe we should turn the speed up one. Student1: … look, it’s just this last turn, like right around here it starts going off course.</td>
</tr>
</tbody>
</table>

**Results**

**Overall effectiveness of the model exploration activity**

Students across both conditions executed the simulation in average 23.1 times (SD=4.3), and manipulated each parameter in at least about 20% of the experiments. Student groups in general converged on parameter
configurations that enabled them to discover the functionality of all parameters: 12 out of 20 groups found one of the six optimal solutions, while each of the remaining 8 groups had configurations with a negative coupling and a non-zero rotation. There were no differences by condition, \( p > .3 \). Students’ understanding of parameters is further reflected in how the groups named them: They named the coupling parameter “light sensitivity” (8), “reaction” (3) or “attraction” (3) to light; two names were unclear (number of groups in parentheses). They named the roll parameter “rotation / turning of the eye” (6), “rotation speed” (7), “eye sight” (1); two names were unclear. Four groups did not name the parameters.

### Learning outcomes by condition

A MANOVA of the inference question on condition was significant, Wilk’s \( \lambda = 0.80, F(2,28) = 3.4, p = .05 \) (see Table 2). The LIGHT condition was marginally better on the light sequence question than the SIM condition, \( t(39) = -1.8, p = .07, d = 0.6 \). Students in the SIM condition omitted certain light directions, but did not mention wrong directions. The SIM condition performed better on the parameter questions, \( t(29) = 2.2, p = .04, d = 0.8 \). The ten students who did not answer this question were evenly split between the conditions.

### Table 2: Descriptive statistics for the inference questions, normalized by the maximal possible scores

<table>
<thead>
<tr>
<th>Inference Questions</th>
<th>Max</th>
<th>SIM</th>
<th>LIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Light Sequence</td>
<td>5</td>
<td>0.68</td>
<td>0.26</td>
</tr>
<tr>
<td>Parameter Adjustment</td>
<td>3</td>
<td>0.63</td>
<td>0.27</td>
</tr>
</tbody>
</table>

### Model exploration strategies by condition

A MANOVA on the percentages of manipulations of the three parameters reveal a trending difference between conditions, Wilk’s \( \lambda = 0.70, F(3,16) = 2.2, p = .13 \). We clustered the strategy vectors using hierarchical cluster analysis using Ward’s method on the cosine distance between the vectors. We found two well-defined clusters (avg silhouette value = 0.6). These clusters can be characterized as **systematic** and **non-systematic** in terms of model exploration strategies (Figure 2): The systematic cluster had in average a significantly higher CTRL, \( t(18) = 5.1, p < .001, d = 2.3 \), a significantly lower REP, \( t(18) = 5.5, p < .001, d = 2.5 \), and a significantly lower BURST, \( t(18) = 3.1, p < .01, d = 1.4 \). There was no difference in MIX, \( p > .3 \).

Table 3 shows that the majority of SIM groups belong to the systematic cluster, while the majority of LIGHT were in the non-systematic cluster, Fisher’s \( p < .01 \). The clusters differed also in terms of performance on the inference questions, Wilk’s \( \lambda = 0.8, F(2,29) = 2.9, p = .07 \). While there was no difference on the light question, \( p > .5 \), the systematic cluster was significantly better on the parameter questions, \( t(29) = 2.4, p = .02, d = 0.9 \).

### Table 3: Experimental conditions by cluster of exploration strategy

<table>
<thead>
<tr>
<th>Condition</th>
<th>Systematic (n = 10)</th>
<th>Non-Systematic (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIM (n = 11)</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>LIGHT (n = 9)</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

### Impact of light as an additional degree of freedom

Given the goal of matching the model to the real path, we expected LIGHT groups that used light sequences closer to the reference light sequence (SIM group) to perform better. Students generated a total of 32 time sequences that completed a simulation run, with at least 2 runs per group. We found two clusters, using hierarchical clustering with the centroid linkage method on the correlation distances between the light sequences across all LIGHT groups (avg silhouette score = 0.3). Figure 3 shows the average light sequence of each cluster (dashed lines) with the standard deviation bands. An angle of 0 degrees corresponds to light from the right, an angle of 45 degrees to light.
from the top-right, and an angle of -45 degrees to light from the bottom-right, etc. The black line shows the reference light sequence of the SIM condition. The **aligned cluster** (18 sequences) contained light sequences that were in average positively correlated with the reference light ($r=.3$, SD=.4); the **non-aligned cluster** (14 sequences) contained light sequences that were in average negatively correlated with the reference light ($r=-.2$, SD=.4); the difference in correlations was significant, $t(30)=3.8$, $p<.001$, $d=1.4$.

For each LIGHT group, at least 75% of the sequences belonged to the same cluster. Thus, we assigned the groups themselves to the clusters: 4 out of the 9 groups belonged to the non-aligned cluster. Splitting all student groups into aligned cluster, non-aligned cluster, or SIM condition revealed significant differences on the inference questions, Wilk’s $\lambda=0.7$, $F(2,28)=2.9$, $p=.01$ (Figure 4). Post-hoc comparisons between conditions on each question type revealed that the non-aligned cluster performed better on the light question over both the aligned cluster, $t(17)=1.9$, $p=.08$, $d=0.9$, and the SIM condition, $t(28)=2.5$, $p=.02$, $d=1.0$. They performed worse on the parameter questions, compared to both the aligned cluster, $t(12)=-2.2$, $p=.05$, $d=-1.2$, and the SIM condition, $t(20)=-3.5$, $p=.002$, $d=-1.8$.

Cognitive engagement by condition, and impact of visual feedback

While analysis of the quantitative data indicated that the SIM condition was more systematic in the parameter exploration, and hence performed better on the post-test, analysis of the student conversations paints a different picture of students’ engagement in the model exploration: here was no difference between conditions in the frequency of explicit comparisons of model and real Euglena, $t(17)=.5$, $p=.6$ (SIM=1.9, SD=1.5; LIGHT=2.3, SD=2.1). In both conditions, students hardly compared model and real Euglena. Contrary to what we expected, the LIGHT groups reflected significantly more on the model or parameters (LIGHT=12.9, SD=5.3) than the SIM groups (SIM=7.6, SD=2.3), $t(17)=2.9$, $p=.01$. In contrast, students in the SIM condition referred significantly more often to the purple path of the real Euglena, or were engaged in conversations about the match of the model with the real path (SIM= 8.3, SD=7.4) than in the LIGHT condition (LIGHT=3.0, SD=3.4), $W=20.5$, $p=.048$ (Wilcoxon rank sum test due to non-normality of the data).

Discussion and conclusions

We have presented a technology prototype for science inquiry in biology designed to support inquiry-based activities that interweave multiple scientific practices, in line with the bifocal modeling framework. The technology combines a remote biology lab with a model exploration interface that goes beyond physical-only or virtual-only technology approaches. Apart from the feasibility demonstration, a second goal of this paper was to examine potential interplays between the design of technology for science inquiry and how students go about the inquiry activity. We developed two interfaces for model exploration that differed in the degrees of freedom for manipulation and the type of visual feedback provided; Table 4 shows that students engaged in different processes.

**Table 4: Summary of results, broken down by measures of learning and inquiry processes**

<table>
<thead>
<tr>
<th>Measures</th>
<th>Results (SIM=model+real; no light control; LIGHT=model-only; light control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Outcomes</td>
<td>SIM better on parameter questions; LIGHT better on light question.</td>
</tr>
<tr>
<td>Exploration Strategies</td>
<td>SIM more systematic and deliberate in parameter exploration.</td>
</tr>
<tr>
<td>Cognitive Engagement</td>
<td>SIM more focused on matching the path; LIGHT reflected more on model behavior or parameters.</td>
</tr>
</tbody>
</table>
However, the three-pronged approach for measuring students’ learning reveals both strengths and weaknesses in each proposed design when it comes to fostering productive inquiry. Assessment of the relative effectiveness of the interface designs depends on what one considers to be the goals of the activity. We elaborate on this point by means of two pictures that emerge from the analysis:

**Picture 1: The SIM condition was more productive for parameter exploration**

If one considers the learning goal to be about understanding the model parameters by themselves, the SIM interface design seems to be better suited. Students in the SIM condition explored parameters more systematically; they belonged mostly to the cluster of student groups that manipulated more often only one parameter at a time, did less repetitions and spent more time between manipulations. And we showed that students who were more systematic in the parameter exploration performed better on related questions, which is aligned with literature on inquiry strategies in discovery-based activities (Zimmerman, 2000).

We can only speculate why SIM students explored parameters more systematically, because the study design was confounded at the level of design dimensions. However, we think that difference in visual feedback between the conditions had little to no impact on students’ inquiry process, as students in both conditions hardly engaged in explicit comparison of model and real organism. Rather, it seems that the additional light control in the LIGHT condition simply increased the difficulty of the task; LIGHT students had to use the limited amount of time to understand both the light and the model parameters, while the SIM students could focus on only model parameters. Furthermore, the interpretation of parameters hinged on the light sequences students generated; students who generated “good” light sequences performed similarly to the SIM students on the post-test. On the other hand, by keeping the light sequence constant, the SIM interface might have freed up cognitive capacity required to engage in systematic exploration of the parameters.

**Picture 2: The SIM condition played the “matching game”, and not the “inquiry game”**

While the simplified interface of the SIM condition (in terms of reduced degrees of freedom) enabled students to focus more on parameter exploration, they appeared to engage in cognitive processes different from the intended processes of coordinating model with real Euglena. In other words, they played a different *epistemic game* (see Sandoval & Reiser, 2004). Epistemic games are activities that engage people in cognitive and discursive practices involved in making and evaluating knowledge. Students in the SIM condition seemed to play a “matching game”, in which they focused mainly on manipulating parameters to get the model Euglena to match the path of the real Euglena, without engaging in discussions about the parameters or the model. We knew that the model was too simple to ever perfectly match the real path; we hoped that students might have recognized these limitations and discussed about why that might be the case. However, SIM students continuously tried to optimize the match by doing iterative changes to the parameter values, as exemplified in the excerpt in Table 5. We think that the systematic parameter manipulation was a consequence of students playing the “matching game”, rather than a deliberately chosen strategy of inquiry. Thus, what seemed like a productive inquiry behavior based on the interaction and outcome measures alone was less productive in terms of cognitive engagement during the activity.

**Table 5: Excerpt of conversation in the SIM condition reflecting the “matching game”**

| 1. Student2: Watch this. It will be perfect. Turn! | 4. Student1: Alright, you're good, you're good buddy. |
| 2. Student1: Come on, turn. | 5. Student2: You're good. Now, turn... Aahh... |
| 3. Student2: Yes (Euglena goes down). Yes, that's good, it is kind of a bit far, but that's ok. | (Turns too early) |
| 6. Student2: Do -35 (parameter value) |

The LIGHT condition however was showing more reflective discussions on the parameters and the models, which emerged in their struggles to control the model Euglena through the complex interaction of light sequences and parameter configurations. If one considers the learning goal of our inquiry activity to be about reflecting on models and the interaction of models with the environment (light), the sorts of discussions that emerged among the LIGHT students might have provided a more fruitful ground for subsequent learning.

The results of this study have to be interpreted within its limitations: The group-level sample size was small, and some of the missing data could have introduced potential biases. Furthermore, the lesson still represents a rather simplified version of the full bifocal modeling framework; nevertheless, we were able to go beyond experimentation and evaluation by integrating the computer simulation not as a different version of the real lab with different affordances (see de Jong et al., 2013), but as a means of finding model-based explanations for observations made in the real lab.
Interactive biology laboratories provide opportunities for more integrative approaches to science inquiry; but careful attention needs to be given to how the systems are designed. Using a mixed-methods approach, we found that neither of the modeling interface designs was categorically better; rather, they were conducive to different forms of engagement in the inquiry activity, each offering distinct affordances for learning. However, neither interface design lend itself to the coordination of model and real Euglena, which is ultimately what we want to support. Future research will have to focus on developing designs that are more likely to achieve this goal.

References

Acknowledgements
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Engineering Discourse Development in an Informal Youth-Driven Maker Club

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Abstract: This paper investigates opportunities to learn engineering design discourse within maker activities. Drawing from a study of youth participation in an informal, out-of-school, youth-driven maker club this study investigates processes of discourse use and learning. This study contributes to the ongoing conversation in the learning sciences about how youth gain access to valued disciplinary discourses. The authors employ Sfard’s (2008) commognitive framework to conduct a detailed examination of mentor-mentee interactions in order to uncover mechanisms of disciplinary learning. Findings suggest that youth can pick up aspects of discourse relatively quickly, but that negotiating discourses in real time can be challenging for both youth and mentors.

Introduction
There is a broad consensus that more work is needed to uncover the processes by which young people become interested and skilled in STEM fields. In this study, we report results from a study of youth participation in an informal, youth-driven maker club as a setting for engineering design learning. We view learning as a development of a specialized discourse (Sfard, 2008). While in formal learning setting like schools, one role of the curriculum and teachers is to introduce students to disciplinary discourse in explicit ways, in informal settings like the one examined in this study, these processes are usually implicit. The goal of this study is to contribute to the body of research that explores how disciplinary discourse develops in interest-driven youth-led learning environments.

A growing body of literature examines maker spaces and maker activities as contexts for STEM learning. One line of work examines the particular practices of making, and the opportunities that youth and other participants have to engage in those practices. Gravel, et al. (2015) found that experienced makers identify, organize, and integrate information across sources. Blikstein (2013) reports that youth who worked on projects using digital fabrication techniques received an opportunity to explore STEM concepts like electricity, magnetism and motion. Martin and Dixon (2016) describe opportunities to engage in frequent dialogic interaction around unexpected events within a community that values conceptual understanding – practices believed to foster the development of adaptive expertise. Halverson, et al. (2014) show the importance of the community within maker spaces, demonstrating the fluidity of mentoring in such spaces and its impact on just-in-time learning.

Others have looked for evidence of change over time. Fields and King (2014) found that college-age women in a craft technologies course changed their view of themselves and their ability to be designers of technology. Blikstein (2013) showed that youth in his studies showed increased interest in STEM fields. Bevan, et al. (2015) found that question development and moments of struggle were key learning indicators during tinkering. Dixon and Martin (2017) found that youth with more maker experience showed greater and more dynamic interactions within the community. Calabrese Barton, Tan, and Greenberg (2016) show how maker spaces can be important sites of identity development.

While the number of studies that investigate the potential of making and tinkering to STEM learning is growing, there is a need for additional work examining the mechanisms of learning in making and the way disciplinary discourse develops in these settings. The goal of this study is to contribute to this body of literature on STEM learning and making by focusing on practices of engineering design. From a disciplinary perspective, one important routine within engineering design is the design process (Dym et al., 2005). There are many different versions of the design process, but all share a commitment to iterative design: as the project moves forward, participants gain new insights that feed back to earlier stages, which may direct a new path for the project. For any specific stage in the process there are norms of what counts as acceptable contribution in that stage. To examine how young makers learn in an open-ended out-of-school learning environment, we closely track changes in engineering design discourse that take place during mentor-mentee interactions within work sessions of youth-driven maker projects.

Theoretical framework
This work is guided by sociocultural theory of learning, looking closely at the relationship between culture and learning as a social activity, where knowledge is built within a community of practice (Lave & Wenger, 1991). Our research uses Sfard’s (2008) commognition framework, which views thinking as individualization of interpersonal communication and learning as change in learner’s discourse towards becoming a participant in a community with a certain type of discourse. Discourse, according to Sfard, is a form of communication that defines a community and was developed along the history of a profession to answer certain communicational needs within that community. Each discourse is characterized by four features: (1) words and the way they are used as defined by the discursive community; (2) visual mediators that are operated upon as part of the process of communication; (3) routines, which are repetitive patterns characteristic of the way participants in a discourse act in specific situations; and (4) endorsed narratives, which are texts (written or stated) that the discourse community endorses as true.

Methods
The purpose of this study is to contribute to our understanding of how engineering design discourse develops in a particular kind of informal maker project work, where projects are driven by youth interests and are supported by disciplinary expert mentors. The research questions addressed in this study are: 1) What opportunities for disciplinary learning develop in open-ended interest driven maker projects? 2) What mentor-mentee interactions enable or constrain disciplinary learning?

Research context
The data for this analysis comes from a study of youth participation in Maker Club, an organization that brought together small groups of young makers and helped them find adult mentors suited to their interests. Maker Club’s goal was to support 8-to-18-year-old youth in creating and ultimately presenting projects of their own choosing at a local Maker Faire. The full study details the work of four separate clubs, but for this paper, we focus on one club consisting of five boys, ages 12 to 14, and three adult mentors. Three of the boys, Parker, Kobe, and George, had already worked together for two years designing two other projects for the Maker Faire. One of the boys, Barnes, joined the team for the second year. A fifth boy, Barkley, was new to the team and to the making experience. The three mentors each had different expertise. Betty, the mother of Parker and Barnes, was an artist and a home-school mom. She organized the group and most often took the role of coordinator. Stephen, the leading mentor, was a retired electrical engineer with vast experience in product design. He had also mentored the group in previous years. The third mentor, David, was recruited by Stephen midway through the project to help with the main mechanism, as he was a mechanical engineer with years of experience in design.

After several meetings of brainstorming project ideas, the team decided to build a human-sized “creepy” cymbal banging monkey, inspired by a figure in the movie Toy Story 3. Figure 1 illustrates the cymbal banging mechanism the group designed (left), and the final project as displayed at the Maker Faire (right).

Data collection and analyses
There were two main sources of data for this study. First, we took field notes and made video recordings of group work sessions. We observed seven collaborative work sessions of about two hours each, spanning around four months of work. Second, we conducted interviews with youth and adult participants. Data analysis started by transcribing all interviews and watching all seven work sessions and creating content logs. For this paper, we focused on observational data from the work sessions. For each session, we flagged moments of interaction between mentors and mentees. To allow a close look at changes in disciplinary discourse, we transcribed and then coded the first and last work sessions. Our initial coding pass was focused on differentiating broad types of mentor-mentee interactions: work discussion, demonstration, planning and management, building interactions, and social related interactions. For a second pass, we coded for the features of engineering disciplinary discourse and then looked for the following: changes in discourse, differences between participants, and instances where we should expect a potential for change even if it did not happen. This initial coding work was a preamble to our discourse analysis, which is the primary analytic method for this paper. The coding was a means to identify significant moments for further analysis.

Findings
The examples in this paper are taken from the first working session after the team decided on their project (the Cymbal Monkey). This session took place at Betty’s home and was divided into three sections: brainstorm discussion, prototyping session, and wrap-up design discussion. Both the first and third sections were facilitated by Betty, who asked questions and kept the conversation focused, with the participation of four young makers and the leading expert mentor, Stephen.

In this section, we will highlight three aspects of discourse development in the setting. The first example contrasts the discourse of the newcomer with the oldtimers to illustrate the learning of the design process routine, a central routine in the work of a design project team. The second example tracks changes in a newcomer discourse and describes the mentor moves and mentor-mentee interaction that allow this change. The third example tracks a team discussion where we saw an opportunity for a shift in youth discourse that was missed in the moment.

Learning to be a part of a product design team
In the brainstorming discussion below, for example, the goal was to figure out how to design the monkey’s main body. As a first analytic pass, we coded the contribution of each boy into one of three options (see Table 1).

Aligned: An utterance that relates to the design and aligns with the goals of this specific design process stage.
Not Aligned: An utterance that relates to the design but does not align with the goals of this specific design process stage.

We can see that Parker and Kobe had a similar number of utterances both for aligned, not aligned and playful talk, while George and Barkley had notably different numbers of utterances. Because George arrived late to the session and entered the conversation much later we will not use his data in this analysis.

Table 1: Number of aligned, not aligned and playful talk utterances per participant

<table>
<thead>
<tr>
<th></th>
<th>Aligned utterances</th>
<th>Not aligned utterances</th>
<th>Playful talk utterances</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parker</td>
<td>39</td>
<td>5</td>
<td>12</td>
<td>56</td>
</tr>
<tr>
<td>Kobe</td>
<td>42</td>
<td>5</td>
<td>13</td>
<td>60</td>
</tr>
<tr>
<td>George</td>
<td>13</td>
<td>0</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Barkley</td>
<td>9</td>
<td>18</td>
<td>12</td>
<td>39</td>
</tr>
<tr>
<td>Total</td>
<td>103</td>
<td>28</td>
<td>39</td>
<td>170</td>
</tr>
</tbody>
</table>

The table shows that the number of playful talk utterances was similar between Parker, Kobe and Barkley. This similarity in playful talk may indicate that all three boys were comfortable socially in the space. However, comparing the number of aligned and not-aligned utterances shows that Barkley differed from Parker...
and Kobe. Barkley was the newcomer to the team, while Parker and Kobe were completing third maker project. This difference in experience could explain differences in his patterns of participation.

Guided by the two mentors, the two oldtimers (Parker and Kobe) brainstormed ideas for the design of the monkey body. They mentioned their past experiences, suggested materials, and identified possible solutions among known off-the-shelf products. Barkley, the newcomer, made fewer contributions to the brainstorming session, and when he did contribute, he mostly made suggestions for new features rather than solutions for the design problem under discussion. His new feature suggestions were not taken up by others in the group, likely because they were not appropriate to this juncture in the design process. The oldtimers replied with statements like “I don’t think that’s going to happen” or “I thought we figured that out last week.”

We hypothesize that this difference between Barkley and the more experienced boys represents their prior learning of a particular design discourse, learning that took place over an extended period of time through repeated participation in design work. Despite his relative lack of experience with design discourse, Barkley was able to make shifts in his contributions even on the short time scale of one design session. Table 2 presents some representative, contrasting examples of Barkley’s contributions at the beginning and end of this one maker session.

Table 2: Barkley’s statements at the beginning and end of one session

<table>
<thead>
<tr>
<th>Beginning of session</th>
<th>End of session</th>
</tr>
</thead>
<tbody>
<tr>
<td>“He’s definitely coming up with the outfit. We could give him a scarf, top hat.”</td>
<td>“So the cymbal, so there are these pieces of sponge on the bottom. And when, I, I was thinking that we could put them on the cymbals and when it will send, it will send volts through the arms. And you know how the motors reverse back into starting position”</td>
</tr>
<tr>
<td>“I think you guys should not do the moving arms thing and like if he is gonna be dressed up in a thing, like a high fashion thing he should like do this like … I mean you would press a button and like he would say like ‘High Fashion’. And you could raise – you could just make like something that would make his chin lift up”</td>
<td>“Because a sponge, sponge. Well I thought with this sponge here, we could wire it up to something, and uh electric, electric, electricity. This is what this is. When these touch they tell you. It. The electricity goes through and that tells the gears, oh, turn it back. And when it goes back it starts the routine over and over”</td>
</tr>
</tbody>
</table>

Reading Barkley’s contributions closely, and watching how he presented them, we saw a difference in his choice of words and the visual mediators, both important characteristics of a discourse in the commognition framework (Sfard, 2008). While at the beginning of the session Barkley was focused on the way features looked or the way the user interacts with their functionality, at the end of the session he took up the group’s focus on the way things actually operate, including the hidden mechanisms that control their operation, while incorporating engineering words like volts, motor, reverse, wires, electricity, gears, and routines like taking apart and using it in a new way.

Mentor-mentee interactions

To understand what may have led to this change in Barkley’s discourse, we analyzed the expert mentor moves and interactions with the boys during the session. The mentor, as an expert in the engineering discourse, introduced the boys to engineering narratives, modeled design routines, and emphasized engineering vocabulary within conversations with youth about their ideas. To illustrate this process, we present a moment where the mentor coupled talk about the engineering concept of feedback with an engineering routine of disassembling a product to see how it works. We show how Barkley made attempts to gain access to the engineering discourse through explorative imitation of the mentor’s discourse and physical manipulation of materials.

At the beginning of the session, the mentor, Stephen, brought a printer to the table and took apart the modules to illustrate the idea of feedback in the printer’s design. Stephen did not explicitly define feedback, but he described the way the idea of feedback is realized in the printer design.
“So that’s kind of a feedback thing, where you have a motor that moves something and then something else that tells it where it is. And then you can get it to go to the right spot. That’s a common thing you run into – the combination of a motor and a sensor connected together with a computer.”

When Stephen used the printer to introduce feedback, he also demonstrated an engineering design routine: taking apart designed objects to learn how they work in order to inform the current design. Here again we see an important characteristic of a discourse, a routine, modeled by the expert. Barkley used this routine later in the session, when he decided (without prompt) to take apart a video game controller that was brought by the mentors to the work session. He took apart the controller and, prompted by the mentor, examined ways to use its parts in the mechanism of the cymbals.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Speech</th>
<th>Gesture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barkley:</td>
<td>Can I take this apart?</td>
<td>Pointing the game controller</td>
</tr>
<tr>
<td>Stephen:</td>
<td>I thought we were building a monkey.</td>
<td>Holding the controller</td>
</tr>
<tr>
<td>Barkley:</td>
<td>I need to take it apart ‘cause someone jammed this piece in. I need to get something. Anybody have – do you know where a screwdriver is?</td>
<td>Give it to Barkley</td>
</tr>
<tr>
<td>Betty:</td>
<td>Here’s one. It’s a Phillips though.</td>
<td>After some time of work, when Barkley took out some parts, Stephen approaches him</td>
</tr>
<tr>
<td>Stephen:</td>
<td>Did you figure out how the buttons worked?</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>Yeah, so they’re actually magnets.</td>
<td>Using his own fingers to demonstrate how the electric circuit looks like</td>
</tr>
<tr>
<td>Stephen:</td>
<td>Actually they’re just conductive material. It’s not a magnet, it’s just any kind of metal that – or something that conducts electricity. And so there’s a little set of fingers that goes like this and a little set of fingers that go like that and if they both make electrical contact between the fingers that closes the circuit.</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>We could use this.</td>
<td></td>
</tr>
<tr>
<td>Stephen:</td>
<td>You could use that.</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>Huh. That’s always good.</td>
<td></td>
</tr>
<tr>
<td>Stephen:</td>
<td>What do you want to do when the switch closes?</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>Oh, when the switch, when the switch closes, we could make his fingers go like this, like</td>
<td></td>
</tr>
<tr>
<td>Stephen:</td>
<td>I thought he was gonna have cymbals in his hands</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>Oh, we could do it on the cymbals</td>
<td></td>
</tr>
<tr>
<td>Stephen:</td>
<td>So that little black thing in there, that’s conductive foam. It’s conductive like this. It’s really soft rubbery stuff.</td>
<td></td>
</tr>
<tr>
<td>Barkley:</td>
<td>You could put those on the cymbals, and when the cymbals touch, it would make them go back to their position.</td>
<td></td>
</tr>
<tr>
<td>Stephen:</td>
<td>So when they touch, that would tell the motor to reverse direction.</td>
<td></td>
</tr>
</tbody>
</table>
Barkley: Yeah, reverse

Betty: We’re, boys, we’re pretty much done, so you’re gonna draw up some sketches and –

Barkley: I’ll sketch.

Kobe: What’s that?

Barkley: So the cymbal, so there are these pieces of sponge on the bottom. And when, I, I was thinking that we could put them on the cymbals and when it will send, it will send volts through the arms. And you know how the motors reverse back into starting position?

Kobe: It depends how far it is.

Barkley: Yeah. This is easier. Because then when they touch it just throws it back

Kobe: Yeah, but it’s more wiring on the cymbals. Plus they’ll be obvious. Like people will see it.

Barkley: Or you can cut a hole in the cymbals.

In this interaction we see Barkley took initiative and took apart a game controller. This action diverges from the main activity, but the mentors do not stop him or tell him to join the main activity. We see several examples of Barkley’s explorative imitation of Stephens’ discourse – the use of fingers, the use of engineering vocabulary, and the parallel reasoning about feedback in Barkley’s cymbal mechanism that resembles Stephen’s explanation of the printer mechanism. The move between physical objects, embodied modeling, and talk allows Barkley to imitate in an explorative way and to move from a peripheral participation at the beginning of the session to fuller participation later on when he sketches ideas for a presentation and gains the attention of one of the more experienced boys.

A missed opportunity for discourse development

An environment like this also presents challenges to mentors when opportunities arise in the moment and are not always easily picked up. One example of such instance happened during a discussion on the next step in the design of the monkey. The main participants in this discussion were the three oldtimers, Parker, George, and Kobe, and the two mentors, Betty and Stephen. Betty managed the discussion about the “skeleton”, asking the team to brainstorm ideas on “what is the project’s skeleton made of”. Table 3 offers a transcript of this conversation with our interpretations for the statements.

Table 3: The ‘skeleton’ discussion

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Speech</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betty:</td>
<td>Ok, so if we say the next step is the skeleton, then what is the skeleton made of?</td>
<td>For Parker, the skeleton should be made of foam and we should wrap it in fabric and awesomeness.</td>
</tr>
<tr>
<td>Parker:</td>
<td>The skeleton should be made of foam and we should wrap it in fabric and awesomeness.</td>
<td>For Parker, the skeleton functions also to set the shape of the monkey.</td>
</tr>
<tr>
<td>Kobe:</td>
<td>We could make the thing out of foam, right? And then we could uh We could take like – you could make a mold of it and make it like a hollow thing.</td>
<td>For Kobe, the skeleton also functions as setting the shape.</td>
</tr>
<tr>
<td>Stephen:</td>
<td>I, I was sort of visualizing kind of a frame board made out of metal or wood or something.</td>
<td>For the mentor, the skeleton functions as a structural support.</td>
</tr>
</tbody>
</table>
Betty: [to George who just arrived] So we’re going to catch you up to date to where we’re at right now. We’ve talked about some ideas for materials. Or first we asked what was the next step. And then people answered skeleton and we talked about ideas for materials for the skeleton, we said foam or layered cardboard or wood or aluminum. Betty at this stage is familiar with all participants’ ideas. Her interpretation of the discussion is from a material perspective and not a functional one.

George: Wood seems kind of hard to cut it into the shape of a skeleton. Couldn’t we – I kind of like claymation where you have a little thing and then you put wires. George interprets the word “skeleton” in its everyday use (e.g. skeleton of a human body).

Parker: Couldn’t we technically use one of those ceramic skeletons they have in like horror, or like molded skeletons out of plastic or something? Like they have in classes and stuff. Like a skeleton of a human and the skeleton of a monkey are kind of kind of close. Parker, too, interprets the word skeleton in its everyday human-body context.

Kobe: What if you got a little store mannequin and made it sit down and just made it look like a monkey. Because it’s already hollow. It’s already strong. Shape and support.

Stephen: I’m just thinking, it would just be…it would just be like a rectangular solid thing. You know like four sides, four posts. Stephen restates his frame idea. This time he addresses implicitly the shape argument by emphasizing that the frame can be rectangular (not a body shape).

Kobe: What happened to the mannequin? That was a genius idea. Kobe advocates his idea.

Stephen: Make a square – a rectangular base, a rectangular top. And then start adding stuff around the outside of it. Stephen restates the idea of the frame as a structural support.

Kobe: Mannequin mannequin Kobe expresses his frustration.

Kobe: Stephen, I challenge you to a battle of wits. Kobe expresses his frustration.

Stephen: Stephen, I challenge you to a battle of wits. Kobe expresses his frustration.

Stephen: Uh oh.

This conversation is an example of a commognitive conflict (Sfard, 2008). A commognitive conflict happens when participants in a conversation actually participate in two different discourses. In this case, we can see that Betty and the boy’s discourse is based on an everyday discourse of designed objects. In their discourse, skeleton embodies both the shape and function of an object. In a design engineering discourse, a skeleton is a structural support to which modules are attached (Slocum, 2008). Therefore, there is no required connection between the form (shape) and the functionality of the object. The frame can serve the function of structural support without attending to the shape requirements, an engineering narrative of the separation of form and function. Stephen’s discourse is a professional engineering design discourse. When engineers work on product design, they take into account different requirements: for example, mechanical (e.g. mechanisms), structural (e.g. stress, flow), and industrial design (look and feel). They separate functionality requirements from shape requirements to maximize degrees of freedom in the design. The mentor, who is the expert in the professional
discourse, is the only person who can expose the conflict to the group and introduce the other participants to the rules of his discourse. However, Stephen did not make any moves to do so here. He missed the opportunity to develop the young makers’ disciplinary discourse. We do not mean this as a critique, but rather note it as an example of the challenges of negotiating this complex discourse space on the fly.

Conclusions and implications
Learning can be viewed as a development of a specialized discourse. In formal settings, introduction to disciplinary discourse can be an explicit goal of instruction, but in informal, youth-driven, and/or project based learning environments, those processes can be implicit. As a field, we need good models and examples of how young people develop disciplinary discourse in such settings.

Youth participation in making and the maker movement is a germane setting to investigate these issues. Many have identified making and tinkering as spaces where youth can gain access and experience with STEM disciplines in an informal, youth-driven space. While some have noted the topical and practice-based connections between making and STEM fields (and engineering in particular), there has been less work to examine precisely how making can help youth develop these disciplinary discourses. This study employed Sfard’s (2008) commognition theoretical framework to investigate a group of young makers and their mentors. We identified moments where youth exhibited shifts toward disciplinary discourse, and the mentor moves that preceded these shifts. We also identify moments of communicational conflict where mentors and youth seemed to “talk past” each other and did not shift their discourses.

This study contributes to the ongoing conversation in the learning sciences about how youth gain access to valued disciplinary discourses. It does so within the context of the maker movement, a genre of learning environment that has recently gained traction in the field. In doing so, we also bolster claims that making can be a productive site for learning STEM, while also highlighting the fact that such learning is not automatic, but depends on careful articulation between mentors and youth.

References
The Influence of Students’ Transformative and Non-Transformative Contributions on Their Problem Solving in Collaborative Inquiry Learning

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Abstract: The effectiveness of collaborative inquiry learning in simulation-based learning environments for STEM education has been well-documented. At the same time, research indicates that some students struggle with articulating relevant concepts, making their reasoning explicit and regulating their learning—skills that are necessary for effective collaboration. In this study, using qualitative and quantitative analysis as well as data mining techniques, we investigated what promotes meaningful interaction between students when conducting collaborative inquiry. One hundred and fifty-six students from five high schools and colleges in the United States worked in groups of three to solve electronics tasks with increasing complexity in a virtual environment called Teaching Teamwork. The results showed that when the groups successfully solved the tasks, they showed statistically significant higher proposition generation, regulation and sustaining mutual understanding; when they did not solve the tasks, they showed significantly higher orientation, interpretation and conclusion. Explanations for these results and research recommendations are provided.

Introduction

There is a well-documented body of research that shows the effectiveness of using computer networks for collaborative learning on STEM education (see Jeong, Hmelo-Silver, Jo, & Shin, 2016, for review). In computer-supported collaborative inquiry learning (CSCI), two or more learners collaborate via the computer, typically in a simulation-based learning environment, to solve problems (e.g., electrical engineering topic as is used in the present study) and co-construct knowledge (e.g., understanding the relation between the values of voltage and resistance). This process entails searching for information, hypothesis formulation, experimentation, interpretation, articulation and sharing ideas for collaborating partners to build upon (Stahl, Koschmann, & Suthers, 2006). Research on collaborative inquiry learning has consistently shown that most students struggle to regulate their learning, articulate relevant concepts in order to actively make sense of the subject matter (e.g., through hypothesis generation and data interpretation) and make their reasoning explicit (de Jong & van Lazonder & Rouet, 2008; Raes et al., 2012; Popov et al., 2017). The core of the present research therefore is concerned with the question of how to effectively promote the kind of meaningful interaction between students when conducting inquiry tasks that allow them to reap the benefits of collaboration.

According to Gijlers and de Jong (2009), when conducting typical collaborative inquiry tasks, students are engaged in transformative learning activities (those that are directly related to knowledge construction) and regulative activities (those that are necessary to coordinate and sustain mutual understanding at all times). Transformative learning processes include: orientation, hypothesis generation, experimentation, and conclusion. Regulative learning processes include: sustaining mutual understanding, planning and monitoring (Gijlers & de Jong, 2009; de Jong, 2006). Each learning process has specific objectives and requires specific types of collaboration, activities where information is transferred from one participant to another, to be effective. Coordination of such collaborative activities and appropriate distribution of group efforts and resources are of critical importance to the group problem solving (Rummel & Spada, 2005). Furthermore, learning is particularly likely to occur when the collaborating students engage in meaning-making processes by formulating hypotheses about certain phenomenon and connect these hypotheses to prior knowledge, or form new insights based on their experiences in the learning environment (Gijlers & de Jong, 2009).

Building on previous research, this study investigated to what extent students’ engagement in transformative and non-transformative learning processes predicts groups’ learning outcomes within a simulation-based collaborative inquiry learning environment. By examining which process characteristics positively influence groups’ learning outcomes, it may be possible to help teachers encourage specific types of student activities to improve students’ learning gains.
Peer collaboration as a source of support in the inquiry learning process

Inquiry tasks are highly challenging for students if they are not sufficiently supported (Makitalo-Siegl, Kohlhe, & Fischer, 2011; de Jong & van Joolingen, 1998). Relevant sources of support are typically teachers, small group scripts (i.e., scaffolding that guides students on what to do, what roles to play, what sequences of activities to perform during a learning task), a knowledgeable expert (Makitalo-Siegl et al., 2011) or peers (Okada & Simon, 1997). In this study, we focused on peer support by exploring how students find support in working with other peers through collaborative learning, i.e., peer scaffolding. Okada and Simon (1997) found that students who worked in dyads were found to outperform students who worked alone on a molecular biology inquiry learning task, because dyads were able to formulate more alternative scenarios. Piaget’s (1926) ideas about sociocognitive conflicts and Vygotsky’s (1978) “zone of proximal development” help explain why scaffolding (either provided by peers, teachers or other instructional sources) can be effective in addressing students’ individual cognitive abilities. A good scaffold can link a student’s current understanding to the learning context. For example, with peer scaffolding, a student may be good at explaining how chemical reactions relate to energy, yet have limited understanding how to interact with dynamic visualizations (Gerrard et al., 2009). The partner student may have expertise in constructing models, yet struggle to design consequential experiments. Each collaborative or knowledge integration unit will enable students to take advantage of the peer expertise.

Based on the Piagetian approach of socio-cognitive conflict, the efficacy of collaborative learning effort is thought to be influenced by the extent to which students can identify and discuss conflicts in their knowledge and beliefs (De Lisi & Goldbeck, 1999). For instance, participatory simulations create a kind of collaborative learning in which every student’s experience and contributions build towards a collective understanding of the whole system. This process encourages students to make their thinking visible by explaining their reasoning to their collaborative partners. It is assumed that students working in groups reach a shared understanding through the negotiation of meaning, which requires students to ask questions, have discussions, explain their thoughts and ideas, and support their viewpoints with additional information (De Lisi & Goldbeck, 1999). Previous research supports that learning is likely to happen when the collaborating students build on each other’s reasoning by critiquing, challenging and synthesizing opinions, because this form of discourse triggers cognitive activities that stimulate knowledge construction (Andriessen, Baker, Suthers, 2003).

This study explores a series of collaborative (non-)transformative learning processes: orientation, hypothesis generation, experimentation, conclusion drawing, regulation, and sustaining mutual understanding (see Table 1). During orientation, students elicit ideas so that they become aware of their views of the situation, add new ideas to fill in missing information to make sense of the topic and strategize about how to approach/solve a problem at hand. During hypothesis generation, students typically form a statement or a set of statements concerning the relations regarding the values, variables and relation between them in order to solve the task. Previous research studies have particularly examined hypothesis generation process and ways to support this process. This process is important because it triggers students’ activation of their prior knowledge that they try to connect to the variables presented in a problem to explain phenomena. During experimentation, students design, test, run experiments and make sense of the outcomes; this occurs very quickly in computer assisted simulation-based learning environments. When drawing conclusions, students review their propositions/hypotheses based on the experimentation data/experiences (Gijlers & de Jong, 2009). During regulation, students manage time allocated to complete the tasks and discuss the big procedures of solving tasks and so forth. Another important aspect of collaborative learning is the ability of group members to sustain mutual understanding throughout the whole process. Several aspects of online communication (e.g., reduced social presence, lack of nonverbal and social cues) might further hinder mutual understanding between collaborative partners, especially when they do not know each other and are collaborating for the first time.

Research questions

1. How do the transformative/non-transformative learning processes look like in more and less successful groups in a collaborative inquiry learning environment?
2. How do groups’ transformative/non-transformative processes influence their group problem solving results in a collaborative inquiry learning environment?

Method

Setting
The platform supporting this study was Concord Consortium – an online collaborative inquiry learning environment that includes a database of interactive STEM activities. The participants involved in a series of
activities in the electronics domain, which were designed to help them understand and apply Ohm's Law by exploring the relationship between resistance and voltage in series circuits. As shown in Figure 1, the virtual electronics environment includes a series circuit with supply voltage \( E \), external resistance \( R \), \( R_1 \), \( R_2 \) and \( R_3 \) (at the bottom of Figure 1); the initial conditions and the goal (at the upper left of Figure 1); a digital multimeter (DMM) with a black and a red probes that can be used to measure the voltage, current, or resistance of the resistor as controlled by a student (at the middle left of Figure 1); a calculator which will appear if clicked ‘calculator; and a chat window that allows group members to talk about their goal, discuss how to solve their task, monitor their progress and so forth.

The students worked in groups of three on separate computers. They were all in the same room, but team members were kept separate from one another and were not allowed to communicate other than by the computer-supported chat window. Before working on the tasks, the students watched an introduction video and were informed that each of them only controlled part of the circuit and they had to work together as a group to solve the tasks.

The electronics domain was divided into four tasks with increasing complexity. The reason for increasing complexity gradually rather than requiring students to work on full complexity at the beginning is to avoid overwhelming them (Carroll & Carrithers, 1984). Students were free to start at any level and to move back and forth of different levels. However, in practice, students usually started with Level A, and then moved to Level B and other more complex tasks. Often, they did not move to the next task until they solved the current one. In Level 1, both \( E \) and \( R \) values are given, \( R \) equals \( R_1 \), \( R_2 \) and \( R_3 \), and the goal voltage across \( R_1 \), \( R_2 \), and \( R_3 \) equals; in Level 2, both \( E \) and \( R \) values are given, \( R \) does not equal zero, and the goal voltage values across \( R_1 \), \( R_2 \) and \( R_3 \) are different; in Level 3, \( E \) is unknown, \( R \) is given and does not equal zero, the goal voltage values across \( R_1 \), \( R_2 \) and \( R_3 \) are different; and in Level 4, both \( E \) and \( R \) values are unknown and the goal voltage across \( R_1 \), \( R_2 \) and \( R_3 \) are different.

![Figure 1. Screenshot of a simulation of Level 1 task.](image)

**Participants and procedures**

156 students from five different high schools and colleges in the United States participated in this study, and they worked in 52 groups. The teachers did not assign the students to any groups ahead of time. Students from the same class were given a class code so that they could join in the same class space. When they did their teamwork, they could select to join in any team as long as there were fewer than three students in the team. Therefore, the grouping process was random. Each student was assigned a fake name, and the students did not
know who their team members were in the teamwork process unless they discussed this issue in the chat window.

Before students participated in the Teaching Teamwork, they read an introduction on the design of the tasks, how to get started, how to use the online chat window and on-screen calculator, and how to submit results. Students were also provided with an introduction video to help them get familiar with how the system works and how to operate the tools.

Predicting transformative and non-transformative discussion

In order to understand group discourse while doing their teamwork activities, we adapted a coding scheme (as shown in Table 1) from Gijlers and de Jong (2009) to analyze what kinds of transformative/non-transformative utterances influence collaborative inquiry learning. Group discourse was categorized into transformative and non-transformative utterances. Transformative utterances closely relate to knowledge construction, and are further divided into orientation, proposition generation, experimentation, and interpretation and conclusion. The non-transformative utterances relate to technical features and time/group/task management, such as regulation and sustaining mutual understanding.

Most previous research on communication in small group learning is based on manually coding small samples of messages (e.g., Kwon, Liu, & Johnson, 2014; Lee, Ó’Donnell, & Rogat, 2015). These qualitative and content analysis techniques are impractical, at least difficult, for thousands of lines of log data in our context. Previous research has demonstrated that it is possible to automate the analysis of conversations in CSCL (Mu, Stegmann, Mayfield, Rosé, & Fischer, 2012; Rosé et al., 2008). Therefore, in this study, machine learning models were built to automatically identify the transformative and non-transformative messages in the small group collaboration. Machine learning models apply statistical procedures to map a set of input features to output targeted categories (Wang, Krut, & Levine, 2012). In our data, the inputs were various kinds of features and the outputs were categorical values representing the category of transformative and non-transformative discussion an utterance belongs to.

This machine learning model construction involves three steps: first, two human coders manually code a random sample of 25% messages to identify which category of transformative and non-transformative discussion each message represents. Their judgements are considered as the ground truth data. Second, all these manually coded messages are represented by a set of linguistic features as input into machine learning algorithms. Third, various algorithms are tested with different combinations of feature sets, and then evaluated for their performance based on 10-fold cross validation. After the machine learning model is constructed, this model will be applied to the rest of the dataset so that every message in all groups can be classified into transformative or non-transformative category.

For the first step in creating a machine learning model, 25% of the chatting messages were randomly sampled from the entire dataset. Two senior researchers with extensive background in CSCL coded them independently. The sample of the coding is demonstrated as Table 1. The initial agreement between the two researchers was 76.8%; the remaining disagreements were discussed and resolved. Second, three types of textual features were used to capture the different language strategies employed by students when engaging in collaboration: 1) rule-based structural features discovered by the coders that capture the key elements of high-order concept propositions. These features are based on the researchers’ qualitative insights as what words or number combinations are more likely belong to which kinds of transformative or non-transformative categories; 2) functional and linguistic relevant words (e.g. emotion and cognition words) from the Linguistic Inquiry and Word Count (LIWC) program (Pennebaker et al., 2015); and 3) topical features based on Latent Dirichlet Allocation (LDA) topic modeling to create specialized small group collaboration related dictionaries (as shown in Table 2). Then each LDA topic feature computes the frequency of words in an utterance matching its corresponding topic dictionary. Third, to optimize the performance of the machine learning model, four different kinds of classic algorithms were used: Naïve Bayes, Logistic Regression, Support Vector Machines (SVM), and Decision Tree. Details of these algorithms can refer to Kotsiantis, Zaharakis, and Pintelas (2007). All these algorithms were evaluated based on 10-fold cross validation to show the robustness of the prediction performance.

Results

By using various algorithms and features, the machine learning models were built and their performance is shown in Table 3. The performance of the machine learning model was measured by precision measure, a classical metric to evaluate the supervised models. Through comparing various algorithms and different features sets, the results showed that the decision tree with structural features had the best performance, reaching 79.8% predictive power.
Table 1: The coding scheme of the chatting history during the collaborative inquiry learning process

<table>
<thead>
<tr>
<th>Contribution type</th>
<th>Category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformative (utterances that directly result in knowledge construction)</td>
<td>Orientation</td>
<td>Form an idea of the structure and the complexity of the task at hand by collecting goal-related information, the current values of the resistance or voltage and how these measures meet the individual or group goals.</td>
<td>( r = 560 ) here; ok i need 6.69; i got my v; how many volts do you guys need? its a series circuit</td>
</tr>
<tr>
<td>Proposition generation</td>
<td></td>
<td>Form a statement or a set of statements concerning the relations regarding the values of the resistance or voltage in order to solve the task.</td>
<td>youre gonna need a higher resistance value then; so we can find the current at 6.71mA going thru the resistor, then we can find our r values using ohms law</td>
</tr>
<tr>
<td></td>
<td>Experimentation</td>
<td>Include testing their ideas, and adjusting the resistors by making them lower or higher.</td>
<td>everyone set to 180 - see what that does; let me get 1v hold up; let me readjust; ok let me go a little higher then; R1 at 680 ohms just lowered to 3.8 V; I will switch R1 to 680; can u just change your resistor to 4.7k ohms i jsut wanna see</td>
</tr>
<tr>
<td></td>
<td>Interpretation and conclusion</td>
<td>Review the proposition in light of the experimentation outcomes.</td>
<td>i still need to adjust; well our total v of c1 - c3 is12.24 right; so there is a 3.76 drop across r=560 totals to 16</td>
</tr>
<tr>
<td>Non-transformative (utterances relate to technical features, and time/group/task management, etc.)</td>
<td>Regulation</td>
<td>Manage time, group dialogue, the big procedures of solving tasks and so forth.</td>
<td>Lets get move on snow; one sec; where tf is the other person; lets try calculating; get to the goal; dont we need the third pers</td>
</tr>
<tr>
<td></td>
<td>Sustaining mutual understanding</td>
<td>Indicate shared/different understanding among different group members.</td>
<td>Ok; same here; yea; got it; now it does; thats good</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>Information that cannot be coded with the six categories above.</td>
<td>who this; who cares; and i aint trynna do this math tbh;</td>
</tr>
</tbody>
</table>
Table 2: Feature sets

<table>
<thead>
<tr>
<th>Structural features</th>
<th>LIWC features</th>
<th>LDA topical features</th>
</tr>
</thead>
<tbody>
<tr>
<td>deed (to be) + number, getting + number, number + away, at + number, what is everyone.</td>
<td>Summary Dimensions – word count, sentence count, tone Punctuation marks – period, comma colon, exclamation, dash, quote etc. Function words – pronounce, article, adverb, negate Other Grammar – verb, adj, compare, number, quant etc.</td>
<td>anger, sad, family, friend, social, insight, cause, differ, hear, feel, percept, body, affiliation, power, reward, risk, forecast, future, motion, space, time, money, leisure, assent, swear etc.</td>
</tr>
</tbody>
</table>

Table 3: Prediction Performance

<table>
<thead>
<tr>
<th>Feature sets</th>
<th>Naïve Bayes</th>
<th>Logistic Regression</th>
<th>SVM</th>
<th>Decision Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Features</td>
<td>43.0%</td>
<td>72.3%</td>
<td>72.2%</td>
<td>79.8%</td>
</tr>
<tr>
<td>LIWC Features</td>
<td>20.2%</td>
<td>35.2%</td>
<td>41.6%</td>
<td>44.1%</td>
</tr>
<tr>
<td>Topic Features</td>
<td>38.5%</td>
<td>61.8%</td>
<td>54.4%</td>
<td>52.2%</td>
</tr>
<tr>
<td>Structural + LIWC Features</td>
<td>39.1%</td>
<td>69.4%</td>
<td>64.5%</td>
<td>76.0%</td>
</tr>
<tr>
<td>LIWC Features + Topic Features</td>
<td>34.6%</td>
<td>61.8%</td>
<td>60.2%</td>
<td>61.9%</td>
</tr>
<tr>
<td>Structural + LIWC + Topic Features</td>
<td>42.9%</td>
<td>66.5%</td>
<td>60.2%</td>
<td>72.6%</td>
</tr>
</tbody>
</table>

Table 4: Significant Univariate Effects for Performance

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Performance</th>
<th>Means</th>
<th>Standard Deviations</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>1 (Task solved)</td>
<td>64.9</td>
<td>10.04</td>
<td>9.55</td>
<td>0.003**</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>73.4</td>
<td>15.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposition generation</td>
<td>1 (Task solved)</td>
<td>0.78</td>
<td>1.87</td>
<td>5.74</td>
<td>0.018*</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>0.04</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimentation</td>
<td>1 (Task solved)</td>
<td>13.2</td>
<td>1.25</td>
<td>9.55</td>
<td>0.266</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>11.18</td>
<td>8.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpretation and conclusion</td>
<td>1 (Task solved)</td>
<td>1.09</td>
<td>2.21</td>
<td>4.34</td>
<td>0.040*</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>2.51</td>
<td>5.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>1 (Task solved)</td>
<td>7.44</td>
<td>8.96</td>
<td>4.7</td>
<td>0.032*</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>4.08</td>
<td>4.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustaining mutual understanding</td>
<td>1 (Task solved)</td>
<td>12.59</td>
<td>7.68</td>
<td>6.9</td>
<td>0.010**</td>
</tr>
<tr>
<td></td>
<td>0 (Task unsolved)</td>
<td>9.78</td>
<td>6.41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* < .05, ** < .01, *** < .001

We then applied this built model to the rest of the group chats. Then for each category of the transformational and non-transformational discussions, we calculated the percentage of each category in each task chat. Table 4 shows the descriptive statistics of those transformative and non-transformative discussions over the tasks groups.

A MANOVA analysis in which students’ performance on tasks as independent variable and the six codings as dependent variables showed a significant multivariate effect for the six latent variables as a group in relation to performance of different group students in different levels of tasks (p<0.001). Univariate ANOVAs (as follow-ups to MANOVA) were conducted in order to check which individual variables (as opposed to all variables together) differ between solved and unsolved tasks. The results indicated that the frequency of proposition generation, regulation and sustaining mutual understanding were significantly higher in the solved tasks than that in the unsolved tasks; the frequency of orientation and interpretation and conclusion were significantly lower in the solved tasks than that in the unsolved tasks; and the difference of experimentation in the solved and unsolved tasks was not significant (as shown in table 4).
Discussion

This study was conducted in an authentic setting and on large scale, which supports its ecological validity. The intellectual merit of this study originates from its contribution to our understanding of the role that both transformative and non-transformative learning processes play in collaborative inquiry learning and how important they are to the success of problem-solving. Specifically, we discovered the extent to which transformative and non-transformative learning processes contribute the group problem solving outcomes. For example, the importance of orientation, as well as interpretation and conclusion, is well recognized in the literature (Gijlers & de Jong, 2009), but we found that if students do not go beyond orientation and focus too much on making conclusions without sufficient experimentation evidence or without discussing about the relationship between variables seriously through proposition/hypothesis generation process, they do not end up solving the task. Also, it should be noted that the groups, which had higher frequency of sustaining mutual understanding contributions, were more likely to solve the task. This finding shows the importance of the social aspect, which plays a large role for the group cohesion, coordination efforts and interactional dynamics of the group in general (Kreijns et al., 2003).

The results showed the importance of understanding topic-related cognitive knowledge, forming it into a statement and conveying it to other group members, managing time, dialogue and problem-solving procedures, and achieving shared understanding between the group members. On the other hand, when the group members focused too much on discussing their goal and reporting their resistor and voltage status but did not really discuss the relationship between resistance and voltage or interpreted and concluded without enough evidence or explanation, they were likely to fail in the collaborative problem solving. Previous studies also showed the difference between high-performing and low-performing groups. For instance, Malmberg, Järvelä, Järvenoja and Panadero (2015) indicated that high-performing groups mainly focused on regulating the cognitive, motivational, and social aspects of their collaboration while low-performing group focused more on external challenges such as the environment and time management. Sinha, Rogat, Adams-Wiggins and Hmelo-Silver (2015)’s study showed that some social, cognitive and metacognitive, as well as emotional indicators, may influence students’ engagement in collaborative learning, resulting in improving students’ learning performance. Their study indicated that the low engagement group developed vague and incomplete plans; the ideas contributed by the group members were not elaborated, backed up with evidence, or further discussed; their task monitoring was mainly focused on the spelling of components rather than its content; and the words they used indicated a focus on individual thinking and individual activity such as “I think”, “I am going to” and “my turn”, while the high engagement group used words that refer to the collective (e.g., we).

Furthermore, in this study we built accurate machine learning models to identify the transformative and non-transformative discussion in small group collaborative learning. While previous CSCL studies (e.g., Kwon, Liu, & Johnson, 2014; Lee, O’Donnell, & Rogat, 2015) usually applied qualitative analysis to examine a few group collaborative processes, this research examined a relatively large number of groups and their collaborations. Such larger scale endeavors can provide more generalizability compared with qualitative cases studies. In addition, this study is not a purely quantitative and data mining research. In fact, we started with human qualitative coding and examination of the group collaboration process for the transformative and non-transformative discussion, and then applied machine learning algorithms to capture the human insights for automatic coding. By using diverse set of features through various algorithms, we optimized the performance of the automatic coding process. The extracted features can be easily applied to construct prediction models in other group learning contexts. While the LIWC features can be readily to use in other scenarios, the rule-based features and LDA topic features may need to be adapted for specific context. These two steps usually require little effort. As a whole, this study is a practical exemplar for future research to conduct large-scale CSCL analysis while not losing the human insights.

Collaborative inquiry learning manifests many facets and remains a complicated process, as demonstrated by the results of this study. The findings can inform instructional design choices as well offer recommendations for teachers in terms of what specific types of student activities need to be fostered and where support is most needed to benefit from CSCiL.

References


Wang, Y. C., Kraut, R., & Levine, J. M. (2012, February). To stay or leave?: the relationship of emotional and informational support to commitment in online health support groups. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work* (pp. 833-842). ACM.
Rethinking the Teaching and Learning of Area Measurement

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Abstract: This study focused on exploring an innovative way of teaching and learning measurement, what we refer to as Dynamic Measurement or DYME. Without relying on the common approach of counting square units, our goal was to engage students in contextually rich digital dynamic tasks to visualize area as a continuous quantity and evaluate the area of a rectangular region as a multiplicative relationship between the two lengths of the sides. In this paper, we briefly describe the iterative process of designing, testing and refining the tasks for DYME pointing to the significance of the design for developing students’ thinking of area as length times width.

Geometric measurement: What we know and pushing forward

Extensive research on measurement has described the importance of using square units to cover rectangular surfaces and quantify that covering by counting the square units (e.g. Barrett & Clements, 2003; Battista, Clements, Arnoff, Battista & Borrow, 1998; Izsak, 2005; Kamii & Kysh, 2006). For instance, we can use twenty 1 sq. inch tiles to cover a 5 by 4 inches rectangle as in Figure 1a and claim that its area is 20 sq. inches. Similar to these studies, the Common Core State Standards for Mathematics (CCSSO, 2010) in the United States introduce third grade students to area measurement first by counting unit squares in a rectangular surface, thus forming an array (Content standards 3.MD.C.5 and 3.MD.C.6). Next, the standards assume that students will use this tiling experience to “show that the area is the same as would be found by multiplying the side lengths” (3.MD.C.7.A). However, the standards do not provide information on how students will transition from counting individual units to constructing the multiplicative area formula.

Figure 1. Progression of structuring area based on a synthesis of the measurement literature.

Although the measurement research studies mentioned above suggest a progression of structuring area (Figure 1 a-d), to understand how area is generated by multiplying lengths is a different notion conceptually from the construction of a matrix like shown in Figure 1d. As Piaget et al. (1960) argued, “the difference between the two operational mechanisms is the difference between a matrix which is made up of a limited number of elements and one which is thought of as a continuous structure with an infinite number of elements” (p. 350). Indeed, area, length and width are continuous quantities (Kamii & Kysh, 2006) that are related multiplicatively while covering a surface with discrete unit squares is one-dimensional and additive in nature (e.g. Outhred & Mitchelmore, 2000; Reynolds & Wheatley, 1996).

As a result, this study aimed to go beyond the static perspective of understanding area as the counting of discrete square units and find a more intuitive and accessible approach of illustrating area as a continuous quantity that involves a multiplicative relationship between length and width. To do that, we built on the work of Confrey et al. (2012) and Lehrer, Slovin, Dougherty, & Zbiek (2014) on visualizing area as a ‘sweep’ of a line segment of length $a$ over a distance of $b$ to produce a rectangle of area $ab$.

Figure 2. Visualizing area as a continuous structure through ‘sweeping.’
For instance, imagine a paint roller with length 5 inches sweeping for a distance of 6 inches and generating a surface of 30 square inches (Figure 2). In this approach, which we refer to as Dynamic Measurement or DYME, area can be visualized as a continuous dynamic quantity which depends on both the length of the roller (length) and the distance of the swipe (width). DYME involves engaging students in dynamic experiences of generating 2D surfaces and 3D shapes by iteratively (and multiplicatively) composing lower-dimensional objects (linear measures).

**Aims and methods**

Our goal was to examine the potential of DYME as an innovative pathway for teaching and learning area measurement. More specifically, we aimed to explore:

a) What type of tasks may be designed for developing students’ DYME reasoning?

b) How do these tasks assist students in thinking of area as a continuous quantity?

To provide the experience of visualizing area as a continuous quantity, we used the ‘dragging’ and ‘trace’ features of Geometer’s Sketchpad (GSP) (Jackiw, 1995) to design a set of tasks. We conducted design experiments (Brown, 1992; Cobb, Confrey, diSessa, Lehrer & Shauble, 2003) with six pairs of third-graders and had 6-10 sessions of 45-90 minutes with each pair of students. The students represented various abilities according to their teacher and all students had some instruction on area as tiling the year before the design experiment. A design experiment starts by formulating some initial conjectures, and these conjectures evolve following an iterative cycle of design, enactment, analysis and redesign:

On the reflective side, design experiments are conjecture-driven tests, often at several levels of analysis. The initial design is a conjecture about the means of supporting a particular form of learning that is to be tested. During the conduct of the design study, however, more specialized conjectures are typically framed and tested (Cobb et al., 2003, p. 10).

These conjectures evolve throughout the duration of the design study including further iterations that continue in the form of follow-up design experiments. Drawing on the existing literature on area measurement, we gathered measurement constructs identified in previous studies (e.g. indirect/direct measurement, measuring with no gaps or overlaps) and wondered, “How can this construct be interpreted/modified/used in terms of DYME?” We used these wonderings to design some initial tasks and framed humble theories (conjectures) about prospective interactions between our task design and the students’ responses. We examined the changes in students’ thinking about area when interacting with the DYME tasks, and modified and refined the task design accordingly. During this ongoing analysis (Cobb & Gravemeijer, 2008), our initial conjectures evolved and we modified the tasks in light of iterative examinations of changes in students’ thinking about area when interacting with the DYME tasks. The goal of this ongoing analysis (Table 1) was to develop iterative cycles of invention and revision of tasks and humble theories (Cobb et al., 2003). The following section describes in brief this iterative design process aiming to illustrate how our task sequence was constructed.

**Table 1: Description of ongoing analysis**

<table>
<thead>
<tr>
<th>Description</th>
<th>Questions to guide the analysis</th>
<th>Evidence</th>
<th>Goal</th>
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<tbody>
<tr>
<td>Formulation of research-based initial conjectures that will evolve throughout the duration of the design study (Cobb et al., 2003).</td>
<td>How does the task or sequence of tasks engage students in DYME reasoning experiences? What is the nature of students’ DYME reasoning in each task or sequence of tasks? How is students’ thinking changed, modified and refined in each task or after a sequence of tasks? How does this thinking connect to understanding the area formula?</td>
<td>Iteratively examine the changes in students’ thinking about measurement when interacting with the DYME tasks and modify the task design accordingly.</td>
<td>To produce a series of tasks and a framework for learning DYME resulting from the actual teaching of children that consists of an explanation of students’ initial schemes, explanations of changes in those schemes, and analysis of the contribution of the activities involved in those changes (Steffe, 2003).</td>
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**Designing tasks for DYME**

Influenced by the work of Thompson (1993; 1994) on quantitative reasoning, our goal was to design meaningful tasks around a storyline that would illustrate area as an attribute that measures the space covered by a rectangular shape. Aiming to trigger students’ interest, we developed an overarching storyline, where students become part of a “Maker Team” that solves a series of DYME challenges embedded in an interactive digital
To illustrate the continuous nature of area we used the context of painting with paint rollers (Confrey et al., 2012; Lehrer et al. 2014) where we asked students to color surfaces by dragging a roller of a given length over varying distances and also dragging rollers of different lengths over the same distance (Figure 3). The task introduces the quantities of ‘length of a paint roller’ as the length of a rectangle, ‘rolling distance of the paint roller’ as the width of a rectangle, and the ‘space covered by the paint roller’ as the area of the rectangle. Our humble theory was that by providing students with opportunities to create a rectangular surface through dragging and tracing, they would develop an understanding of area as a continuous quantity that depends on two other continuous quantities: the length of roller and the rolling distance.

Indeed, the dynamic nature of the task enabled students to visualize area as a continuous structure and helped them recognize that the length of the roller and the rolling distance define the size of a shape. As they could drag the roller as far as they could, students reasoned that, “the further we drag the roller, the bigger the shape we create.” Although the task was successful in presenting those quantities as continuous, it did not provide us with evidence that students a) realized that they need to coordinate both quantities (length of roller and rolling distance) in order to make judgments about size and that b) they connected these dynamic experiences of generating area to the more ‘static’ length and the width measures of a rectangle.

Subsequently, we thought to engage students in experiences where they had to modify a shape to fit another shape, in order to create the need for considering both the base and height when comparing two shapes. (Due to the ambiguity of the word ‘length’ we used the terms ‘base’ and ‘height’ in the beginning, and ‘length’ and ‘width’ later.) Thus, in the next set of tasks we asked the students to modify envelopes to fit the size of some cards. Students had to change only the base or the height or both on the envelope (Figure 4a). Then students were asked to color each envelope they created by modifying the length of a paint roller and dragging the roller over a distance to color the whole shape (Figure 4b).

Indeed, through task 4a students’ articulations showed that they began looking at both the base and the height of the rectangle to compare two shapes. Examples included, “the height needs to change and the base remains the same, because it’s the same [the base] as the envelope’s.” Additionally, task 4b assisted students in connecting the dynamic experiences of painting to the static attributes of a rectangle, such as “If the height is 8, so you are gonna want to make the length of the paint roller 8 cm too so that it can match. If the base is 10 then the distance of paint should be 10 cm.” Although our design up to this point was successful in assisting students in comparing two shapes by comparing and making inferences about their dimensions, students still could not relate their dimensions multiplicatively.
Figure 4. (a) Modifying the base and/or height of the rectangle to fit in the card, (b) Coloring the envelop using a paint roller.

This led to a reformulation of our humble theory to include the conjecture that students could reach to the goal of length times width if they recognize the proportional relationship between length and area (when one dimension is constant.) Subsequently, we designed tasks that asked students to explore ways to double/half a rectangular parking space designed by GSP (Figure 5). Through this task, students recognized that to double/halve the area they needed to double/halve the length or the width. Although this task helped students to move from non-numeric covariation ("The bigger the roller the bigger the shape") to expressing covariation numerically ("If I double the length, the area is doubled") providing some evidence of understanding the multiplicative relationship that underlies length and area, still they were not able to identify the multiplicative relationship of the formula.

Figure 5. Students double the length of a rectangle to double the area.

Therefore, our focus shifted on research about iterating a fixed unit to find area (Izsak 2005; Lehrer, 2003). We conjectured that if students could iterate a roller of a fixed length (e.g. 1 inch) to cover a surface, they would consider the distance covered in one swipe of the roller with the number of swipes, and construct a repeating pattern for covering the shape (Outhred & Mitchemore, 2000; Reynolds & Wheatley, 1996). This involved identifying that a length can be partitioned into a number of equal-sized units (Izsak 2005; Lehrer, 2003), which in our case would mean 1-inch rollers. To do that, we designed a task where students had to paint shapes of different lengths and widths using a single 1-inch roller (Figure 6). Students’ articulations showed that the task design encouraged students to describe area using the multiplicative ‘times’ language, such as "this is 30 [bottom right rectangle in Figure 6] because the base is 10 and we are going to swipe three times” or “we need to do 10 three times.”
Figure 6. Students use 1-inch rollers to paint walls of different lengths and widths.

Aiming to show that the position of the roller can vary and also illustrate the commutativity of the multiplicative relationship in our design, we constructed tasks where the roller was placed vertically or on the right of the shape (Figure 7). Viewing both the horizontal and the vertical alignment of the roller led to generalizations like “4 swipes of 5 cover the space as 5 swipes of 4.”

Figure 7. Students use 1-inch rollers in various positions and reason about the space covered.

Although our conjecture of iterating a 1-inch roller along the length of a rectangle was helpful for expressing the space covered multiplicatively, still students were not able to describe area as base times height. This led to a reformulation of our humble theory. Our next conjecture was that central to the construction of the area formula would be to give students a roller with the same length as the height of the rectangle and help them identify that a 3-inch roller covers the same space as three 1-inch rollers. For example, students painted a
rectangle of base 4 units and height 3 units using a roller of 3 units (Figure 8). We observed that to find the space covered, students began decomposing mentally the large roller to 1-inch rollers. They realized that decomposing the length into unit lengths does not affect the area, for example, “we could cut a 3-inch roller into 3 parts and go across 3 times for a distance of 4, the shape will cover 12.” Engaging students in these tasks helped them visualize a large swipe as a composite of 1-inch swipes. As we progressed towards the final sessions of the design experiments, students gradually distanced from the terminology of rollers and began using length times width intuitively recognizing that the height of a shape shows the number of 1-inch swipes and the base shows the rolling distance.

![Figure 8. Students cover a rectangular park with grass rollers of different measurements.](image)

Using the 1-inch rollers and iterating was a compromise we had made in our design in order for the students to think multiplicatively about the relationship between length, width and area. As students’ multiplicative thinking of area developed further, our next conjecture was that students could use this knowledge to think about the proportional relationship between length and area. We designed tasks, such as the one we had in Figure 6, and also included tasks for students to recognize that in order to split area (fractional thinking), they need to split the length or the width. The tasks engaged students in creating shapes that have a fraction of an area of another shape. For example, students were asked to create a cafeteria which is 1/4 of an 8 by 5 inches garden (Figure 9) and argued that “If we split this into four parts, then one of the parts will be the cafeteria. It would be 2 inches [the height of the cafeteria] because the if we use only 1-inch roller it would go 8 times across but if you use 2-inch roller then it would go 1,2,3, and that would go 4 parts.”

![Figure 9. Students create a cafeteria which is ¼ of an 8 by 5 inches garden](image)
Additionally, we wanted to test the conjecture that students could use this dynamic measurement knowledge to recognize area as a multiple of its dimensions and identify factors that give the same area. Our tasks involve asking students to create different rectangles of the same area (e.g. 12 sq. inches) (Figure 10). This connects area measurement to geometry and the concept of congruence by recognizing congruent shapes in different orientations (e.g. 2 x 6 or 6 x 2) and describing congruence by using geometric motions, such as rotation (Huang & Witz, 2011). It also directly relates to the properties of multiplication (e.g. commutative property) as well as factors and multiples, for example during this task students stated, “length 4 and width 3 is doing 4 swipes of 3. This is same as two swipes of 6, so length 2 and width 6.” Although students were not asked to paint as they did in previous explorations, we provided paint rollers as a resource. We found that these rollers became a powerful tool to help students visualize the size of covered spaces and for transitioning from sweeping-based reasoning to reasoning about area as length \times width.

Figure 10. Students create stores that have area of 12 sq. inches and different length and width from other stores.

Concluding remarks
This study examined a dynamic way of learning and teaching measurement. The aim of this paper was to illustrate the iterative process of designing tasks for DYME aiming to show how the task design and the sequence of tasks evolved to assist students in visualizing the multiplicative relationship underlying the area formula. The examples of student behavior presented in this paper illustrate some of the ways that students’ thinking of area progressed through the study. Results showed that the paint rollers were a very powerful tool for students in visualizing area as a continuous, dynamic structure defined by two quantities: length and width. Students also used this knowledge to understand more advanced notions such as scaling, factors and fractions.

This paper presented a snapshot of the first cycle of design experiments. In subsequent cycles, that included whole classroom design experiments, we explored further how students’ thinking progresses through the particular tasks and designed a learning trajectory (Simon, 1995), illustrating how students’ DYME reasoning may develop over time (Panorkou, 2017). The overall study shows DYME’s potential as a route to area measurement that would make the multiplicative formula of area more intuitive and accessible. These findings are also useful for continuing the discussion around the potential of technology to change what is possible to learn. In the future, we plan to examine further how DYME thinking may assist students in making connections between various mathematical ideas, such as multiplication/division, fractions, transformations, and covariation. We are also currently exploring how DYME may be extended to non-rectangular surfaces and volume in the later years of schooling.
References

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Characterizing Computational Thinking in High School Science

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Abstract: This study identifies high school students’ computational thinking practices in the context of science, technology, engineering, and math (CT-STEM practices) and the relationships between their practices-in-use. More specifically, we explore the CT-STEM practices that emerged as a result of students’ participation in a two-day biology lesson featuring the exploration of a computational model on predator-prey dynamics. Digitally recorded data were taken from seventy-six students across four classes of one teacher. By applying a grounded analysis to students’ written responses to two different assessment items embedded within the lesson, we found four CT-STEM practices related to identifying a model’s limitations and eight practices related to exploring the model. Applying a network analysis to responses coded for these practices, we found networks representing common patterns of practices-in-use. This work identifies the informal CT-STEM practices that students bring to their learning and models combinations of practices-in-use.

Introduction
In recent decades, computational thinking (CT) has become critical in a variety of mathematical and scientific fields (Foster, 2006). In turn, STEM education communities have recognized the importance of integrating computation into school curricula (Quinn, Schweingruber, & Keller, 2012; Wilensky, Brady & Horn, 2014). However, computation still remains a separate area of study in most K-12 contexts. Because of the separation, students from groups that have been historically underrepresented in computational fields, such as women and racial minorities, are less likely to be exposed to authentic CT practices (Margolis, 2008; Margolis & Fisher, 2003). Integrating CT into the context of science not only gives all students access to a more authentic image of science, it also increases access to powerful modes of thinking and marketable skills for many careers (Levy & Murnane, 2004). For these reasons, we believe that integrating CT practices into K-12 STEM curricula is critical for 21st century education. Our group has worked to create curriculum and assessments to promote CT practices in the context of STEM content (CT-STEM practices). In the present report, we document and characterize the CT-STEM practices in which students engaged as a result of their participation in one of our computationally-enriched science lessons. We then explore particular combinations of practices the students used synergistically in order to address tasks within the lesson.

Theoretical framework
Our perspective on CT is motivated by Wilensky and Papert’s (2010) Restructuration Theory, which demonstrates that the representational form in which knowledge is embodied significantly influences how it may be understood. Restructuration Theory builds on a long history of psychological and historical research that has argued that representational forms shape human knowledge and understanding, both at the individual and societal level (e.g., Goody, 1977; Olson, 1994; diSessa, 2001). In light of this theory, we argue that the representational affordances of computational tools are changing the way knowledge can be constructed, expressed, and understood across disciplines. However, the field has not yet understood how to measure the affordances of computational representations for learning or how to characterize practices when engaging with such representations.

Our group addressed one aspect of this challenge and characterized the nature of computational thinking practices in the STEM disciplines. On the basis of interviews with computational STEM researchers, we developed an operational definition of computational thinking as a set of practices organized in four major strands: Data Practices, Modeling and Simulation Practices, Computational Problem-Solving Practices, and Systems Thinking Practices (Weintrop, et al., 2015). We have used this taxonomy to inform learning objectives, curriculum, and assessments to foster and evaluate students’ development of computational thinking practices in STEM subjects at the high school level.

While this taxonomy has informed our design, it is also important to consider the prior knowledge students bring to their learning. diSessa (1993) has argued that students develop more expert knowledge through
the reorganization and refinement of prior knowledge. He further argued that knowledge is a complex system of smaller elements. In the novice knowledge system, elements are loosely interconnected and cued variably for sense-making depending on context. In the expert knowledge system, elements are more reliably connected and cued more consistently in contexts where they are productive. Learning (and the transition from novice to expert) occurs through the reorganization and refinement of the networks of elements in the knowledge system. The novice knowledge system is therefore viewed as a resource rich with potentially productive building blocks for the construction of more expert knowledge networks. Research within the KiP program has documented elements of naïve knowledge in a variety of forms including (but not limited to) intuitions for why things work the way they do (diSessa, 1993), naïve epistemologies (Hammer & Elby, 2002), and competencies for representational practices (diSessa & Sherin, 2000).

Such networks of novice and expert knowledge systems can be visualized and analyzed through network analysis tools. In general, network analyses trace the flow of information, uncover prominent patterns in networks, and detect the effects of such patterns. In social network analysis, for example, researchers examine patterns among people’s interactions, where the nodes of the network represent people and links among the nodes represent how strongly certain people are connected (Freeman, 2006). To measure connections among CT-STEM practices, however, the nodes do not represent people, but rather represent the knowledge and skills of one individual. These nodes are elements identified in discourse (e.g., written documents, conversations, or actions), and the links represent the individual’s associations between nodes. These links are analytically determined when elements co-occur in the discourse. Researchers have shown that co-occurrences of concepts in a given segment of discourse data are good indicators of cognitive connections (Arastoopour, 2016; Lund & Burgess, 1996). In effect, discourse networks allow us to analyze the connections among CT-STEM practices.

One tool for developing such discourse networks is Epistemic Network Analysis (ENA) (Shaffer et al., 2009; Shaff er, Collier, & Ruis, 2016; Shaffer & Ruis, 2017). ENA measures when and how often students make links between domain-relevant elements during their work. It accomplishes this by measuring the co-occurrences of discourse elements and representing them in weighted network models—meaning when someone repeatedly makes a link between elements, the weight of the link between those elements is greater. Furthermore, ENA enables researchers to compare networks both visually and through summary statistics that reflect the weighted structure of connections (Collier, Ruis, & Shaffer, 2016). Thus, researchers can use ENA to not only model discourse networks, but also quantitatively compare the discourse networks of various individuals and groups of people.

In this study, we take a KiP lens to students’ activity in the context of our curriculum and chart the space of the informal CT-STEM practices in which they engage. We then use ENA to model the relationships between students’ practices in the context of instructional tasks. The specific research questions we address are: (1) What is the character of students’ CT-STEM practices that emerge in the context of one biology lesson? and (2) How are the practices connected when students use them to accomplish a particular task within the lesson?

**Methods**

We approached our research questions by analyzing data from the fifth iteration of a design-based research cycle (Collins, Joseph, Bielaczyc, 2004). The implementation spanned the 2016-2017 school year and was tested in eight classrooms across three partner high schools in a large Midwestern city. Over the course of the school year, students ranging from grades 9 – 12, participated in three CT science lessons, each lesson approximately two days in length. In order to understand the character and connectedness of CT-STEM practices that students enacted in our curricular lessons, we conducted a fine-grained analysis of a smaller sample of student work produced in the context of a single high school biology lesson which focused on predator-prey dynamics and ecosystem stability. For this preliminary analysis, we chose to investigate the work of the students of one participating biology teacher.

**Lesson description**

“Ecosystem Stability” is a 2-hour biology lesson designed to engage students in CT-STEM practices within the Modeling and Simulation strand of our taxonomy. This lesson builds on ecology lessons designed for high school biology classes (Wilensky & Reisman, 2006; Wagh, Cook-Whitt, & Wilensky, 2017). For this lesson, students explored population dynamics in a NetLogo (Wilensky, 1999) simulation of an ecosystem consisting of three organisms (grass, sheep, and wolves) (Wilensky, 1997). Students investigated the population-level effects of parameters for individual organisms (such as initial population and reproduction rate) by running the simulation with different values for each organism. Through their exploration, the students learned about the complex population dynamics that emerge from the interactions between individual organisms. In this way, students both learned about factors affecting the balance of an ecosystem and developed practices related to using and assessing
computational models (e.g., exploring a model by changing parameters; identifying simplifications made by a model).

Participants and data collection
The lesson was implemented during the fall of 2016 in the five regular biology classes of Ms. Buckthorn, a 9th grade biology teacher at Greenboro High School. Seventy-six 9th grade students participated in the lesson. Ms. Buckthorn’s students were representative of the students at Greenboro (44% White, 29.4% Black, 18% Hispanic, 5.6% Asian, 2.4% Native American, Pacific Islander, or Bi-Racial; 40.5% low-income; 4.2% English Learners; 12% IEP students).

Data were collected in the form of student responses to assessment items embedded in the lesson. Student responses to two particular prompts were coded for this analysis. The first prompt was “Describe 3 limitations of using a model like this to make predictions about what could happen in the real world.” This prompt was designed to engage students in CT-STEM practices related to identifying the simplifications made by a model, a practice within the Modeling and Simulation strand of the taxonomy. These practices are important to students’ epistemological development, as they relate to their understanding of a computational model as a tool that is both powerful and limited with regards to the construction of new knowledge. The second prompt followed a challenge that asked students to adjust parameters to stabilize the system (i.e., keep both the wolf and sheep populations from going extinct). This prompt had two parts: “Which specific variable(s) did you change and how did you change them?” and “Explain why you made these changes. How do you think these changes helped to stabilize the ecosystem?” It was designed to engage students in CT-STEM practices related to exploring a model by changing parameters, a practice also organized within the Modeling and Simulation strand of the taxonomy.

We addressed our first research question with a qualitative approach to characterize the nature of students’ CT-STEM practices. We addressed our second research question by using a quantitative approach to explore the relationships between these practices. We began by conducting a grounded analysis of students’ written responses to identify and characterize their CT-STEM practices within the Modeling and Simulation strand of the taxonomy under the general practice identifying model limitations or exploring a model by changing parameters (1). We used these practices as the basis of coding schemes which we applied to student responses to the two questions from the lesson. Two researchers coded a subset of ten student responses from the data as a training set and calculated their inter-rater reliability using Cohen’s Kappa. If the researchers had a kappa higher than .60, they split the dataset and coded the remainder of the responses. Cohen’s Kappa statistics are reported in the findings for each code below.

In order to quantify the connections between practices-in-use, we used Epistemic Network Analysis (ENA). In this context, ENA measures when and how often students use CT-STEM practices together when addressing a particular question. The network representation allows for an examination of two aspects of student work: (1) the density of the networks, which shows how many practices a student is connecting and (2) the thickness of the links, which tells us which practices students are connecting more frequently. Additionally, ENA allows for the comparison of multiple student networks because it fixes each practice in the same Cartesian space for all students. Although ENA also provides other features such as an interpretable multi-dimensional projection space and offers a variety of confirmatory statistical analyses, in this study, we used only the basic weighted networks to conduct an exploratory analysis of the various student patterns of CT-STEM practices-in-use.

Findings
Our findings focus on students’ CT-STEM practices for identifying model limitations and exploring a model by changing parameters. We present our findings for research question 1 by characterizing student CT-STEM practices. We then present our findings for research question 2 by exploring the connections between practices-in-use.

Research question 1: Characterizing student CT-STEM practices
Through a grounded analysis, our team identified four CT-STEM practices relevant to identifying the limitations of a model in students’ responses to prompt 1: “Describe 3 limitations of using a model like this to make predictions about what could happen in the real world.” We identified eight CT-STEM practices relevant to exploring a model by changing parameters in students’ responses to prompt 2: “Which specific variable(s) did you change and how did you change them? Explain why you made these changes. How do you think these changes helped to stabilize the ecosystem?” We present these CT-STEM practices and characterize and illustrate each with examples from the data.

Identifying model limitations
Identifying general limitations. Thirty-six students (47%, Cohen’s Kappa = .61) addressed prompt 1 by noting general inaccuracies or missing factors as limitations of the model. For example, one student wrote: “This model may not be accurate, and it does not factor in outside variables.” This suggests these students are aware that the wolf-sheep model is an approximation of reality, but they have not engaged in careful thinking to identify particular inaccuracies or missing factors.

Identifying visual representational limitations. Nine students (11%, Cohen’s Kappa = 1) noted visual inaccuracies as limitations of the model. One student wrote: “It isn’t 3-D.” This suggests that these students understand that the model is not an accurate depiction of reality. The model used presented a 2-D projection of the environment which is certainly an approximation of the true reality. However, this is not a “meaningful” limitation compared to other limitations that students mentioned, as in this case, the approximation does not influence the interactions between the elements of the model and therefore does not influence the outcome of any given simulation trial. In other words, wolf and sheep are confined to movement about the Cartesian plane and the addition of a third dimension would not influence any possible outcomes of this model.

Identifying completeness limitations. Forty-five students (60%, Cohen’s Kappa = .65) offered specific elements or factors that were missing from the model. One student listed three missing or incomplete aspects of the model: “1. You only have two animals, 2. You don’t have an entire country, 3. You only have one thing a sheep can eat.” These students recognize that the wolf-sheep model is an approximation of reality. They have compared it with the real world and identified factors that are found in the real world but missing from the model. It is probable they believe these factors are somehow important to the model and would change the outcome of a simulation trial. Limitations such as these are important for scientists to identify, because they help them interpret their results and recognize their limitations.

Identifying procedural limitations. Ten students (13%, Cohen’s Kappa = .75) noted differences between the interactions or behaviors encoded in the model and those they expected to find in the real world. One student wrote: “The moving of the animals is random, they run out of energy which isn’t very similar to the real world, the real world is unpredictable.” Limitations such as this are extremely important for scientists to recognize, as they are related to how successful the model is at approximating reality. Procedural limitations of the model influence the outcome of a simulation run in an important way: if the simulation does not reproduce patterns found in real-world data, something about the encoded theoretical model is wrong and needs to be revised.

Exploring a model by changing parameters

Varying a parameter. Sixty-eight students (92%, Cohen’s Kappa = 1) noted the specific parameters they changed. One student wrote: “We changed every single variable until we found the closest one until the sheep kept spiking so we changed the reproduction rate and they became more balanced.” It is not surprising that so many students engaged in this practice, as they were directly prompted by the lesson to do so. Tinkering with a model by varying parameters is, however, an activity fundamental to exploring a model.

Testing a parameter. Forty-six (62%, Cohen’s Kappa = 1) students noted the range of values (or specific values) they tried for different parameters. One student wrote: “We changed both sheep and wolf reproduction, sheep reproduction from 4% to 3%, and wolf reproduction from 4% to 9%. We changed the initial wolf population from 50 to 55. We changed the wolf gain from food from 20 to 25.” This is evidence that they tested specific parameter values. This is a more particular instantiation of varying a parameter that the student executes with perhaps greater intentionality (e.g., they might intend to investigate the relationship between a parameter and system behavior by comparing extremes). This is a more systematic approach to exploring a model than a tinkering approach.

Describing effects qualitatively. Forty-nine students (66%, Cohen’s Kappa = 1) qualitatively described how the system responded when they changed particular parameters. One student wrote: “These changes, such as raising the reproduction rate of wolves grew the wolf population and by result lowered the sheep population.” It is important to attend to outcomes of the simulation when tinkering with or testing parameters, in order to notice relationships between cause and effect. Simple qualitative characterizations of the relationships within a system are a foundation for constructing more detailed or mathematical relationships. A simple qualitative almost gestalt understanding of a cause-effect relationship can be a powerful tool for reasoning about system dynamics and for conveying the big ideas about the relationships within a system to others (in the scientific world these “others” might be collaborators or members of the scientific community at-large).

Describing effects quantitatively. Six students (8%, Cohen’s Kappa = 1) included quantitative information from the simulation when describing how the system responded to their changes to parameters. One student wrote: “I lowered the reproduction rates of both wolves and sheep to 1%. I started with 90 sheep and 50 wolves. The sheep had 2 for their gain from food and the wolves had 40.” This suggests that these students were attending to particular evidence in the data and trying to describe the relationships they saw in a more precise and
mathematical way. Note that while this practice is similar to “testing a parameter,” it requires students to attend to model outcomes, not just input parameters.

**Describing the evolution of a system over time.** Ten students (14%, Cohen’s Kappa = 1) described how the system progressed over time. One student wrote: “I actually didn't change anything and just clicked go, after watching the graph and the animation for 884 ticks it seemed to be stable, grass goes up sheep begin to go up, sheep go up wolves go up. grass goes down sheep go down and wolves will go down too.” This is an important part of exploring a simulation: letting it run and observing how it changes over time. Complex systems such as the one represented by this ecosystem model, are dynamic systems—they exhibit patterns of change over time. Important changes can only be observed if simulations are run over a long enough period. Describing behavior as it changes over time can lead to recognizing important patterns.

**Explaining reasoning.** Forty-nine students (66%, Cohen’s Kappa = .60) provided explanations for why changing a particular parameter resulted in a system outcome. One student wrote: “I made these changes because the sheep population was growing to o large. This caused the wolf to eat more, then reproduce more. Then eventually the sheep would die off, causing the wolfs to die off.” Explanations such as this convey the students’ reasoning and suggest that they are not only attending to cause and effect, but that they are going one step further and trying to make sense of the relationship between cause and effect – a fundamental activity of science.

**Strategizing.** Thirty-nine students (53%, Cohen’s Kappa = .74) wrote responses that showed evidence of goal-directed or planned behavior. One student wrote: “I changed the reproduction rate because the wolves started to spike so I figured the wolf reproduction was too high.” This suggests the student was drawing on a hypothesis about the relationship between reproduction rate and population size to make decisions about changing parameters, strategically.

**Comparing across multiple trials.** Fourteen students (19%, Cohen’s Kappa = .62) gave responses that were evidence they ran the simulation over multiple trials and compared results across those. One student wrote: “I changed the reproduction rate for each organism and changed the initial amount of each. It was difficult to get the things exactly right but I got close my closest was 228 ticks.” When exploring a model to learn more about the dynamics of, or test a hypothesis regarding, a complex system, it is important to observe more than one simulation run. This is because complex systems are inherently random and the results of changing a parameter vary over different simulation trials. A pattern of cause-effect relationships will hover around an average tendency, but this average tendency may not be exactly embodied in one (or several) simulation trials. So, if a student only runs one trial, they may have a misguided impression of a pattern in system behavior. It is also a good idea to run multiple trials in order to systematically compare the effects of different parameter values on system behavior.

**Research question 2: Exploring connections between CT-STEM practices**

Using ENA, our team identified the most frequent individual student networks of CT-STEM practices using students’ responses to prompt 1 and prompt 2. To answer research question 2, we characterize and exemplify each network of students’ CT-STEM practices with data.

**Identifying model limitations**

The first question asked students: “Describe 3 limitations of using a model like this to make predictions about what could happen in the real world.” Thirty-nine students (53%) had discourse networks which consisted of zero connections (not pictured). Eleven students (15%) had discourse networks which consisted of one link between General Issues and Completeness (Figure 1). We interpreted a link between General Issues and Completeness as a student claiming the model was incomplete and then listing general issues related to a lack of completeness. For example, one student responded, “In the real world there are more variables like day to day weather, other predators, hunters and so many other things that could affect their habitat.” This student claimed the model was incomplete (“In the real world there are more variables like day to day weather...”) and concluded with a general statement (“...and so many other things that could affect their habitat.”).
Of the remaining students, two had a network that consisted of links among General Issues, Completeness, and Procedural Limitations (Figure 2). For example, one student provided a variety of limitations of the model: “Nature isn’t a perfect system so it won’t be completely accurate. There is more than one type of predator and more than one type of prey. Weather isn’t taken into account in this model.” This student identified procedural limitations (“Nature isn’t a perfect system”), provided a general statement related to such procedural limitations (“so it won’t be completely accurate”), and then claimed that the model was incomplete (“There is more than one type of predator and more than one type of prey. Weather isn’t taken into account”).

![Figure 2](image)

Figure 2. The discourse network with the most connections for prompt 1 which consists of connections among General Issues (Identifying general limitations), Completeness (Identifying completeness limitations), and Procedural Limitations (Identifying procedural limitations).

Exploring a model by changing parameters

This question had two parts and asked students: “Which specific variable(s) did you change and how did you change them?” and “Explain why you made these changes. How do you think these changes helped to stabilize the ecosystem?” Ten students (13%) had discourse networks which consisted of zero connections (not pictured). Eight students (11%) had discourse networks which consisted of one link between Varying Parameters and Testing Parameters (Figure 3). For these eight students, this link occurred in the first part of the question; these students did not make any links in the second question. We interpreted a link between Varying Parameters and Testing Parameters as being able to vary parameters and then provide specific values for testing. For example, one student responded, “the variables that we changed was the grass regrowth time to 50” which coded for both Varying Parameters and Testing Parameters. For the second part of the question, the same student responded, “Because the grass is like the most important part to keep the system alive,” which did not contain any co-occurrence of codes and thus, did not appear in the network representation.

![Figure 3](image)

Figure 3. The most frequently occurring discourse network for Q2 which consists of one connection between Varying Parameters (Varying a parameter) and Testing Parameters (Testing a parameter).

Out of the remaining students, one had the most connected network which consisted of links among Comparison, Reasoning, Describing Effects Qualitatively, Strategy, Varying Parameters, and Testing Parameters (Figure 4). This student linked between Varying Parameters and Testing Parameters in the first part of the question. In the second part of the question, the student again connected Varying Parameters and Testing Parameters (hence, the link is thicker in the network representation), but also added Comparison, Reasoning, Describing Effects Qualitatively, and Strategy. The student’s response to the first part was, “I changed the initial number of sheep to 150 and the initial number of wolves to 75,” and his response to the second part was “I made these changes from trial and error. I switched them so that the wolves and sheep wouldn't die out so quickly, so giving them a greater initial population helped, while the reproduction percentage kept the populations balanced.” The student explained the use of a “trial and error” strategy “so that the wolves and sheep wouldn’t die out so quickly,” which was a qualitative description of the effects and a comparison of the predator and prey populations. The student’s reasoning for those actions were that “a greater initial population helped, while the reproduction percentage kept the populations balanced.”
Discussion

In this study, we examined student responses to two prompts given in one CT science lesson which introduced students to predator-prey dynamics through exploration of computational models. Through a grounded analysis, we identified emergent student CT-STEM practices and classified them within the Modeling and Simulation strand of our theoretical taxonomy. We then analyzed patterns of co-occurrences of these practices-in-use and represented these co-occurrences as discourse networks using ENA. Such networks allowed us to shed light on characterizing student CT-STEM practices in terms of the relationships among students’ CT-STEM practices-in-use and varying levels of expertise regarding their synergistic use. Our results showed that students brought a variety of informal CT-STEM practices to accomplishing tasks within a computational biology lesson and that they drew on multiple practices while working on particular tasks within the predator-prey lesson.

We found that students engaged in practices relevant to identifying model limitations, including identifying general, representational, completeness and procedural limitations. We found that the majority of students noted general model limitations and missing elements, while very few students noted inaccuracies regarding visual representations or inconsistencies between the behavior of model elements and that of their real-world counterparts. We found that students engaged in practices relevant to exploring a computational model. These practices included varying parameters by tinkering, testing particular parameters, describing the effects of changing parameters in both qualitative and quantitative terms, describing the evolution of a model over time, explaining their reasoning for a system’s behavior in response to changing a parameter, approaching their exploration of a model strategically, and comparing simulation results across multiple trials. All students varied parameters and most tested specific parameters. The majority of students qualitatively described the relationship between changing a parameter and its effect on the system behavior and explained their reasoning for why the cause-effect relationship made sense. A majority of students also showed evidence of approaching their exploration of the model strategically. Taken together, these findings suggest that participating students brought many informal practices to their learning that can be developed into more sophisticated CT-STEM practices (Smith, diSessa & Roschelle, 1994).

Our network analysis revealed a range of complexity in students’ patterns of practices-in-use, from students who drew on very few practices to students who drew on numerous practices to respond to a particular sense-making task. The supporting qualitative analyses of these networks indicated that students with more highly connected networks (i.e., students who drew on more practices to accomplish a task) provided more sophisticated, detailed responses to the assessment prompts. This suggests that as students develop more complex and meaningful patterns of practices-in-use, they may develop more highly and meaningfully connected representations of understanding (diSessa, 1993). We argue that the networks we presented represent patterns of practices-in-use at varying levels of expertise and could be used to model and understand developmental trajectories of student CT-STEM practices.

Endnotes
Although students’ written work may not give us as complete a picture of their engagement in CT-STEM practices as, for example, video footage, student responses provide evidence of CT-STEM practices, as they often include descriptions of how the student engaged with computational tools.

References


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Developing Productive Discourse among Low Achievers in a Knowledge Building Environment

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Abstract: This study investigates how an understanding of and engagement with productive discourse can be developed among low-achieving students in a knowledge building (KB) environment supported by Knowledge Forum® (KF). Participants were two classes of 9th Grade students in a Hong Kong secondary school. The design involves students engaging in productive discourse, talking about what constitute good discussion, and explicit reflection on their discourse using KB principles. Quantitative analysis shows that students improved more on their understanding of discourse than comparison student and engaged in discourse that become more productive over time. Qualitative analyses reveal how the low-achieving students engage in the classroom meta-talk to deepen their understanding of progressive views of discourse and knowledge building.

Introduction
Developing students’ productive discourse has been the focus of recent research on learning, specifically in the learning sciences (Sawyer, 2014). Traditional teacher-student discourse, structured as initiate-response-feedback (IRF), has been the most frequent discourse pattern in the classroom (McNeili & Pimentel, 2010). However, under this rubric, students lack the opportunity to work collaboratively and to build-on each other’s ideas for sustained inquiry and knowledge building. Consequently, there has been a growing interest in dialogical teaching in classroom discourse and teacher mostly as facilitator in developing a rich dialogic discourse (Chen, Clarke & Resnick, 2014; Hennessy et al., 2016). As discourse is epistemic in nature and central to knowledge development, how educators can help students develop a productive discourse and how knowledge-building discourse in classroom is manifested needs to be examined. Knowledge building (KB) is an educational model and pedagogy that has been examined in various domains and across grade levels, but relatively little work has focused specifically on low achieving students. Discourse development is often thought to be particularly challenging for low achieving students, as they tend to be perceived as unable to engage in high-level inquiry and thinking (Zohar, Degani, & Vaaknin, 2001). If the facilitation of classroom discourse is important for students to develop a complex, epistemic understanding of their inquiry and discourse, then a focus on enabling low-achieving students to engage in KB is even more pressing. How low-achieving students experience and perform in KB work in both classroom and online settings are thus important to examine. The purpose of the present study is to investigate the role of design in enhancing students’ discourse understanding and to examine how productive discourse can be developed among low achievers.

Theoretical perspective
This study is based on the knowledge building (KB) educational model and pedagogy (Scardamalia & Bereiter, 2014). KB calls for the pursuit of idea improvement and collective responsibility. In the KB community, students engage in progressive discourse supported by Knowledge Forum® (KF), an online community platform. Students advance their community knowledge through sustained progressive inquiry using the embedded metacognitive scaffolds; (for instance, “I need to understand”). Ideas are regarded as a social product of the community (Scardamalia & Bereiter, 2014). However, students often engaged in disconnected and short-threaded discourse instead of productive discourse in their online discussion (Zhang & Chen, 2013). Just as discourse is central to researchers’ and scientists’ advancement of knowledge, students need to engage in purposeful discussion and explanation-inquiry driven discourse (Kuhn et al, 2011; Sandoval & Reiser, 2004). An increasing number of studies have been conducted to investigate students’ discourse development and its role in learning, with many considering the role of discourse in students’ understanding of science and students are scaffold to talk like scientists in interpreting data and relate data to theoretical claims (Sandoval, 2003).

From the perspective of KB, discourse is about progressive inquiry processes, understood to be a central epistemic practice in knowledge creation. As such, it is important for students not only to engage in discourse and inquiry, but also to understand why and how such discourse is important. KB proposed a set of 12 principles that are seen to be core to KB communities (Scardamalia, 2002), epistemic agency, collective responsibility, which together, provides epistemic criteria for students to better understand the development of
discourse. Engaging with discourse reflexively is seen to help students advance their epistemic understanding, to acknowledge that knowledge itself is evolving and extendable, and that it can be created collectively.

While helping students to understand productive discourse for epistemic growth and metadiscourse engagement are important (Yang, Chan, van Aalst, & Tian, 2016), it should not be assumed that students will spontaneously develop productive discourse, even in inquiry-learning environments (van Aalst, 2009). In science education, explicit reflection on the epistemic criteria of scientific model can help students to engage in the scientific inquiry and understand the nature of science (Pluta, Chinn, & Duncan, 2011). This is similar to the KB principles, in that it is important to help students and particularly low-achieving students to explicitly reflect on their discourse, rather than merely engaging in collective inquiry. Students need to engage in meta-discourse to reflect on their online talk and to identify deeper questions for further inquiry (Zhang & Chen, 2013).

Crucially, KB and other inquiry experiences are considered difficult for low-achieving students, who often have literacy problems and learning difficulties (Shen et al., 2007). They are perceived as being limited to low-level metacognitive strategies and unable to engage high-level strategies, making it difficult for them to plan, monitor, and reflect on their tasks and learning process and to highlight essential insights (Azevedo, Cromley, & Seibert, 2004; van Aalst, 2009). As such, it becomes particular important to help low-achieving students to develop productive discourse engagement using KB principles as epistemic criteria to monitor and evaluate their discussions. Earlier research provides some evidence of KB for low achievers (Yang et al., 2016), but the dynamics of classroom discourse and students’ conceptions of discourse have not been investigated.

Overall, the goal of the present study was to design a KB environment that is focused on specifically on discourse development, reflection, and understanding for low-achieving students to help those students engage in productive discourse, and to examine the role of the KB environment on students’ epistemic understanding, KB discourse development, and classroom productive discourse. Specifically, three research questions were addressed: (1) What characterize students’ understanding of discourse, and how did they change after instruction? (2) What was the nature of KB discourse and to what extend did students engage in KB discourse? (3) How did students engage in the classroom discourse to reflect on their online talk?

**Methods**

**Research context and participants**

Two classes of 9th Grade students enrolled in a visual arts class at a Hong Kong Band-3 secondary school participated in the study. Secondary school are organized into three groups, from Band 1 (highest-achieving) to Band 3 (lowest-achieving) based on students’ public examination results, and students in the present study are thus institutionally recognized as low-achieving students. The study was conducted in a classroom with students engaged in a KB environment augmented with explicit reflection (n=31). A comparison class, engaged in a regular KB learning without reflection and discourse design, was also included to provide additional data (n=32).

**Pedagogical design**

In this study, we designed a KB environment with an emphasize on understanding of discourse and explicit reflection to support student’ production of knowledge and progressive productive discourse (Figure 1). An explicit reflection cycle was developed and implemented in the KB pedagogy (Chan, 2011).

(1) Creating a collaborative classroom culture with group work and ideas made public through a Knowledge Building Wall (KB Wall) (Figure 2) (Week 1–4). In developing a collaborative classroom culture, students first worked in groups to develop collective ideas through mind map and then presented ideas to the whole class; this was followed by creating a KB Wall to generate questions and build-on others’ ideas in the
community; (2) Starting and developing progressive inquiry in KF with questions and ideas generated, as well, good KF notes identifying under teacher’s scaffolding (Week 5-7). Students generated meaningful questions from the KB Wall to continue to inquiry on KF. After a period of discussion on KF, students were also asked to identify good notes based on their KB Wall and KF discussion; (3) Scaffolding understanding of discourse in an explicit way and deepening productive discourse moves with KB principles discussion and KF discourse reflection and comparison (Week 8-16). KF discussion and classroom talk were intertwined. The teacher started to help students to review on what they had learned, monitor their learning process, identifying core problems for further inquiry, and reflect on their KF discussion. The comparison class also went through the phase 1 to 2. But whereas the intervention group had KB Talk on discourse understanding and reflection of KF discourse moves, while the comparison group only continued to work in KF without intervention.

Figure 2. An example of students’ mind map and KB Wall.

Data collection
Over a four-month period, students in both of the two groups inquired and discussed the topic of what is art and arts appreciation. Through this period, various data were collected including: (1) Pretest-posttest on discourse understanding. We collected and analyzed students’ pre-posttests on their understanding of discourse with a written questionnaire to examine “what do you think is a good discourse?” (2) KF engagement. Students’ online participation was examined Knowledge Building Discourse Explorer (KBDeX) (Oshima, Oshima, & Matsuzawa, 2012); (3) KB discourse. We conducted content analysis to examine students’ written in KF and used individual notes as the unit of analysis; (4) Classroom discourse. We video recorded all of the lessons and focused on the classroom discussion of discourse understanding and reflection in this paper.

Data analysis and results
Characterizing students’ understanding of discourse and change
Students’ responses were analyzed to characterize their epistemic understanding of discourse aligned with KB perspective. As Table 1 shows, students’ understanding of discourse move towards to more sophisticated views in the enriched KB group in the posttest, such as “putting ideas together to make our knowledge rise above…” and “to continued build-on…” For the comparison group, even though students’ discourse understanding also appeared to have developed in the posttest, such as “…argumentation…obtain an agreement…”, they still did not engage in a sophisticated view of discourse understanding while students’ discourse understanding in the enriched KB group corresponding more to the KB principles, which are the key themes of KB theory.

Students’ responses were coded using a 3-point scheme ranged from simple to more sophisticated views of discourse. A second rater independently coded 30% of the data, with Cohen’s Kappa calculated, K=.873, p<.001, indicating a good inter-rater reliability. Significant change was obtained from pretest to posttest for the enriched KB group, \( t(30) =4.224, p<.001 \). The significance of which is corroborated by baseline analysis suggesting no significant difference for pretests between the two groups while an independent sample t-test indicated significant difference for the posttests between the two groups, \( t(61) = 2.063, p<.05 \).

Table 1: Students’ responses about their understanding of discourse

<table>
<thead>
<tr>
<th></th>
<th>Enriched KB Group</th>
<th>Comparison Group</th>
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<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>CYR: “A good discourse need to have a fruitful discussion with everyone participate in”</td>
<td>CYR: “… everyone express their ideas, then putting our ideas together to make our knowledge rise above…”</td>
<td>GWF: “A good discourse…have argumentation and…obtain an agreement.”</td>
</tr>
<tr>
<td>FRM: “a good discourse is collaboratively working…”</td>
<td>FRM: “… we need to have diverse ideas…from different perspectives…”</td>
<td>GBY: “…focus on the conceptual topic…identify the dis/advantages…”</td>
</tr>
<tr>
<td>LQW: “a good discourse need to develop a harmonious discussion environment”</td>
<td>LQW: “… continued build-on and questions asking for sustained inquiry, which help us to improve our ideas…”</td>
<td>LTY: “for good discourse…have group discussion first, then summarize our ideas to present in the community”</td>
</tr>
</tbody>
</table>
How did students engage in KB discourse and sustain the discussion?

Students’ online engagement and discourse network
The second research question examined how students contributed to and engaged in online discussion and how they sustained their inquiry through the discussion in KF. We conducted KDBDeX analysis to explore how the discourse networks of students’ KF notes changed over time between the enriched KB and comparison group. Students’ KF notes were exported into KDBDeX and it produced a network analysis of students, discourse, and keywords. In this paper, we examined the discourse network only. As Figure 3 shows, the discourse network changed from segmented to coherent over time in the two groups. However, in each phase (phase 1 – notes 1 to 30 and phase 2 – notes 1 to 100), the discourse network was more connected with fewer fragmented notes indicating a more cohesive discussion in the enriched KB group. In phase 1, only two separate notes (highlighted in red) remained outside the main cluster in the enriched KB group, while for the comparison group, the discourse network was segmented, with many separated notes. In phase 2, the discourse network was still segmented in the comparison group with eight fragmented notes, while for the enriched KB group, the discourse network was integrated in one cluster without any fragmented notes. This suggests that over the discussion, students in the enriched KB group engaged in a more cohesive and progressive discussion than in the comparison group.

Figure 3. KF Discourse Network Change over time between enriched KB and comparison group.

Inquiry thread analysis of online productive discourse
Students’ notes in KF were analyzed to examine their productive discourse engagement. All KF notes were classified into 10 threads (thread 1-art and life; 2-artist; 3-re-creation; 4-purpose of art; 5-definition of art; 6-arts representation; 7-plagiarism of art; 8-difficulties solving by art; 9-how to read art; and 10-arts appreciation) adapted from the notion of inquiry thread with students addressing a conceptual problem (Zhang et al., 2009).

Table 2: Coding scheme for analyzing KF discourse in inquiry threads

<table>
<thead>
<tr>
<th>Codes</th>
<th>Sub-codes</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questioning and Identifying Gaps</td>
<td>Fact-seeking</td>
<td>Questions on seeking factual information</td>
<td>What is visual elements?</td>
</tr>
<tr>
<td></td>
<td>Explanation-seeking</td>
<td>Questions on seeking open-ended responses with explanation</td>
<td>How can we use visual elements to appreciate an art piece?</td>
</tr>
<tr>
<td></td>
<td>Sustained inquiry</td>
<td>Asking further questions based on previous notes or ideas and make the discussion deeper</td>
<td>Art is innovative…but how can art represent emotion? (a further question asked based on previous notes)</td>
</tr>
<tr>
<td>Theorizing and Improvable Ideas</td>
<td>Simple claim</td>
<td>Simple (dis)agree or repeat a statement</td>
<td>Art can be free designed (repeat previous note)</td>
</tr>
<tr>
<td></td>
<td>Proposing an explanation</td>
<td>Proposing a theory that explain certain phenomena for the first time</td>
<td>Art include various elements and combines different color and shape</td>
</tr>
<tr>
<td></td>
<td>Supporting an explanation</td>
<td>Supporting an already existing theory proposed by another student and providing a justification</td>
<td>Different color can represent different meaning and give people different feeling, blue represents melancholy...</td>
</tr>
<tr>
<td></td>
<td>Improving an explanation</td>
<td>Improving an already existing theory through elaboration, specifying details and using new evidence</td>
<td>You mentioned that people think that art is useless, but art is an indispensable element in our life…the clothing were designed by art…</td>
</tr>
<tr>
<td>Meta-discourse</td>
<td>Connection</td>
<td>Reference to their own or others’ notes, or quoting extra sources to advance understanding</td>
<td>“arts not equal to pictures”, arts represent many forms...photographing...(reference to a student’s note and quote extra sources)</td>
</tr>
<tr>
<td></td>
<td>Rise-above</td>
<td>Students refer back to previous discussion by asking a metacognitive question for monitoring the inquiry process and generating an explanation or evaluation</td>
<td>Everyone are artists? You said that “artists? A special existence”, artists refers to people who design projects…. I am wondering that everyone can be artists as long as they drawing or designing projects...Are we artists?</td>
</tr>
</tbody>
</table>
Within each inquiry thread, individual notes were coded. The coding framework includes three main categories of questioning, theorizing, and meta-discourse, all of which correspond with sub-codes. The development of the coding scheme (Table 2) was based on a theory- and data-driven approach, in which several theoretical frameworks were integrated including questioning and explanation (Hakkarainen, 2003), ways of contributing (Chuy et al., 2011), and the social dynamics of KB (Yang et al., 2016). A second rater coded 30% of data, K=.830, p<.001, indicating a good inter-rater reliability. As Table 3 shows, the results from our analysis suggested that students’ questions were primarily explanation-seeking, moreover, asking sustained questions for further inquiry; in addition, students focused on generating a theory and providing a detailed explanation to support the theory. Overall, results showed that students were engaged in productive discourse with high-level responsibility taken for knowledge building.

Table 3: Number of different categories of epistemic questioning, theorizing, and community in inquiry threads

<table>
<thead>
<tr>
<th>Thread</th>
<th>Fact-seeking</th>
<th>Explanation-seeking</th>
<th>Sustain inquiry</th>
<th>Simple claim</th>
<th>Proposin g</th>
<th>Supporting</th>
<th>Improving</th>
<th>Connection</th>
<th>Rise-above</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>18</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td>0</td>
<td>29</td>
<td>1</td>
<td>3</td>
<td>17</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>43</td>
<td>27</td>
<td>29</td>
<td>88</td>
<td>24</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.5</td>
<td>4.3</td>
<td>2.7</td>
<td>2.9</td>
<td>8.8</td>
<td>2.4</td>
<td>0.8</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.71</td>
<td>5.95</td>
<td>2.16</td>
<td>3.07</td>
<td>5.18</td>
<td>1.51</td>
<td>1.14</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>

To understand how students’ productive discourse changes, we divided KF notes into two periods (before and after the intervention on discourse understanding and reflection). In the comparative analysis, we analyzed the frequency of high-level discourse moves (Table 4), which suggested that patterns in students’ KF discourse changed to a more explanation-oriented inquiry and discourse over time.

Table 4: Frequency of notes within each inquiry thread in period 1 and period 2

<table>
<thead>
<tr>
<th></th>
<th>Period 1 (week 1 to 7)</th>
<th>Period 2 (week 8 to 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation-seeking question</td>
<td>19</td>
<td>24</td>
</tr>
<tr>
<td>Sustained inquiry</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Proposing a theory</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>Supporting a theory</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Improving a theory</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Connection</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Rise-above</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>

In addition to analyzing the notes within each thread, Figure 4 provides a holistic picture of students’ thread discussion development. In Figure 4, the numbers in parentheses represents the number of notes created and the number of authors in each thread, respectively. Dotted lines across threads represent notes that were included in more than one inquiry thread indicating that one idea was discussed among different conceptual topics. As Figure 4 shows, even among low-achieving students, discussion was able to be sustained over a length period of time on key conceptual issues. These threads also lasted from the beginning of the semester to the end, suggesting that students were more engaged in these topics and even inquired further by asking sustained questions, proposing and improving explanations.

Additional quantitative analyses indicated that these productive discourse moves correlated with students’ epistemic understanding of discourse. For questioning ($r=.556, p<.01$), theorizing ($r=.471, p<.01$), and a reasonable correlation in metadiscourse ($r=.349, p=.054$). The findings suggested that students with deeper understanding of discourse were more likely to be engaged in productive discourse.
The third research question examined how low-achieving students were engaged in productive classroom discourse in developing their knowledge building work. Three themes were identified. For low-achieving students, one of the scaffold is to have them engage in drawing and visualizing their work. Figure 5 shows the drawings that students made to illustrate their understanding of discourse and engaged in explicit reflection to compare KF discourse across two classrooms. Low-achieving students reflect on their own discourse albeit by more with limited ways of drawing and language, followed by classroom meta-talk.

**Theme 1: Explicit reflection and discussion on discourse comparison**

In the following excerpt, the students explained the difference between their own and another class KF notes structures. The teacher (T) asked students to identify and explain the notes structures difference. Student 1 (S1) then proposed that the reason for their “straight line” was due to the focus on a single question, S2 made a supplementary point that their ideas are explained directly, then S1 synthesizing the ideas by reflecting on their KF discussion. This excerpt shows how the teacher scaffold students’ meta-discourse, to engage deeper thinking about their discourse shapes and why their discourse moves were stopped by comparing with another better discourse moves.

T Based on our discussion, what do you think a good discourse type should look like? Can anyone explain the differences of the KF structures?

S1 We only focused on one question, and we did not think and discuss from different perspectives.

S2 Our ideas followed by another ideas directly.

...
T  So our class KF discussion stop at this point, meaning we cannot move to a new stage. The “octopus-shape”, can you explain the reasons for this by reflecting on your KF discussion?

S1  In the beginning, our initial idea had four build-on notes, but later, our build-on notes become a line and one followed by one directly. However, the other class, they had two build-on notes for the initial note, and later, they had another two build-on notes in response to the above different notes, and continue to rise-above for inquiry, then, a new question was emerged. In our case, we only have one question, all the build-on notes respond to this question directly, and we did not inquiry further.

Theme 2: Reviewing and reflecting on the state of knowledge and understanding
The teacher started to help students engaged in meta-talk by reflecting on what they had learned, the teacher initiated a question on “can you reflect on what you learned from these KB lessons?”

T (Teacher)  Can you reflect on what you learned from these KB lessons?
S1  What I had learned is how to set goals, and how to think about a problem towards setting goals.
T  Any more ideas or build-on?
S2  I think we needed to have diverse ideas, means that we need to think about a problem from various perspectives.
S3  We discussed the knowledge building principle of collective responsibility, as we are doing now, we listen to others’ ideas, then work collaboratively and discuss together for further problem solving.
T  Any ideas?
S1  What we had learned is…how to build ideas and knowledge. We are learning a thinking model that is taking collective responsibility advance community knowledge…we also learned that we need to put our ideas together, to rise-above further through continued idea improvement.

As shown in this excerpt, the students tried to review what they had learned. This meta-talk showed reflection on the state of their knowledge and understanding and how students reflect on their epistemic goals and collectively building on each other’s ideas for discourse understanding. Students were able to illuminate their understanding of KB principles and their emphasis on being able to “…listen to others’ ideas…discuss together for further problem solving…” and “put our ideas together…continued idea improvement”.

Theme 3: Identifying deeper focus and core problems
In another excerpt, discussion demonstrates how low-achieving students were able to gradually develop understanding of KB concepts and principles, as they apply discourse insights to their own work in visual arts.

T  Can anyone explain how can we use this learning model we discussed in visual arts learning?
S8  We can find materials…take a note, as what we did in knowledge building. We can write down our questions, then our classmates can read our ideas…which can help us to generate new questions for further inquiry.
S9  …when you have an idea, you will generate new problems or ideas based on the initial one…

S1  In the first lesson, we discussed that visual art is a representation of creativity…Similar to KB, we can learn and develop from others’ ideas from different directions. When you get ideas from others, your art works will become diversified. So art is an integration ideas…the similar of KB.

In the above excerpt, students started to bridge the KB and their visual arts learning. For example, student 8 responded the application of what they did in KB to arts learning, “…find materials…taking notes”, followed by student 9 emphasized on generated new problems based on the initial one. Through the discussion,
student 1 tried to apply KB into arts learning by proposing an idea about the connections between KB and creativity learning and explain the similarities between them.

Conclusions and Implications
The study examined productive discourse developing including both online and classroom discourse to support low-achieving students in their KB work and understanding of discourse. We characterized students’ epistemic understanding of discourse aligned with productive discourse engagement. Analysis of discourse on the KF using KBDeX indicated how discourse began to cohere and change over time. Through the KB lessons, students began to engage in discourse in productive ways, including attempts to use meta-discourse to regulate, monitor and advance their knowledge inquiry. There was also sustained inquiry over time. Classroom discourse suggests how low-achieving students can be engaged in meta-talk about their KB discourse supported by explicit reflection. Excerpts from classroom discussions also showed how students were able to talk about KB principles in relation to their own KB work. There have been many studies on pedagogical approaches based on the principles of KB, however, this study showed how students reflect on and talk about KB principles explicitly integrate with understanding of discourse. In sum, this study is particularly important as very little research has focused on how low-achieving students engage in KB work and meta-talk on discourse itself with KB principles.

References
“We Were on the Same Level”: Young Engineering Researchers Taking Up Agentic Positions in a Diverse Learning Community

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Abstract: This study reports on the design and enactment of a summer engineering research experience for high school students focused on increasing interest and knowledge and removing barriers to participation and preparedness for underrepresented students through expansive framing of program experiences and opportunities for consequential engagement. A cadre of twelve outgoing eighth-grade students drawn from one Title 1 district learning to participate in photovoltaics engineering research and collaboratively designing a community solar engineering project over a period of six full-days. These Youth Scholars were intentionally embedded within a larger cohort of summer research participants including undergraduates, teachers, and international graduate students. Though all participants were novice in solar energy engineering, all were positioned as both learner and contributor. This design-based research study addressed the question: What were the affordances and constraints of being positioned as a learner and a contributor in a diverse cohort of novice engineering researchers?

Introduction

This study reports on the design and enactment of a model of a summer engineering research experience for high school students focused on increasing interest and knowledge and removing barriers to participation and preparedness for underrepresented students in engineering. Specifically, the project aimed to support a cohort of outgoing eighth-grade students drawn from a Title 1 district with high proportions of Hispanic students, a population historically marginalized in engineering (Gibbons, 2009). Twelve students participated in the program two days a week over three weeks (six full-day sessions), learning to participate in PV engineering and collaboratively designing a community solar engineering project that was the core activity of the program. By design, and taking a situative approach to fostering learning (Greeno & Engestrom, 2014), these Youth Scholars (YS) were embedded within a larger cohort of summer research participants that included undergraduate students trying to become engineers, local teachers developing learning to do research and create curriculum for their classrooms, older high school students exploring engineering as a possible major, and international graduate students taking on responsibilities in new labs, along with the YS working on their community solar project. Though all these sub-groups had different goals for their program participation, they all shared an interest in solar energy engineering as well as the experience of working on solar energy projects while being mentored by established graduate student-mentors from photovoltaic engineering research labs. The summer research experience participants represent differing levels of professional competence, but each participant must navigate as a learner and a contributor to the cohort and to the field, negotiating meaningful involvement in the PV engineering community while being supported by like and diverse peers and mentors. For each of these sub-groups, three focal activities organized their program experience: working on their own meaningful projects, receiving feedback from other cohort members, and giving feedback to others. Through these activities, all cohort members, including the YS, were positioned as both learners and contributors, not only as consumers of knowledge, but also as producers of knowledge (Ito et al., 2014) with the moral position, rights and responsibilities, to discursively produce their engineering selves (Davies & Harre, 1990). The purpose of this intentional positioning was to facilitate a support system where participants could draw on the affordances of their own and others’ diverse perspectives and backgrounds in order to help one another move forward the consequential work with which they were engaged (Page, 2010). Although many learning scientists investigate the affordances for learning of fostering communities of learners in relatively homogenous groups (e.g., Engle & Conant, 2002), there is little research exploring the possible benefits of fostering learning relationships in such diverse cohorts.

The current study was part of a larger research project investigating the designed-for and emergent patterns of relationships among participants and their influence on trajectories on engineering pathways. Here we focus specifically on the YS sub-cadre of this diverse cohort. Taking a design-based research approach, we examine the meaning the YS made of their participation in the program, particularly of their interactions with their older cohort members, and of their consequential engagement (Gresalfi, Barab, Siyahhan, & Christensen, 2009) in a variety of PV engineering activities. In particular, we were interested in the following research question:
What were the affordances and constraints of being positioned as a learner and a contributor in a diverse cohort of novice engineering researchers?

Membership in a diverse cohort as an innovation to address barriers to engineering

Through a consideration of the complex interaction of factors that often inhibit STEM trajectories, the project components provide a sustained cohort-based network that we anticipate is needed to broaden the participation of underrepresented students in engineering. Despite increasing emphasis on the importance of STEM-related fields by the National Science Foundation and other national organizations, the number of U.S. students pursuing STEM college degrees and careers has declined in recent decades (National Center for Education Statistics, 2015), especially for underrepresented demographic groups who have historically been excluded within STEM, namely, women and minorities (Joyce & Farenga, 2000). These disparities carry over to post-secondary education, where Hispanic students’ college entrance SAT math scores and their persistence rates in STEM fall well below that of their White counterparts (Landivar, 2013). Multiple barriers contribute to Hispanic students’ underperformance and underrepresentation in STEM domains. Inadequate K-12 academic preparation is a major factor (Museus, Palmer, Davis, & Maramba, 2011). A large proportion of K-12 ethnic minority students are raised in low income areas and do not get exposure in underserved schools to rigorous educational experiences or adequate math and science courses that comprise preparation needed for college STEM degree paths (e.g., Adelman, 2006).

Broadening underrepresented students’ participation in engineering requires effective K-12 innovations because many such students self-select out of engineering-related learning opportunities and career trajectories before entering college (Museus et al., 2011). More broadly, the majority of college students who major in STEM fields make that choice during high school. That choice is related to a growing interest in mathematics and science that develops as early as middle school (Maltese & Tai, 2011). Thus, K-12 formal and informal education experiences need to provide equitable opportunities and outcomes in three key ways: increase interest in engineering, promote knowledge in STEM content areas and opportunities for participation in engineering practices, and develop awareness of career pathways to engineering fields (Svihla & Petrosino, 2008). It is critical that learning-teaching designs aimed at broadening participation begin in high school in order to nurture learners’ initial interest and support their commitment to pursuing STEM learning and STEM careers.

We argue that current educational approaches to developing historically underrepresented students’ interest and preparation in engineering through informal learning experiences are limited in at least three ways. First, most programs consist of one-day workshops (e.g., Molina-Gaudo, Baldassarri, Villarroya, & Cerezo, 2010) or short-term afterschool club experiences (e.g., Nugent, Barker, Grandgenett, & Adamchuk, 2010). Second, current diffuse approaches introduce multiple engineering fields in surface fashion with few opportunities for rigorous preparation or deep, sustained connection to a single field. Finally, programs targeted at demographics that relate to risk or underrepresentation frequently fail to recognize that engineering cultures are characterized by particular ways of doing and “being an engineer” (Godfrey & Parker, 2010, p. 9) that may be at odds with the cultural practices and identities of historically underrepresented learners (Wilson-Lopez, Mejia, Hashbun, & Kasun, 2016). Thus, they fail to consider cultural connections that facilitate meaningful bridge-building. For example, many Hispanic groups are characterized by collectivistic orientation, familism, and an emphasis on community (vs. individual) outcomes (Knight et al., 2009). Accordingly, “helping” professions may provide more salient career pathways for many Hispanic students compared to science and technology. Yet, engineering programs for youth rarely offer experiences that highlight these aspects of students’ identities and experiences.

Given the above, there is a need for studies that test sustained educational models aimed at fostering adolescents’ interest in engineering and other STEM disciplines, participation in STEM opportunities, and preparedness to pursue engineering career trajectories. Moreover, there is a need to understand the impacts of longer-term, after school education experiences that take a focused approach, promoting deep knowledge through consequential engagement in meaningful projects, and rich social relationships within a single field (e.g., PV), while also creating a culture of support among familiar and like peers. Finally, there is a need to examine the impacts of extending this culture of support and build a community of learners that includes those with a diverse range of backgrounds, experiences, interests, and ages. This type of cohort not only approximates the collective, familial orientation of many of these students, but also positions everyone as a learner, everyone as a contributor.

Designing for consequential engagement in a diverse cohort

Here we explore the affordances and constraints of a summer youth program that attempted to systematically address the aforementioned barriers and limitations by situating incoming high school students in a diverse cohort of summer research participants, widely varying in their age, education level, and goals for the program, yet all with limited prior knowledge of PV, all interested in solar energy engineering, and all consequentially engaged (Gresalfi, Barab, Siyahhan, & Christensen, 2009) with authentic engineering research. Our designed innovation
of consequential engagement in PV engineering differs greatly from the broad, exploratory overviews of the engineering field common in other engineering education models, and is designed to foster deeper knowledge of disciplinary core ideas, crosscutting concepts, and engineering practices, skills, and habits of mind as well as to position students to learn and contribute in meaningful ways within a diverse cohort (National Academies Press, 2009). Further, through expansive framing (Engle, 2006), we sought to help students see themselves as connected to the past, present, and future of PV and its impact on broader social and environmental issues. We also framed the students’ project and their participation in the summer program in terms of potentially contributing to the field, providing opportunities to engage with their local communities and other engineers, and as products they could share digitally with a much wider audience. It was our belief that integrating this team of young scholars into a diverse cohort of summer engineering researchers would further forward the same goals we were aiming for through consequential engagement and expansive framing, to support engineering identities, which we believe are a discursive production (Davies & Harre, 1990), a joint accomplishment between individuals and their social environments (Hand & Gresalfi, 2015).

Method
Design research begins with the belief that research must attend carefully to the context of learning in order to produce knowledge that can have a positive, and potentially transformative impact (Barah, Dodge, Thomas, Jackson, & Tuzun, 2007). Thus, design researchers attempt to “engineer” learning and teaching processes and systematically studies these processes to iteratively illuminate and refine how a designed educational innovation influences learning and teaching systems (Brown, 1992). Rather than “fixed packages of strategies with readily measurable outcomes,” design research tends towards “open-ended social or socially embedded experiments that involve ongoing mutual engagement” (Gutiérrez & Penuel, 2014, p. 20). Such was the stance we took in trying to ascertain the meaning these youth scholars made of their participation in a diverse cohort and the affordances and constraints of being positioned as both learners and contributors. Design-based studies take a variety of methodological turns. Here, we took an ethnographic approach much in the style of learning scientists concerned with fostering STEM pathways for youth (e.g. Calabrese Barton et al., 2013, Rahm & Moore, 2016).

Context and participants
The context of this study was a summer research experience program at an engineering research center embedded in a university in the southwestern U.S. Within this context, twelve outgoing eighth-grade students (6 boys and 6 girls) participated as Youth Scholars, traveling to the university twice a week for three weeks. These youth scholars had recently completed eighth-grade in one of two middle schools in a large urban district serving a majority Hispanic student population (94% non-Caucasian; 93% low SES, 17% English language learners). The majority of YS participants were Hispanic; half the cadre reported their primary home language as other-than English. Attendance at the six full-day sessions was high (89%). YS participants were recruited based on their demonstrated academic proficiency and interest in STEM. All three authors, one research faculty member, one middle school teacher, and one graduate student, participated as facilitators in the program and also contributed to the program’s design.

The central activity of the YS program was designing a community solar energy engineering project. Facilitated by a local middle school science teacher, the YS participants scoped and framed a problem of interest to them: promoting solar energy in their community through a co-op membership model, with energy drawn from a field of solar panels that would simultaneously provide shade structures in five local parks. Participants collected survey data from members of their local community and the PV engineering community, and conducted interviews with PV experts. Their project culminated in a video project sharable with wider audiences. Through these activities, we intentionally sought to recognize and honor strengths these Hispanic adolescents brought to the summer program, including, family, community, peer, and popular culture funds of knowledge (Wilson-Lopez et al., 2016).

The YS program was embedded in a larger summer research cohort that included 11 undergraduate students, 2 older high school students, 3 international graduate students, and 7 local K-12 teachers. These older cohort members worked on 9 different photovoltaics research projects, guided by graduate student mentors for 5 to 9 weeks. Working with engineering program facilitators, we purposefully designed the summer research program to take advantage of the diversity in this larger cohort (Page, 2010), foster a sense of belonging and develop interest and identify that sustain engineering pathways for underrepresented students (Packard, 2015). Thus, we intentionally created participation structures aimed at decreasing potential social hierarchies (e.g., those due to age, experience, SES status) and level the playing field among members. In so doing, we hoped to foster reciprocal relationships among diverse cohort members, thus positioning YS participants as contributing members, consequentially engaged in meaningful work in order to foster these engineering identities. For instance,
each project group presented their work in a weekly cohort lab meeting; all participants presented their work-in-program and all were taught to take up audience roles (Herrenkohl & Guerra, 1998) in order to offer helpful peer critique (Dannels, 2005). Other activities that were intentionally designed to jointly position the YS as learners and contributors, and to scaffold their consequential engagement as members of their larger heterogeneous cohort are listed in Table 1.

Table 1: How youth scholars were positioned as learners and contributors across the six-day program*

<table>
<thead>
<tr>
<th>Positioned as Learners</th>
<th>Positioned as Contributors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch with undergraduates</td>
<td>- Audience for teacher lesson ideas</td>
</tr>
<tr>
<td>- began scoping their community solar project, facilitated by teacher</td>
<td>- Learned how to collect &amp; record data for teacher research project to prepare for substituting when teachers on a field trip</td>
</tr>
<tr>
<td><strong>Day 2</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch talk by PV graduate student on applications of solar</td>
<td>- Lab meeting: presenter &amp; audience roles</td>
</tr>
<tr>
<td>- Learned how to collect data for teachers’ research project</td>
<td></td>
</tr>
<tr>
<td><strong>Day 3</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch talk by PV grad on options of solar panels for YS project</td>
<td>- Learned how to collect &amp; record data for teacher research project</td>
</tr>
<tr>
<td>- Kinesthetic astronomy led by teacher participant</td>
<td></td>
</tr>
<tr>
<td><strong>Day 4</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch talk by older high school student on how to find STEM opportunities beyond the program</td>
<td>- Friday Lab meeting: presenter and audience roles</td>
</tr>
<tr>
<td>- Gave feedback on teachers’ lesson pilot test, short feedback training, critique form, paired with teachers 2 to 1 for increased confidence and peer support</td>
<td></td>
</tr>
<tr>
<td><strong>Day 5</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch talk by PV grad student on his project similar to YS project</td>
<td>- Collected and recorded data for teacher research project while teachers were on a field trip</td>
</tr>
<tr>
<td><strong>Day 6</strong></td>
<td></td>
</tr>
<tr>
<td>- Lunch talk by older high school students about how to succeed as entering freshmen</td>
<td>- Lab meeting: presenter and audience roles</td>
</tr>
<tr>
<td>- Feedback to undergraduates on writing project, scaffolded by close reading, critique form, and paired 2 to 1 paired with undergrads 2 to 1 for increased confidence and peer support</td>
<td></td>
</tr>
</tbody>
</table>

*At the end of summer, the YS presented their research to PV engineering scholars and solar energy industry leaders, alongside the older cohort members.

Data collection and analysis

This study was part of a larger program of research aimed at interrogating and informing further iterations of the design of the summer research program. Data collection took place throughout implementation of the summer program and across all cohort members who consented to the study. Data sources included daily survey responses, audio-video recordings and ethnographic field notes of cohort members’ participation in core activities, semi-structured interviews to elicit participants’ perspectives (Bogdan & Biklen, 2007; 20-30 minutes), and participant-generated artifacts (e.g., written feedback, project videos/posters, Google Classroom posts). Initial data analysis progressed along with data collection, as study team members wrote extended memos and met regularly in order to capture independent insights about participants and program activities, and to analyze broad patterns across persons, types of cohort members, and events.

As the current study focused on the meaning YS participants made of their positioning as learners and contributors in the larger cohort, closer analysis focused on YSS’s survey responses and transcribed interviews, and data logs of video recordings related to networking activities with the larger cohort. Data from other cohort members were used as secondary sources. All three members of the research team iteratively examined data individually and met for collective work sessions to interpret the meaning these youth scholars made of their experience in this diverse cohort. The team met frequently (and as soon as possible after core events) to compare field notes and negotiate interpretations of observational and interview data, to analyze and interpret survey data, and to synthesize our understandings relative to project goals. Using constant comparative methods, we sought to determine patterns across data sources through multiple iterations of examination (Corbin & Strauss, 2014). Using interactional analysis (Jordan & Henderson, 1995), we identified participation structures and patterns of activity among diverse participants, paying particular attention to how activities for expansively framed (or not) and to how YS participants were positioned relative to their older cohort members and to PV engineering. We tried to follow the means and consequences (affordances and constraints) of social actions through multiple rounds of listening and viewing audio-video recordings in which YS were engaged with their older cohort members, coupled with examination of relevant artifacts. Our interpretations of the meanings that youth participants made of these social actions were informed largely through content analyses of their pre and post program interviews.
Findings

Through our analytic process, we surmised that the young engineering researchers in this study made much meaning of their experience in this diverse cohort in which they, along with all members, were positioned as learners and contributors, all consequentially engaging in important engineering work. Specifically, we surmised that these scholars came to understand that there is important work to be done in PV engineering, I am capable of contributing to that work, and we are all in this together. Furthermore, due to the expansive framing of time and participation (Engle, 2006) intentionally designed into this program, the youth participants came to see the program simply as a vehicle for the diverse members of the summer cohort to do their work, work that will continue past the program. These insights were generated through the confluence of three themes that emerged through analysis: authentic membership, difficulty in giving feedback, and developing engineering identities by consequentially engaging in real, high stakes work, using PV engineering processes and concepts to achieve meaningful goals.

On the same level: Authentic membership

The YS in this study revealed through their participation, interviews, and reflections, that they saw themselves as legitimate members of this diverse cohort where all participants were explicitly positioned by the program as learners and contributors. This was especially apparent in an interview segment in which Ryan shared her experience giving feedback to a teacher, demonstrating how it had given her a new positionality relative to teachers:

It was like, they weren’t doing the whole superiority complex. I know - it’s not exactly that, you need control in a classroom. But it was like we were on the same level – because we were learning about the same thing. So, it was pretty cool.

Another YS, Mikki, related her first experience with one of the teachers in the program, saying, “He helped me…At first, he introduced himself to me…when we did the research or data collection… he made me feel more confident about being here…he was one of my favorite people here.”

Analysis also indicated that being positioned as sources of critique and feedback, thereby contributing to the adult cohort members’ learning, was particularly meaningful to these young scholars. Many responded in surveys that providing feedback to the teachers’ instructional plans and the undergraduates’ writing projects was their favorite activity on the days that these activities occurred. Audio-video analysis indicated that the students were meaningfully engaged in these activities. Not only did video show students participating in the teachers’ lessons and attending to instruction, positioned in the traditional learner role, but also giving suggestions, positioning themselves in the contributor role as well. For example, a teacher demonstrated his model for a solar powered drone, and then asked what the students thought. One student responded that it would be even better if the drone could be steered in some way, and then posited a possible design for a steering mechanism. The teacher, intrigued by the idea, positioned himself as a learner to discover more about the student’s ideas. Throughout the remainder of the interaction, the student and teacher flexibly moved between learner and contributor roles, focusing on the goal of improving the lesson in general and design of the drone specifically.

Further, through analysis of interviews, we garnered deeper insights about how these young learners saw themselves as potentially re-positioned relative to their prior positioning to teachers. Ryan connected her experience to one she might have with a peer her own age:

They did a lot of stuff that was easy to understand because they’re used to talking to less [knowledgeable] kids…. But at the same time, it was like talking to a peer about wearing the wrong clothes or something. So it was pretty awesome.

In this example, Ryan felt that, while the teachers did well presenting their lessons and making them comprehensible, as they were used to talking to students, there were things about the lessons that did need to be critiqued. This had the potential to be awkward, and generally would not be something she mentioned to a teacher. However, because of her positioning and being “on the same level” as the teachers, she felt it her duty to point it out, as she would for a peer she felt was in need of her help. It was this re-positioning that she found “pretty awesome.” This was even more evident in another part of her interview. She talked about how she wanted to help the teachers improve their lessons, as she recognized that they actually would be implemented with the students in these teachers’ classes. Ryan’s view extended past this task as just an assignment for the program, to the expansive and consequential implications of her work. Mikki shared a similar perspective, “It felt cool. I liked...
being heard... I liked how they asked my opinion in it. I liked how they were like, ‘Okay let’s ask for a student’s perspective, not just our own.’” Through being positioned as a contributor and her growing engineering identity, as well as her established identity as a student, Mikki felt confident that she had something important to say and to contribute to the teachers’ work that would be of worth. She noted the difference in this program, where the teachers did not just rely on their own opinion or the opinion of the other teachers, from other learning environments in which she more frequently participated. Being “on the same level” as the other cohort members allowed her to actually “[be] heard.”

Level with me: Difficulty in giving feedback
The youth scholars’ positioning as contributors of feedback in this diverse cohort was not without its challenges, however. As Linehan and McCarthy (2000) explained, in relation to the positioning of students and teachers, “both students and teachers have a degree of agency in how they position themselves in interactions, but this agency is interlaced with the expectations and history of the community, the sense of ‘oughtness’” (p. 442). Anticipating students’ possible difficulties with going against this sense of “oughtness” when giving feedback to those who, in situations outside the program, were generally positioned authority figures, we paired up the youth scholars for these feedback activities. Still, in addition to sharing their positive experiences as peer critiquers for the teachers and undergraduates in their cohort, many YS also reported the difficulties. Mikki described it as “hard” and Ryan noted, as mentioned previously, that it could be awkward, “like talking to a peer about wearing the wrong clothes or something.” This seemed to be especially true of the process of reviewing the undergraduates’ writing project, and then meeting with them to give feedback. In the audio recording of the Ryan, Mikki, and Jaxon’s meeting to give feedback to an undergraduate on her online article, Ryan began with saying that the article was engaging, but complicated and that the “big words were threatening.” Ryan further suggested that the abundance of these words could discourage the readers who might “scroll down instead of getting into it.” Jaxon agreed, suggesting adding a glossary to explain the words. However, when the undergraduate then explained that her article was not really targeting a younger audience, Ryan responded with “It seems very professional. It’s perfect.” Similarly, other youth scholars, who made many annotations of possible improvements or changes on the written copies, did not share their written comments in their discussion with the undergraduate to whom they were offering feedback. Further investigation is needed to determine the specific factors involved in this reluctance to give feedback face to face with the undergraduates, and whether, as “older college students” they either positioned themselves or were positioned in a way that discouraged feedback from “young high school students.”

Leveling up: Consequentially engaging in real, high stakes work
In addition to the youth scholars’ feelings of being authentic cohort members, we found much evidence that they saw their involvement as real, high stakes work, and that they saw themselves as consequential contributors to that work. Returning to Ryan’s comment that the youth and teachers in the program were “on the same level”; we assert that this did not indicate that the teachers in the program talked down to the youth’s level. Rather, Ryan indicated in her comment that they were all scholars together, and “all learning the same things”. Therefore, when embedded in this summer program environment in which everyone was positioned as a learner and a contributor to the important work of engineering research and its consequential implications, the level and rigor of engagement ramped up and many of these youth scholars responded by also “leveling up.”

As further evidence of this, in their final interviews, all youth scholars identified specific, critical contributions they had personally made to their collective project of creating a viable design for using solar energy in their community and developing a short video to explain it. For instance, Mikki discussed her work on the PowerPoint, and noted that it “took me hours. I was up at 2 in the morning.” Similarly, Jaxon shared that he had done all the math - for the financial and energy information in their video - at home, “so it took until one o’clock [in the morning].” There was no programmatic expectation that the YS work outside the hours they participated in the program. Many of the students simply undertook intentional action, interrogating the usefulness of engineering concepts and processes to move forward a project they believed in. As Jaxon reasoned,

“I just persevered...because I knew that if I kept doing it, eventually I would get it right. Like if I gave up on the math, we wouldn't have the statistics and our presentation wouldn't be as strong. Now we know how much it is going to cost and how much energy it is going to save...[and] it makes our presentation much more powerful.”

Each time Jaxon discussed the group’s video presentation during the interview, he did so in the context of what it would be used for after the program. In this case, he was referring to the importance of making it “much more
powerful” for the people they would be sharing it with in the future: families, community members and leaders, other students and school leaders, and an online audience.

By the end of the program, Ryan demonstrated “leveling up” and owning the responsibility of working with others to develop solutions to consequential problems. She also demonstrated growing acceptance of her engineering identity. During her interview, she explained:

My definition of an engineering is someone who improves a solution or creates a solution - working with others to create a solution that benefits a large number of others, or even a small number of others, so yeah. So yeah, I guess I do [think of myself as an engineer].

In their interviews at the beginning of the program, most students identified engineering as something that you did after going to school to become an engineer and choosing that as your career. However, Ryan is an example of how that perception changed for many of the YS in the time they were in the summer program. Her focus on improving or creating solutions to benefit either large or small groups of people demonstrates her acceptance of our expansive framing of photovoltaics. Further, she felt that the activities she and the other YS were engaged in were consequential and allowed them the chance to participate in a way that would benefit others.

**Significance**

This study sought to interpret what meaning the members of a YS cadre made of their experiences in a summer PV engineering research experience designed to support underrepresented youths’ trajectories on engineering pathways through expansive framing of program experiences and opportunities for consequential engagement consequential engagement in a diverse cohort. Of the emergent themes, two of them are positive, while one has room for growth. The authors found this innovation to be powerful in the way of developing engineering identity; the YS participants felt a strong sense of belonging to their cohort as learners and contributors. The examples presented are just a small representation of the many participants who demonstrated their ability to expansively frame their contributions. Several YS recognized that their engagement was consequential not only for their older cohort members, but potentially for a wider audience in the world, the students who would encounter the teachers’ lessons, the public audience who would read the undergraduate’s projects, members of their own community who might benefit from their community solar engineering research project. Another significant finding was the YS participants’ decision to level up, and accept their roles as both learners and contributors, rather than shrinking away or freezing in the face of uncertainty elicited from being positioned by program participation structures as not only students and learners, but also as key contributors through their own work and feedback on others’ work. Coupled with their explicit expressions of feeling like engineers or future engineers, we take this leveling up as evidence of these young scholars’ developing sense of belonging to the field of PV engineering as contributing members.

However, our findings also reveal the need to provide more scaffolding when asking the YS to give feedback to adults. This task turned out to be more intimidating than the authors expected, even though the YS participants gave feedback in assigned pairs or groups in our attempt to provide added support and bolster confidence in this activity. These findings provide us with a both a foundation to build on for future iterations of this designed summer research experience in our efforts to further engage learners from populations historically underrepresented in the consequential work of engineering. They further contribute to theoretical understandings of consequential engagement and expansive framing by showing how these principles are applicable to examining the affordances and constraints of positioning underrepresented youth in a diverse cohort of novice engineering learners.

**References**


Knowledge Building Inquiry and Reflection in Developing Children’s Epistemology of Science

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Abstract: This study examined how elementary-school students developed their epistemology of science in a knowledge-building environment that involves idea-driven discourse and reflective inquiry. Twenty-two grade-4 students participated inquiring into a topic in earth science; they worked collectively on knowledge-building inquiry supported by Knowledge Forum®, a computer-supported collaborative learning environment. The key designs included students engaging in idea-driven discourse on Knowledge Forum augmented with epistemic talk and reflection, and linking the understanding of their own inquiry process with scientists’ inquiry. Results indicated that students changed towards more sophisticated views of science from concrete-absolutist to evolving views of science. Analysis of classroom events illustrated how students reflected on their inquiry and KF discourse in relation to epistemic features of scientific practice, and developing the notions that they can be little scientists emulating the practice of scientists. Implications of designing knowledge building enriched with explicit and collective reflection to promote epistemic change are discussed.

Introduction
It is widely recognized that students’ epistemology of science, what they understand about the nature of science and scientific inquiry, is important both as an educational goal and for its role in scientific understanding (Elby, Macrander, & Hammer, 2016). Current reforms in science education emphasize scientific practices as ways students develop and use scientific ideas (NRC, 2012, and the Next Generation Science Standards, NGSS). These changes indicate the need to shift from hands-on and activity-based science to helping students engage in authentic inquiry working together to build knowledge. For students to develop scientific practice, they also need to think like scientists and develop ways to think about what science is about, what it means to develop scientific ideas, and how scientists go about creating knowledge; scientific practice involves epistemic understandings of science. The emphasis of scientific epistemology and science practice can also be related to the social-situated perspective of learning in which students learn through participating in a community of practice -- Scientific practice involves collective inquiry to construct explanations and scientific discourse.

There is increasing interest in examining students’ science practices related to epistemological development (Elby et al., 2016) but relatively less attention has been given to examining scientific epistemology from a community of learning perspective supported by technology. This study uses the knowledge building approach (Scardamalia & Bereiter, 2014) premised on the idea that participants, even as school-aged children, can be a community of scientists working creatively with ideas and, adding value to the community. While knowledge-building research has made substantial progress in scientific inquiry, there is still limited systematic investigation of how knowledge-building works to help young students develop more sophisticated scientific epistemology (Lin & Chan, 2018). A key theme in science education examines explicit reflection in promoting students’ understanding of nature of science (NOS) (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) and there are diverse approaches for developing explicit reflection. This study investigated how knowledge building inquiry and practice enriched with reflective discourse can promote students’ scientific epistemology.

Epistemology of science
Different research strands have examined students’ understandings of the nature of science (Elby et al., 2016). Researchers have adopted psychometric and multi-dimensional approaches (Hofer & Pintrich, 1997), such as exploring certainty, source, justification, and development of knowledge to examine epistemic beliefs in science; intervention studies have examined changes in epistemology based on these dimensions (Conley et al., 2004). Research in science education (Lederman et al., 2002) focused on examining the nature of science (NOS), including its empirical, tentative, creative and inferential aspects. Another tradition has examined how students understand the nature of science as constructive and evolving (Carey et al., 1989) involving idea-driven and theory-building processes (Scardamalia & Bereiter, 2014). Carey et al. (1989) examined children’s scientific epistemology and identified three general patterns: science as simply carrying out activities; science as tentative and uncertain; science as a constructive process for generating deeper explanations of natural
phenomena. Smith et al. (2000) examined children’s scientific epistemology in terms of how students understand the goals of science, the nature of scientific questions, purpose of experiments, and the nature of the idea-change process. Chuy et al. (2010) identified four aspects of fourth graders’ understanding of science: the nature of theoretical progress; theory-fact understanding; the role of ideas in scientific inquiry; and, invention.

Chinn, Buckland and Samarapungavan (2011) developed an epistemic cognition model for examining epistemic goals, the structure of knowledge, and justification involving epistemic aims, ideals, and reliability of knowledge; epistemic cognition needs to be examined in situated and complex learning environments. Sinatra (2016) argued for the importance of examining both what students say they believe about science, and how they engage in scientific process and practices. Sandoval (2005) postulated two kinds of epistemology, the formal epistemology of what students understand about the nature of science and scientists’ work, and the practical epistemology pertaining to students’ understandings of their own inquiry. These studies indicate the need to examine the intertwined relations of students’ epistemic understandings of science and their epistemic practices of building knowledge in science.

Knowledge building for epistemic development
Knowledge building is an educational model that postulates students taking collective cognitive responsibility for community knowledge advancement (Scardamalia & Bereiter, 2014). In knowledge building classrooms, a community or class of students posted problems, co-constructed explanations, and refined their theories on Knowledge Forum® (KF) in ways that emulate what scientists do in advancing the frontier of knowledge. Knowledge building is premised on the idea of students creating and improving new knowledge working as a community of scientists; focus is placed on how science knowledge is generated involving explanation and theory building. Researchers have investigated knowledge building from the vantage point of epistemic development. Hakkarainen (2003) analyzed the discourse on CSILE (an earlier version of KF), and showed school-aged children were engaged in explanatory-driven epistemological inquiry like scientists. Chuy et al. (2010) examined how students experiencing knowledge building had more sophisticated views about science compared to those using project learning. We have also examined the role of knowledge-building designs using explicit reflection to promote grade 5/6 students’ epistemology of science (Lin & Chan, 2018; in press).

In this study, we followed our previous work and designed a KB environment focusing on collective inquiry, discourse and reflection, extending the design incorporating model building in earth sciences, a different curricula area. There are two design themes: First, we emphasize students’ idea-driven inquiry and discourse both online and offline, when they worked together for idea improvement and to advance collective knowledge. In doing so, students would better understand nature of progressive science and theory building. A second theme is explicit epistemic reflection in a community KB context - There are diverse meanings of explicit reflection, and in this study “explicit” refers to an intentional design and not didactic or “telling.” “reflection” involves students reflecting on their inquiry/discourse in a collective space; and “epistemic” involves the notion that reflection is conducted in relation to epistemic criteria/standards. Specifically, we examined how young students develop an understanding of science, focusing on linking their practical epistemology (what they experience in their knowledge-building inquiry) and formal epistemology (what they understand about scientists’ inquiry) (Lin & Chan, 2018). In sum, this study aimed to examine how a KB environment facilitates scientific epistemology through knowledge-building inquiry and reflection. We examined the following questions: (1) What characterized students’ views of science and how were they related to domain understanding and KF engagement? (2) How did knowledge-building classroom processes and epistemic talk/reflection support students’ scientific epistemology and practice? And (3) How did students link their inquiry processes with scientists’ inquiry processes in developing their understanding of nature of science?

Methods
Participants and context
Twenty-Two Grade-4 students aged between 9 and 10 participated in a Hong Kong classroom and they came from an average to below average academic class. The teacher had previously conducted knowledge building pedagogy for several years and welcomed the opportunity to extend to diverse students. During 10 weeks’ study, students worked on an earth sciences unit (volcanoes, earthquakes, and tsunamis).

Designing the knowledge-building environment
Students were encouraged to engage in scientific practice and build knowledge together in a KB environment. The specific designs included: (1) Initiating collective inquiry with authentic problems: To stimulate thinking, the teacher showed video clips about an earthquake/tsunami in Japan. Students posed questions after watching,
then worked collaboratively to identify good questions through discussion, and started inquiry on the knowledge-building wall. (2) Classroom inquiry was followed with collaborative online discussions on KF and deepening inquiry through knowledge building talk related to principles (3) Students drew diagrams as models to explain the mechanism of different earth sciences phenomena and reflected on such practice related to explanation. (4) Students engaged in epistemic talk and reflection examining how their classroom and online work reflected knowledge building and good scientific practice; they wrote reflection portfolio with the support of designed scaffolds in KF.

Data sources
The following data sources were included: (1) *Epistemology of science*. A set of five open-ended questions adapted from Lin and Chan (2018) was administered to students at pre-posttests to explore their understandings of nature of science. A Likert-scale questionnaire was administered to assess their epistemic beliefs of science learning. It contained 26 items with 4 dimensions of epistemic beliefs (source, certainty, development, and justification) adapted from Conley et al. (2003). (2) *Domain understanding*. Pre- and post-test domain knowledge (e.g., causes of earthquake) were examined using a set of written questions. Students were encouraged to draw diagrams to help express their understanding. (3) *KF participation and writing*: (a) Data logs based on Analytic Toolkit, an assessment tool within KF, was used to measure students’ participation in online KF discourse. (b) Depth of explanation. Students’ notes were coded on a 4-point scale for level of explanation adapted from the epistemology of inquiry scale (Hakkarainen, 2003), and (c) KF portfolio notes were analyzed qualitatively to gauge students’ reflection in relation to knowledge building inquiry. (4) *Classroom process* and discourse of students’ scientific practice and understanding supported by knowledge-building dynamics were examined. (5) Students’ understanding of knowledge building process was examined using focus group interviews.

Results and analysis
Characterization of students’ scientific epistemology and change over time
Different patterns of students’ views about science were identified using a theory-building perspective (Lin & Chan, 2018; in press; Chuy et al., 2010). Key dimensions included role of ideas, theory change, and social process. For the question on what scientists do (i.e., what do scientists want to achieve?) one student wrote that “scientists invent things to help people” [NJC]; another wrote that scientists want to find out the right answers (WYT); for higher-level responses, a student wrote that “scientists work to think about new theory. They are involved in observation, conducting experiments, and inquiry (TYX). In response to another question on whether they think theory will change, one student wrote that “theory will not change. We always have gravity on our earth.” (TYX); another student said that “every theory will change once in a while for example in every five years” (WSY); for more sophisticated responses, the student wrote that “scientists will continue their inquiry to make science better; they will not only do experiments once; they will do different experiments; and if the results are different, they will think about the problems and make changes; they may change their original theory to some different theories” (WZY).

Students’ responses to the five open-ended questions were coded on a 4-point scale ranging from naive to sophisticated responses (Cohen Kappa, 0.91). Analysis of open-ended responses showed significant changes on students’ scores between pretest 1.68 (.58) and posttest 2.54 (.80), \( t = 3.65, p < .001 \). Overall, students seemed to exhibit better understandings of the purpose and development of science for explaining or creating new theory; students also had a general sense of some key elements in scientific inquiry including data, experiments, and theory. Findings from questionnaires on epistemic beliefs (Conley et al. 2004) (source, certainty, development, and justification) showed pre-posttest differences on the dimension of “development” (3.65 (.69) to 4.06 (.54), \( t = -2.3, p < .007 \). Students seemed to be most influenced after instruction in viewing knowledge as evolving and changing, and not static; such results also align more with the knowledge-building perspective.

Scientific epistemology, domain understanding and KF engagement
Student engagement in KF discourse was examined using data logs information in KF notes. The mean number of notes written was 6.6 (3.4); 20.6% (9.7) of notes were read; keyword use totals were 55.3 (31.47); and the mean number of notes revision was 3.73 (3.61). Correlation analysis indicated that the number of notes written (productivity) showed no association with explanatory notes; however, the number of notes read (collaboration) was significantly correlated with the explanatory quality of notes (\( r = -.66, p < .01 \)). These results suggest that the more students read others’ notes and as they were aware of community work, the more they wrote high-quality explanatory notes. Students showing low levels of epistemological understanding also wrote notes with lower
explanatory value ($r=-.425$, $p<.05$). Quantitative analysis also showed pre/post-test changes on students’ domain understandings. Post-test domain scores were also shown to be correlated with the scientific epistemology scores. These quantitative findings were generally consistent with other studies in knowledge-building research and provided some validation that the identified science epistemology scores are meaningful.

**Knowledge building inquiry, discourse and reflection**
We analyzed key themes emerging in the knowledge building classroom reflecting students’ epistemic inquiry and reflection; online and offline discourse were integrated. These selected themes were guided by our framework emphasizing knowledge building inquiry and epistemic reflection.

**Theme 1: Formulating problems for inquiry and selection of productive questions**
Generating productive questions and formulating problems is key to scientific practice and progress. In the knowledge building classroom, from the start, the focus is about helping students develop the practice of asking questions and formulating these questions into more specific problems. The knowledge-building wall (Fig 1) provided a public space where students posted ideas and questions and made their ideas public and visible for improvement. A developing epistemic culture is that ideas are out there to be improved as in the classroom talk.

T Please look at the knowledge-building wall. What are some questions you are interested in?
S24 How do computers or earthquake warning systems predict earthquakes?
T Could you share what you wrote?
S22 There is vibration in the mantle when earthquakes happen; after ten seconds, the warning system can detect the earthquake.
S21 I think the detector is put in the mantle but the detecting time is different… um… I think it should be longer than 10 seconds.
T Do you have questions about these responses? Do you want to build on these ideas?
S25 How could the warning system detect the vibration in the mantle?
S8 Why must the detector be placed in the mantle but not other parts [crust]?
S24 Why must we use a detector or electromagnetic wave to detect the P wave?

This excerpt illustrated how the teacher helped students to make ideas visible using KF wall; how they began to engage in the scientific practice of asking questions; different ideas were put forward and considered as students worked together to deepen the inquiry problem.

![Figure 1. Student posting ideas on the knowledge-building wall.](Image)

In addition to the scientific practice of asking questions, students were also encouraged to explicitly reflect on their practice of formulating problems; they discussed how they chose the questions for inquiry.

T All groups have written several questions and you chose two each. What are the questions you did not use?
S4 How big is the mantle?
T And why?
S12 This question has a definite answer.
S14 Some questions you can find in the textbook.
T How do you choose your questions then?
As they discussed their selection of questions alluding to features such as certainty [S12], scope for inquiry [S15], community interest [S18], the teacher engaged students in reflection relating to epistemic aspects – he was helping students to develop the epistemic criteria for problem formulation, analogous to scientists choosing productive questions for inquiry. In this process, students would gradually develop the epistemic habits of generating questions, sharing ideas, choosing productive questions, and building on each other’s ideas to advance collective understanding.

**Theme 2: Co-construction of explanation and criteria of good discourse**

Explanatory inquiry and co-construction of ideas is important in scientific practice. After posting questions and ideas on the KF wall, they continued their inquiry in KF. Here are some examples of KF notes that show how students co-constructed explanation on a problem they posted on the KF wall.

[INTU] Why are there earthquakes in Japan but not in Hong Kong? [YHH]

[My theory] I think Japan is in between two plates. [LCH]

[My theory] The plate is near Japan but far from Hong Kong [WTL]

[My theory] Near Japan there are different plates…Pacific, Eurasia…the Japanese islands are there near these 4 plates.. so there are more earthquakes and volcano in Japan. [WCY]

[My theory] Most strong earthquakes in our world occur at the edge of the tectonic plates. Hong Kong is located within the Eurasian plate and not at the edge. The famous Pacific earthquake belt is found at the edge of the Eurasia and Pacific plates that go through Japan and Taiwan... Hong Kong is far from this active belt so I think the chance of major earthquake is smaller. [LHY]

Although student understanding is still rudimentary, they are moving from general responses to more specific ones and progressively improving their explanations together using information and evidence. The last response suggested that the student [LHY], in comparing earthquakes in Hong Kong and Japan, has moved up to a general principle and using the location of plates to explain the occurrences of earthquake. Following their KF writing, the teacher conducted a knowledge-building talk, to help students reflect explicitly on their inquiry.

T What do you think are the good notes on Knowledge Forum?

S6 They provided detailed information....

T yes…details. and what others?

S5 not just something else. Good notes add on.. it is about our original problem.

S12 I like the notes that answer my question.

S21 Not just answer one question… the good notes follow on. We can continue the inquiry

T Which are some notes you like?

S18 I like CX’s note because he provided explanation about the volcano eruption; he also had some source information.

As the excerpt showed, these young students, in their intuitive and simple language, seemed to be developing some notions that it is important to address the key conceptual problem; they need to continue the inquiry; and ideas need to be explanatory. In this classroom, student engaging in KF writing and discourse was enhanced with explicit reflection on epistemic standards of good discourse moves; discussion on reflection was enhanced with the collaborative space of knowledge forum.

**Theme 3: Drawing models and evaluating quality relating to processes and mechanisms**

Another aspect of scientific practice is the use of model for explaining scientific phenomena. Students drew diagrams as a model to explain their understanding of volcanic eruption; they shared their artifacts with the class and refined their diagrams through collaborative discussion, as they continued their discussion on KF, then they repeated the drawing of the model and they explained the change in classroom discourse (Figure 2).
Could you share with us your diagrams? Can you explain them?

This is only a diagram without words or explanation [refers to the first one]. My second one explains the reasons and mechanism and I included words.

Both diagrams explained that volcanic eruption is caused by the movement of the plate. However, the first one is not as detailed as the second. I have drawn the whole process of the volcano eruption in the second diagram.

When I drew the second diagram, I referred to the movement of magma and three types of plate movement. I also referred to my first diagram, and discussed with WZL about what other reasons could cause volcanic eruption. And here I also drew the harmful effects of volcano eruption.

Students through drawing these diagrams depicted their model of how volcanic eruption took place. The discussion suggested that these students seemed to have recognized the important role of process and mechanism in explaining scientific phenomena. They were not just describing how volcanic eruption took place; they were evaluating the quality of the diagrams and alluded to epistemic features and role of explanation. Students also noted the positive effects of working together and social interaction in improving ideas.

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**Figure 2.** A student’s first and second drawings on volcano eruption (left and center) and a KF view on formation of volcanos and student drawings (right).

Knowledge Forum provides the environment that emerging ideas and different models can be made public for continuing inquiry; selected diagrams and models were posted on KF for students’ further inquiry in a deepening view when students continued their discourse (Figure 2).

**Theme 4: Epistemic talk and epistemic reflection**

The teacher also helped students to engage in epistemic talk and reflection to develop ways of thinking in line with what scientist do and how they think.

What do you think about geologists and scientists’ work?

They also learn things.

They search information from the internet?

*What are the differences between our inquiry and scientist inquiry?*

They do many experiments.

….um…We also search information like the scientists..

Do scientists trust the information?

No… not all information is true. They would do some investigation; then test again to find out about the information

How then do they test the information?

Do some research…

they also do experiments… they go to places with earthquake for field work

So scientists know a lot?…more than we do……

they will always continue their work …and improve the knowledge.

The excerpt suggested that some students began with intuitive ideas, but through dialogue, diverse ideas emerged suggesting some understanding about science as involving experiments and source of
information; how scientists go about doing experiments and field inquiry in testing external information; and the continual work of scientists for progress.

Students were engaged in reflection on their inquiry related to the epistemic processes of knowledge building. A set of KB principles have been used to inform knowledge-building design (Scardamalia & Bereiter, 2014) that reflect the epistemic standards of knowledge work. Throughout the program, the teacher helped students to talk about selected key principles using simple language including “all ideas can be better” (idea improvement), “questions start us thinking” (epistemic agency) and “we work together to move forward” (community knowledge). Towards the latter part of the program, students were provided with a diagram that illustrated the epistemic criteria of knowledge building as related to scientific practice (Figure 3); they reflected and provided examples from their own experience in relation to these features. Their epistemic reflection on their own inquiry and scientist’s inquiry was extended in their writing of portfolio notes on KF (next section).

**Figure 3.** Knowledge-building principles as epistemic prompts for reflective inquiry.

**Students linking their own inquiry with scientific inquiry**

We included examples from KF reflective portfolio notes and interviews to illustrate how students link their inquiry processes with scientists’ inquiry processes as they discussed their understanding of nature of science.

Scientists use their observation to help them pose questions...Before they do the experiments they would predict... and after that, they would analyze the data and information, they would also work together to ask more questions... they would continue with their inquiry...

For us, we also construct knowledge together. Using KF we read others’ ideas... to help enrich our ideas... we also go and research and look for information so we can have better ideas... We also have changed our ideas... [about volcanic eruption]. When we worked on that first... we don’t know much…we find more information and improve the explanation [TWT].

This response suggested how this student drew upon her KF inquiry and connected the similarities with scientists considering the need to search for information, to test and improve these ideas; and these ideas can be changed to provide better explanation. The interview excerpt shows some similar patterns.

S5 um...it seems yes... we are somewhat like scientists..
I Do you want to tell us more..
S5 We are now finding out more about volcano... these are things that experts do research on...but we are also trying to inquire about volcano; somehow we are beginning to follow.. model after scientists
S5 Yes.. We can do that..
S9 I think we are also like scientists looking for information and doing research; um we are also working to find out why volcano erupt.
S16 We are not like scientists.. they know a lot more than we do…
I So you think scientists have a lot more knowledge than us?…
S5 um. I still think we are like scientists.. we also know something about volcano eruption ...something [in the area of scientists] We are like little scientists.. um following the examples of what scientists do..
S9 um...we are also working together like a community and scientists do that.

In this excerpt, these students indicate how they could be like scientists working on research Interestingly, one student disagreed and noted that scientists have more knowledge [S16]. This brought about
further explanations that they can be like little scientists, working in the same inquiry area, emulating the scientists [S5] and how they can work collectively just as scientists do [S9]. These data suggested for these young children, even in their simple language, had some intuitive sense that while they do not know as much as scientists, they can follow the scientists’ practice on developing knowledge.

Implications and significance
This study contributed to the knowledge building literature and investigated how school-aged students developed epistemologies of science supported by knowledge building inquiry and reflection. The findings supported our earlier work and extended to a younger group in a different curricula area, including both what students said about their epistemic understanding of science as well as how they approached the epistemic work of building knowledge. This study illuminates the ideas that if students are to understand certain aspects of nature of science, they must experience those aspects and make reflection on such experience. Our findings show that knowledge-building supported by KF provides opportunities for students to experience scientific inquiry and practice involving formulating questions, construction of ideas, model building and explanation, and community processes. The findings also show how epistemic talk and reflection on collective work, relating to why and how and criteria, help students to link their practice with their understandings -- they are linking their practical epistemology of knowledge-building experience with the formal epistemology of how scientists build knowledge. Theoretically, this line of research in knowledge building may enrich the notion of explicit reflection examining how it may be enhanced as collective reflection in a community context. There are also design implications of scaffolding young students in idea-driven inquiry and discourse and engaging them in epistemic talks to help them to reflect on their practice as little scientists and knowledge builders.

References


Short Papers
Building a Team Leadership Index Through Computational Methods

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The Ohio State University

Abstract: To help monitoring and controlling the latent social dynamics associated with leadership, we test a methodological approach that makes use of computational techniques to mine the content of online communications and analyze group structure to identify students who behave as leaders. The results allow us to quantify each individual's contribution and summarize their engagement in the form of a leadership index. The proposed methodology is fully automated and has the potential to be easily replicable. The summary offered by the leadership index is intended as actionable information that can guide just-in-time interventions to help sustain student engagement.

Introduction

As pedagogical models for supporting online collaborative learning, structured tasks and peer-moderated online discussions have shown unique benefits (Rovai, 2007). Students often assume leadership roles to facilitate discussions. They can positively affect the dynamics in their groups by engaging with participants, raising questions and advancing problem solving (Zha & Ottendorfer, 2011). The social dynamics in peer-moderated online discussions are complex. For example, student leaders can be appointed officially by the instructor (e.g., Xie, Yu, & Bradshaw, 2014) or can emerge through group interactions (e.g., Wickham & Walther, 2007). However, because students in online educational settings are often physically isolated, these complex processes are often latent and not explicitly observed (Xie, Lu, Cheng, & Izmirli, 2017). This makes the assessment of leadership in online group learning critical yet challenging. While some literature has portrayed team leadership as a set of personal traits (e.g., beliefs, attitude, self-efficacy, and identity), this study focuses on how leadership is manifested through engagement, communication and interaction. In online learning settings, learners exercise their leadership by initiating conversations, setting group goals, moderating discussions, managing conflicts, monitoring project progress, and evaluating team products (Chang & Lee, 2013). In addition, leadership is often distributed among group members and evolves through members’ active participation in group processes (Spillane, 2005). Even when some specific learners are formally assigned a leading role, others may also play informal leadership roles. This shared and distributed perspective directs us to look for the locus of leadership through learners’ behavior and interaction, rather than their individual mental perceptions.

Research on leadership, though, has relied heavily on students’ self-reporting (e.g., Chang & Lee, 2013) or on other qualitative approaches (e.g., Gressick & Derry, 2010) which have methodological and practical limitations (Greene, 2015). Data tracked in technology-based learning systems afford powerful new analytical approaches to uncover the complex processes of group learning interactions (e.g., Xie, Miller, & Alison, 2013; Baker & Inventado, 2014). We propose the adoption of a computational approach, based on natural language processing (NLP) and social network analysis (SNA), for the detection of leadership in peer-moderated online collaborative learning.

Study aim

We aim to develop a quantifiable index of team leadership through the mining of corpus data and log data recorded in an online discussion system. Therefore, we situate the definition of leadership in the context of peer-moderated online discussions, specifically referring to the individual contributions made online and their effect on group structure. Starting from the analysis of the messages logged into the digital forum of an online course, we developed and tested computational techniques capable of identifying patterns of interactions associated with messages that display elements of leadership.

Our objective was twofold: to design a methodology easy to automate and deploy in multiple contexts and to combine our analysis into a single outcome index, capable of reflecting a quantitative summary of students’ leadership behavior and providing actionable knowledge for group instructors to sustain students’ engagement. The following research questions guided the design of this study: (a) To what extent can data mining extract linguistic features to detect leadership in order to minimize human intervention? (b) To what extent can social
network analysis model leadership at an individual level? (c) To what extent does our computational approach provide evidence of emergent leadership?

Context
Participants were 57 students (gender: males 11, females 46; age: min 19, max 53, median 29) from four sections of a mixed-level course at a university in the Southeastern United States. A majority of participants were majoring in education-related disciplines, and their distribution by academic level was: freshmen 4 (7.0%), sophomores 6 (10.5%), juniors 18 (31.6%), and seniors 29 (50.9%). They reported their ethnicity as follows: White 31 (54.4%), African-American 21 (36.8%), and Other 5 (8.8%).

This 16-week course was offered entirely online and presented students with discussion topics drawn from issues related to technology integration in K-12 education. The four sections were taught by the same instructor and followed identical learning procedures. Student-led weekly discussions were the major class activities. In each discussion session, up to two students were appointed as moderators. They designed discussion questions around the topic of the module, while the rest of the class followed instructions designed by the appointed moderators and participated in asynchronous online discussions. Every student was given an opportunity to lead a discussion session during the semester. The instructor facilitated the first week discussion; students led the remaining ones.

Methods
To address our research questions, we analyzed student online discussions recorded in the university learning management system (LMS). The metadata and text content from 4,083 forum posts constituted the starting input. Data analysis involved two steps, each with its own computational technique.

The first analytical step sought to identify and enumerate interactions that exemplify leadership behavior by processing students’ posting content. To that end, we adopted supervised learning techniques based on natural language processing (NLP) to classify posts in two categories: leader messages and generic discussion messages. Leader messages have the function of moderating interactions, facilitating discussion, or eliciting participation from others. They were identified in one of two ways: (1) automatically, assuming that online contributions made by appointed moderators contain leadership elements (term-based condition); (2) manually, by three researchers, who independently reviewed a random sample of posts and labeled them as either leader or generic messages using their best judgement until unanimity in the coding was obtained (label-based condition). As a result, two balanced datasets were generated, and we refer to them respectively as term-based coding and label-based coding. These datasets were then used to train two binary classifier models, a Logistic Regression model (LR) and an Adaptive Boosting model (AdaBoost), which were applied to probabilistically predict the likelihood of each of the remaining posts to belong to the class of leader messages.

The second analytical step studied leadership as a personal characteristic displayed by students in their interactions. With leader messages resulting from the previous step as input, we used social network analysis (SNA) to quantify the influence students had when communicating with their peers and to define their structural relationship. The influence of actors in a social network is a function of the number of connections they have, i.e. their centrality—with eigenvector centrality being a widely-adopted version of this measure and Katz centrality (Katz, 1953) an established variation particularly suited to our domain, characterized by asymmetric networks with a relatively small number of nodes. Our leadership index, a measure useful in ranking students’ contribution to peer-moderation, is therefore built on Katz centrality values in weighted directed networks connecting the senders and the recipients of the forum posts identified as leader messages.

Findings
The NLP modules processed a feature vector matrix containing 1,305 posts of appointed moderators and regular participants with 3,592 unique words as features. The datasets were split into a training set (90% of the entire data) and a testing set (remaining 10%). Ten-fold cross-validation was applied to both LR and AdaBoost models. Accuracy, precision, recall, and F1-measure were measured to evaluate the performance of training and testing steps across the term-based and label-based coding conditions (see Table 1).

Table 1: Comparison of coding conditions in the categorization of students’ forum posts

<table>
<thead>
<tr>
<th></th>
<th>Term-based coding</th>
<th></th>
<th>Label-based coding</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Logistic Regression</td>
<td>AdaBoost</td>
<td>Logistic Regression</td>
<td>AdaBoost</td>
</tr>
</tbody>
</table>
The label-based condition outperformed the term-based condition across both LR and AdaBoost, indicating that a set of leader messages in the first dataset contains more unique linguistic patterns associated with leadership than those in the latter dataset. These results are well within our expectations, since manual coding required intensive labor. More interesting for our purposes, though, the promising performances in the term-based coding condition justify our assumption that an exogenous factor, such as the mechanism of peer-moderation adopted in our online course, affects student behavior in a consistent way.

Social network analysis (SNA) was subsequently used to identify individuals who were central to the network structure and to compare their engagement with that of appointed moderators. Senders’ and recipients’ information was used to visualize the leadership patterns for each weekly discussion as recorded by the LMS. The probabilistic output of the LR model developed in the previous step was applied to weight the edges in the graph, converting communication networks into leadership networks. Our results highlight that appointed moderators, although influential, are not always the most central nodes. As demonstrated in all networks derived from logged interactions, other students emerge as leaders, and SNA can help bring them into focus: they are the emergent leaders our approach aims to identify.

To test the validity of the computational approach, we compared classifications determined through the term-based and label-based coding conditions. We found a positive correlation between the average leadership index obtained by each student in these coding conditions: \( r = .776, t (50) = 8.704, p < .05 \), which indicates that the two conditions are able to capture similar relationships among students. However, term-based coding, which does not require the intensive manual coding of the label-based condition, can provide automatic and real-time feedback and is therefore preferable. We also looked at correlations between leadership index and engagement measures derived from the trace data aggregated at the week level. Table 2 provides the descriptive statistics and the correlation coefficients. In general, students’ leadership index was significantly correlated with their engagement measures. These results align with findings from the literature, which suggest that team leaders often exercise their influence through active interactions and communications (Xie, Yu, & Bradshaw, 2014).

### Table 2: Descriptive Statistics of Weekly Engagement and Correlations (N=365)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>Correlations with Leadership Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leadership index</td>
<td>1.125</td>
<td>.135</td>
<td>1</td>
<td>2.082</td>
<td>.639*</td>
</tr>
<tr>
<td>Number of posts</td>
<td>9.542</td>
<td>6.413</td>
<td>1</td>
<td>50</td>
<td>.623*</td>
</tr>
<tr>
<td>Number of replies</td>
<td>8.933</td>
<td>6.175</td>
<td>0</td>
<td>42</td>
<td>.425*</td>
</tr>
<tr>
<td>Length of posts (character)</td>
<td>5816.121</td>
<td>4152.379</td>
<td>350</td>
<td>27332</td>
<td>.215*</td>
</tr>
<tr>
<td>Topics started</td>
<td>.610</td>
<td>1.183</td>
<td>0</td>
<td>8</td>
<td>.420*</td>
</tr>
<tr>
<td>Topics read</td>
<td>22.421</td>
<td>17.516</td>
<td>2</td>
<td>115</td>
<td>.535*</td>
</tr>
<tr>
<td>Length of logins (second)</td>
<td>20134.24</td>
<td>16122.25</td>
<td>3189</td>
<td>144997</td>
<td>.098</td>
</tr>
<tr>
<td>Times of logins</td>
<td>90.236</td>
<td>67.634</td>
<td>8</td>
<td>430</td>
<td></td>
</tr>
</tbody>
</table>

The leadership index also allowed us to study emergent leadership over time, observing how students responded to being appointed moderators and clustering students based on their recorded patterns of leadership to further highlight specific profiles. Using the leadership index scored during the week they were appointed peer-moderators as reference point, students were grouped in five clusters, according to the gap-statistics (Tibshirani, Walther, & Hastie, 2001). Patterns in the response to the mechanism of moderation appointment are clearly visible: some students were only affected while acting as official moderators (cluster 2); others appeared to carry over that behavior after their turn (cluster 4), while cluster 3 displayed leadership before and up to moderation week, but disengaged from activities after; clusters 1 and 5 represent students with consistently low and

<table>
<thead>
<tr>
<th>Cross-Validation</th>
<th>Accuracy</th>
<th>0.702</th>
<th>0.568</th>
<th>0.799</th>
<th>0.688</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>0.677</td>
<td>0.613</td>
<td>0.808</td>
<td>0.808</td>
<td></td>
</tr>
<tr>
<td>Recall</td>
<td>0.750</td>
<td>0.585</td>
<td>0.750</td>
<td>0.583</td>
<td></td>
</tr>
<tr>
<td>F1-Measure</td>
<td>0.712</td>
<td>0.599</td>
<td>0.778</td>
<td>0.678</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing</th>
<th>Accuracy</th>
<th>0.671</th>
<th>0.718</th>
<th>0.860</th>
<th>0.797</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>0.747</td>
<td>0.762</td>
<td>0.912</td>
<td>0.857</td>
<td></td>
</tr>
<tr>
<td>Recall</td>
<td>0.635</td>
<td>0.686</td>
<td>0.838</td>
<td>0.727</td>
<td></td>
</tr>
<tr>
<td>F1-Measure</td>
<td>0.686</td>
<td>0.722</td>
<td>0.873</td>
<td>0.787</td>
<td></td>
</tr>
</tbody>
</table>
Evals consistenly high leadership. This shows how leadership is a social and developmental process and students develop their leadership in a variety of ways (Emery, Daniloski, & Hamby, 2011).

Conclusions
This study examined student participation in structured tasks and peer-moderated online discussions as recorded by one course LMS and proposed a novel measure to detect leadership in group learning. Our findings underscore the dynamic nature of leadership behavior, the result of both an explicit mechanism of appointment to moderating roles and social dynamics emerging from student interactions. The derived leadership index is the output of a methodology designed to minimize human intervention. Analyzing different linguistic patterns in the context of peer-moderated collaborative learning, the resulting classification performs comparably to one produced by three researchers manually coding samples from the dataset, a conclusion that highlights the reproducibility of this kind of study in the broader framework of learning analytics.

The leadership index is also intended as actionable information, suitable to be incorporated in learning management systems to enhance their reporting and analytical features. A simple but timely signal of the degree to which a student engages in online discussions could constitute the basis for interventions aimed at helping teachers to retain and sustain student participation. Our presentation will discuss directions for future research and the implications of this approach for the fields of learning analytics and online education more broadly.

References
Equity-oriented STEM-rich Making Among Youth From Historically Marginalized Communities

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Abstract: We investigated the ways in which youth makers from two low-income urban communities engaged in sustained STEM-rich, making towards making a difference in their communities. Drawing upon a mobilities of learning framework and four years of ethnographic data across two making spaces (41 youth maker projects), we found that as youth engaged with community across their making efforts, they foregrounded their relationality to communities in their design work, both within activities and across timescales. We also found that engaging making with community opened up new and different opportunities to co-make, as the youth drew on, and expanded their social networks. We discuss how these findings impact understanding of how a more equitable making culture can evolve, and its implications for how youth imagine their social futures in and through making.

Introduction
We are concerned with understanding the possibilities for equity-oriented and STEM-rich making for youth from historically marginalized communities. Given the proliferation of makerpaces across the country, including their growing inclusion in school settings, we seek to contribute new knowledge and practice for transforming the maker culture in ways that are both equitable and consequential for such youth, expanding the ecology of making and the maker movement. Our research questions are:

1. How does community engagement as a part of STEM-rich making impact what, how and why youth choose to make?
2. What are the outcomes of youths’ making practices with regards to their communities, and with regards to shaping the making culture in their community making spaces?

Equity and STEM-rich making
Inequality and underrepresentation of youth from historically marginalized communities in STEM persist. The maker movement has evoked interest for its potential role in breaking down these barriers to STEM learning and attainment (Martin, 2015). Despite growing interest in equity and making, few empirical studies of sustained youth engagement in STEM-oriented making exist. There is little empirical evidence describing how youth are supported, over time, in working towards robust STEM-rich making projects or on the outcomes of such making experiences, especially among youth from historically marginalized communities.

While there are powerful pockets of making and making spaces that serve families and youth from historically marginalized communities (Peppler & Bender, 2013; Vossoughi, Hooper & Escudé, 2016), the statistics of the movement require caution (Brahms & Coley, 2016). As the maker movement has become formalized, the knowledge and practices of communities of color or of low-income communities have not become central to its discourse. Furthermore, making that youth deem consequential to their lives or how such learning or making is supported is not well understood. Most making resources directed towards children promote the “keychain syndrome” – making experiences that are trivial and without prolonged or sustained meaningful engagement towards more complex projects (Blikstein & Worsley, 2016). Even when making projects support authentic engagement on a problem one cares about, there has been limited critical engagement with what constitutes consequentiality in making or for whom. We are interested in this aspect of relationality in making. Whose voices are valued and who counts as legitimate stakeholders in a community making space impacts how various people are welcomed, positioned and recognized for what they know and can do in a making space as a part of shaping the learning and participation that happens there.

We ground our work in a mobilities of learning framework, anchored in expansive and connected learning principles (Engeström & Sannino, 2010). We then layer on an explicit focus on the intersectionalities of race, class and gender, across this framework. There are three dimensions that tie to our study in making contexts: 1) Historicity – emphasizing that making always takes place in particular spaces and times influenced by institutional, societal and individual histories; 2) Remixing, that of resources, relationships and tools for nontraditional outcomes and forging new norms; 3) Identity work – who people are and who they can be, when they are making. Making is a dynamic multi-practice, involving the processes of re-authoring and re-mixing practices from a wide range of experiences. We are interested in how the shifting nature of STEM, making, and
community places are always under negotiation as individuals reproduce and resist the narratives at play, giving rise to new routines, ideas, and ways of being.

**Methods**

The making space programs are housed in Boys and Girls Clubs (BGC), community-based clubs serving low-income families, focused on youth development, homework help, and sports for youth. Both clubs serve low-income, predominantly multi-generational African American communities. Both are also located in mid-sized cities facing some degree of economic depression. In our overlapping researcher-educator roles, we have collaborated with BGC staff to establish these making spaces and the programs within them, with the primary goals of supporting youth in sustained engagement in STEM, while also learning about making in culturally sustaining ways. Our study was carried out as a longitudinal critical ethnography over a four-year period. Critical ethnography is grounded in the idea that researchers can use the tools of ethnography to conduct empirical research in an unjust world in ways that examine and transform inequalities from multiple perspectives (Trueba, 1999). Critical ethnography provided an approach with which to “politicize” the interaction between actors and the social structures through which they act, grounded in the belief that these relationships are never neutral. Data were generated from 2013 to 2017 from 41 youth team projects, including artifacts, weekly youth conversation groups, and video analysis capturing youth interaction with STEM and community experts at various stages in their design process. Data analysis involved multiple stages and levels of coding based on procedures for open coding and method of constant comparison (Strauss & Corbin, 1998).

**Findings and discussion**

**Relationality and making towards responding to and making visible historicized injustice**

Across projects, youth identified problems that were linked to their community’s unique history and context and used community data to justify the urgency of projects. Many youth explored problem spaces that drew from their historicized experiences growing up amidst systemic racism and poverty, and the violence (symbolic and physical) they experienced because of it. Youth noted a prominent lack of access to a wide range of resources by members of their community, such as a lack of access to books and toys, videos made by people who look like them, or fashionable and functional clothing. All sustained maker projects (n=41) reflected these experiences in ways which intersected with other lived experiences, including lack of childhood (n=10), geography/climate (n=9), urban infrastructure (n=8), health/disability (n=8), bullying (n=7), sexism (n=5), healthy peer representation (n=5), caregiver responsibilities (n=4), signaling distress (n=4), policy brutality (n=1), and privacy (n=1).

Some youth makers addressed concerns tied to growing up poor in a place, calling attention to intersecting sociopolitical and geographical histories. Several addressed concerns about getting hurt in the dark because their interview and observational data showed that “where we live it gets dark really early in winter” and “lots of our streetlights don’t work.” Those projects, would “keep my peers and younger children safe when playing football outdoors” (Samuel’s light-up football), or “help kids or our peers play with scooters outdoors in the late afternoon or evening when it is dark” (Jennifer and Emily’s light-up scooter). Alana wanted to assuage fears, noting that beyond increasing visibility and keeping one dry, her light-up umbrella prototype might help “people in my community feel safe on the streets in the rain and at night.” Tamzin drew on her homeless shelter experience and peer interviews to design a light-up, alarmed cautious hat that youth could wear at a shelter, with a carefully embroidered heart design to “make it more attractive. In her interviews, she discussed how homeless youth are made fun of for “looking ghetto.” We see how she addressed the stigmatization of homeless youth alongside the concerns for physical safety. Samuel and Fall’s Little Free Library design addressed concerns about living in a library desert. They observed younger children sneaking into their making club to use materials, and they talked to 75 club-attending youth about whether they had a library card. Fall explained: “It is hard for our parents to take us to the library. Lots of kids do not have library cards, either. If we get a book, we can’t return it on time, and then that costs money, and we can’t check out another book.”

As they delved into the project over two years, Samuel and Fall began to see that the problem went beyond geographical access: libraries themselves were prohibitive by design. Most youth did not have transportation to a library, or could not produce the needed documentation to acquire a card. Other peers who had been to the library before could not check out books anymore because they owed late fines they could not pay. Both youth also noted that STEM books were important for both learning to read and learning STEM. That Fall had been labeled a “struggling reader” in school further punctuates this point. These concerns were therefore intersecting for the youth. As youth moved their projects across different spaces through community engagement,
they expanded scales of criticality and connectivity in their work by engaging with the ideas of others. This emergent cultural knowledge and practices became platforms for seeing patterns of injustice within their community systemically, and for community development.

These projects challenged the youths’ mentors to reconsider their own criticality and connectivity. As one mentor said, “I had not considered the multiple layers of challenges in book access. I noticed at least 6 concerns raised by the youth: the location and hours of libraries, the need for proof of residency to get a library card, the cost of overdue books, whether one feels welcomed in a library, and access to things other than books, like maker kits. The library desert is just the tip of the iceberg.”

Across design processes, youth and mentors began to see problems they faced as bigger than themselves, opening up new ways to talk about and make that challenged systemic injustice. Ethnographic tools, employed as part of the making process, such as dialogic and structured interviews with community members and member checking, supported youth in making sense of the problems they cared about. It assisted them in recognizing those problems as part of broader, entrenched challenges that their community members had struggled with or negotiated over time. These tools also expanded spaces for mentors to share our own experiences with the problems youth identified, which assisted adult-youth collaboration to better understand the ways in which problems were entangled in systemic oppression experienced by their community.

Critical community dialogue was essential, for example, in supporting one group of youth to understand problems of homelessness with more complexity and nuance than is easily reached without such person-to-person interaction. The Donator app group had initially approached the problem space of homelessness as a one-dimensional issue. Well-intentioned, some group members had a limited understanding of actual peoples’ stories, concerns, and tensions. Interviews with a mentor who had experienced homelessness herself, and also with housing campaign organizers and homeless shelter directors helped Donator app designers Zani and Kandy develop a more multifaceted, tangible, and human understanding of what it means to be homeless. They began to discuss the issue in terms of housing rights at national, state, city, and individual levels, and they explored how they could leverage their own experiences with both housing resources and digital technologies to engineer a potential solution. They connected what they learned from interviews and research to a simulation game they played on their phones, inspiring their design of an app that and would allow users to experience homelessness through the lives of individuals. The girls transformed their own knowledge of their problem space and then expanded outward to educate and empower other community members as fellow housing rights allies.

One aspect of expanding scales of criticality is in how the youth began to both see the problems they were trying to solve as tied to but intersecting scales of injustice. As youth moved their projects across spaces through their different forms of engagement with community, they began to make connections among economic, racial, gender, and environmental justice.

Across the cases, youth viewed their design work as tackling multiple, related problems. Most youth, however, did not begin their design work with these intersecting ideas at the forefront. Their participation in surveying community members supported them in noticing which concerns were most salient, where and when, and for whom. While these connections were not made solely through these surveys, the approach created the space for new questions to be opened and new discourses to be legitimized, among both youth and mentors.

**Engaging making with community: Co-making and expanding social networks**

Engaging in making with community centralized what we refer to as co-making, including the co-production of design problems and solutions with a wide range of stakeholders across setting and time. First, engaging in ongoing dialog with community opened up avenues of collaboratively informed exploration no one could fully anticipate. This meant that adults in these settings needed to become co-learners alongside youth to effectively support them. As one mentor stated, “there were times when I just did not know how to help the youth, and we had to seek out input together from others in the community. I think this really shifted the power as we needed each other and the community members to figure out how to move on the project.” While STEM educators may hold deep knowledge of some practices and ideas needed for the youths’ engineering/making designs to be successful, we did not always have the same level of knowledge of community or specialized applications to help youth solve particular problems.

Engaging in ongoing dialog with community created ongoing and snowballing moments for a wide range of others to contribute to design. For example, the Timmy, a heated work boot, began as a concept led by two boys but ultimately involved 12 others in its design. Maken’s emphasized their design’s polyvocality of concerns: “The Timmy is for people that can’t afford shoes, people that don’t have boots for winter . . . We will have a website where we sell boots for free for homeless people. Our product is useful for winter and for people that have cold feet, or just want to look cool.” While the project was led by Maken and Tel, daily discussions of their work during basketball games with friends led to six additional middle school boys offering help in various stages.
of design. In addition, two different engineering undergraduate students assisted in the particularly challenging aspect of figuring out which heating elements could be powered with a single rechargeable battery, and is safe and robust enough to sit in a shoe. Maken and Tel also involved adults in their community by seeking input on what kind of boot might be most fashionable and comfortable. They described the inspiration of their design as coming from seeing one of their teachers in an ankle cast and her concern over a cold foot in the cold/harsh winter.

Our study expands how the field frames a culture of sustained making by highlighting that when youth have opportunities to engage as community ethnographers as a part of their making work, they are compelled to be responsive to basic questions of social justice and equity as a part of – not apart from – the technical and social dimensions of their making work: “Who is their making project for? Whose knowledge counts? Who takes part in defining the problem, data collection, interpretation, and analysis? Who owns their making project, and to what end? How youth makers are taught to examine and incorporate these concerns, as part of making, shapes not only their development as makers, but also how their making work may potentially impact both the individual and society. This intersecting approach reframes making both in terms of process and outcome and supports the deliberate departure from pre-designed making activities redolent of the “keychain” syndrome. The youth’s making culture was geared towards relationality. This is important because it requires maker educators to consider how youth sought to transform the relations among the youth makers, the content/practice of making, and their making peers, mentors and community towards who they are and want to be and towards the possibilities for their making work. The problems addressed were emergent of their locations and histories, rather than the interest of any given individual. The design approach leveraged within these two making spaces foregrounded community voices and co-ownership, offering youth opportunities to build relationality into their making culture. Community engagement helped youth to see and understand their own relationality; that is, how youth are related to the issue they are investigating, to other youth, to community members, adult mentors, and the broader systems of power which shape their experiences in the world as young people of color growing up in lower-income communities. This view has a disruptive dimension that focuses on challenging historicized inequalities as a part of making. By engaging with community as part of their making practices, the youth placed new attention on making as a process not just of producing new artifacts, but also of co-constructing new spaces for imagining new social futures.

Conclusions

Through community-grounded making work, youth demanded widening of boundaries for making in dialectical relationships with the lived experiences of community youth makers. The landscape, population and practices of a community makerspace are reshaped. Who youth makers are, what issues they care about, who other stakeholders could be, what resources and approaches are sanctioned are renegotiated in ways that foster equitable and consequential making for the youth. Equity in STEM-rich making is possible when co-created in locally-centered, community makerspaces where youth can be empowered to collaboratively frame problems and design solutions to authentically address injustices in their everyday lives.

References


Acknowledgments

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“Your Turn!”: Playing Cooperative Modern Board Games to Promote Perspective Taking and Cooperative Attitudes

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Abstract: Though social and emotional learning (SEL) interventions successfully foster enhanced social, emotional, and academic outcomes, the research on engaging methods for teaching specific skills has been limited. This study investigates the potential for modern board games to foster SEL competencies through Cooperative Learning Theory. Because cooperative modern board games combine motivating gameplay and designs that align with elements from Cooperative Learning Theory, they may enhance cooperative attitudes and perspective taking skills. In this pre-test/post-test quasi-experiment, middle school students played either a cooperative or competitive board game. Students who played and highly enjoyed the cooperative game showed significantly greater increases in perspective taking skills after gameplay ($F=11.42$, $p=.001$), suggesting that playing enjoyable cooperative modern board games may be associated with increased perspective taking skills. Our findings suggest the need for further investigation into board games as a low-cost platform for students to practice SEL skills outside of the formal classroom environment.

Keywords: Social and Emotional Learning, Cooperative Learning, Board Games, Games

Introduction

In our collaborative society, strong social and emotional competencies are a must for working with others successfully in the classroom, the workplace, and throughout daily interactions. Social and Emotional Learning (SEL) interventions enhance the competencies of self awareness, self management, social awareness, relationship skills, and responsible decision making (Collaborative for Academic, Social, and Emotional Learning, 2015) and lead to increased academic achievement and reduced behavioral misconduct (Durlak, Weissberg, Dymnicki, Taylor, & Schellinger, 2011). However, research has not fully examined the effectiveness of teaching specific skills within these competencies (Durlak, et al, 2011) or the effectiveness of different teaching methods (Hromek & Roffey, 2009). Further, current research on SEL interventions has not focused on the extent to which students enjoy or are engaged in these interventions.

Games are an engaging way for students to participate in experiential learning. Some games are used within SEL interventions, alongside role playing for students to practice certain skills (Durlak, et al, 2011). For example, Hromek and Roffey (2009) explore the potential of therapeutic board games to promote SEL for young children. Commercial modern board games have not been studied in this context. These games are developed within game design paradigms oriented toward consumer engagement rather than education, so we predict that they should be more enjoyable and engaging. They can potentially also be a way to reach students who may not enjoy collaborative learning in formal learning environments. Because players have to work together to play the game and regulate the rules (Xu, Barba, Radu, Gandy, & MacIntyre, 2009), they are already cooperating by successfully playing a game together. Cooperative play has been shown to increase cooperation and perspective taking skills (Zan & Hildebrandt, 2003). In particular, cooperative modern board games further necessitate that players work together due to the goals structure and mechanisms and may be especially successful for increasing these outcomes. Thus, we predict that cooperative modern board games are an accessible and low cost medium through which players can practice and enhance cooperative attitudes and perspective taking skills.

Modern board games

Both popularity of and innovation within board games have soared during the current Board Game Renaissance (Wingfield, 2014), despite the prevalence of digital games. Since many modern board game players identify "social interaction" as the most enjoyable aspect of gameplay (Woods, 2012), the face-to-face, rather than digitally-mediated, interactions may be a major draw to play these games. We propose that these board games provide a supportive environment where players can develop and practice social skills. Players are physically present and have guiding principles – the game rules – to structure and facilitate social interactions. They can also learn through social learning by observing other players’ behaviors in spontaneous interactions.
Cooperative learning

Although many have distinguished between cooperation and collaboration (e.g. Jeong & Hmelo-Silver, 2016), there is considerable overlap in practice. Because Cooperative Learning Theory has been cited as a theoretical basis for many SEL interventions, and this theory does not draw significant distinctions between the two, this paper will use “cooperation” simply to include both concepts. Cooperative Learning is a way of structuring education so that students work cooperatively towards learning goals (Johnson & Johnson, 1969). It is based on Social Interdependence Theory, which posits that the way goals are structured influences how individuals interact and, subsequently, the outcomes (Deutsch, 1949). Cooperative Learning has been shown to result in greater interpersonal attraction, academic achievement, and cooperativity (Slavin, 1990). Also, “students learn how to communicate effectively, provide leadership, help the group make good decisions, build trust, repair hurt feelings, and understand other's perspectives” (Johnson & Johnson, 1999). These skills fall under the “relationship skills” and “social awareness” SEL competencies.

Johnson & Johnson (1989) proposed that successful cooperative learning environments have five essential elements: (1) positive interdependence, that participants perceive they are reliant on one another to achieve their goals; (2) individual and group accountability, that both the individual and the group perceive responsibility for completing their tasks; (3) promotive interaction, that participants are supportive and take personal responsibility for the success of others; (4) appropriate use of social skills; and (5) group processing, time for the students to reflect on their abilities as a group. Modern board games present a case for increasing cooperative attitudes, because many of their design elements align with these essential elements of cooperative learning. First, task interdependence occurs because players will have to wait for others to complete their turn(s) in order to continue to their own turn(s). Also, because all players are sharing one set of game components (e.g. one board or one deck of cards), there is also positive resource interdependence. Second, modern board games usually require in-person, face-to-face promotive interaction. Additionally, playing modern board games tends to require interpersonal and small group skills, as most games take two to four players and can only be continued if everyone works together at least to a certain degree.

In addition to these inherent qualities of most modern board games, regardless of goal structure, it was predicted that cooperative modern board games would promote cooperative attitudes and perspective taking skills more than competitive modern board games. Cooperative modern board games have an added component of positive goal interdependence, sometimes positive role interdependence, individual accountability, and often spontaneous group processing. Although playing the competitive game may be associated with an increase in competitive attitudes after play, it was expected that their cooperative attitudes may also increase, because most modern board games themselves include multiple forms of positive interdependence, as mentioned before.

The focus of this research is to look into engaging and enjoyable ways for students to practice and enhance their social and emotional competencies. Because cooperative learning has been empirically shown to be successful in enhancing social skills, and because mechanisms of cooperative board games align well with the essential elements of cooperative learning, modern cooperative board games may be successful in enhancing social skills as well. Thus, the research questions are: 1) How does playing modern cooperative board games, compared to competitive ones, affect cooperative attitudes? and 2) How does playing modern cooperative board games, compared to competitive ones, affect perspective taking skills?

Methodology

Participants and procedures

Through a partnership between the University of Minnesota and a local Midwestern middle school, 91 seventh grade students, from 5 different class periods, participated in this quasi-experimental study. About 38.5% of participants self-identified as “girl”, “woman”, or “female”, 55.8% “boy”/”man”/”male”, and 3.8% other. Approximately 37% of participants were people from traditionally underrepresented racial and ethnic populations. Classes were randomly assigned at the class level to either the cooperative or competitive game condition. Because of unequal numbers of students across class periods, there were 39 participants in the Competitive condition and 52 in the Cooperative condition.

Each student participated during one 45-minute school period a day for three consecutive days. On the first day, participants completed pre-test measures, learned the game, and played a practice round of the assigned game. On the second day, participants played the game in a randomly assigned group of 3-5 students during the whole class period, playing the game an average of 1.5 times. On the last day, participants completed post-test measures.
Materials and measures
Participants in the Cooperative condition played Hanabi™ (Bauza, 2015), and those in the Competitive condition played Abracada…What?™ (Kim, 2014). These games were chosen based on similar mechanics and were rated equivalently difficult on the premier board game forum (http://boardgamegeek.com). Hanabi™ requires players to work together to play cards one through five sequentially in each of five different suits. No player can see their own hand and must work together to give hints to other players. Abracada…What?™ also does not allow players to know their own tiles. Players compete with one another to accurately guess what spells they have to defeat their opponents.

For the pre-test, participants were given print copies of the questionnaires, the order of which was randomized between classes. Each questionnaire included questions and answer choices in English and Spanish. Cooperative attitudes were measured through the Cooperative (COOP), Competitive (COMP), and Individualistic (IND) Attitudes scales (Johnson & Norem-Hebeisen, 1969). The 22 total questions across these subscales, measuring liking and valuing of each interdependence condition were randomized. The tendency to utilize perspective taking skills was measured using the Perspective Taking (PT) subscale of the Interpersonal Reactivity Index of empathy (Davis, 1983). This subscale consisted of 10 questions. Participants responded to each question across the subscales using a 4-point scale from “strongly disagree” to “strongly agree”. During the post-test, students completed the same scales as well as a manipulation check to ensure that the games were indeed viewed as cooperative or competitive, respectively, demographics and a post-questionnaire regarding their understanding and enjoyment of the game, relationships with classmates, and an open-ended response on what students thought they learned.

Analysis and results
In accordance with previous data analyses of these measures (e.g. Johnson, et al, 1979), the data were treated as continuous and scores for individual items were summed to create one value for each scale. Participants’ post-test scores on each of the scales (COOP, COMP, IND, and PT) were regressed onto the corresponding pretest scores to provide a standardized residual. These represented differences of actual and expected posttest scores based on pretest, as was used by Jung, McMaster, and delMas (2017). The standardized residuals were used as the outcome variables in a multivariate analysis of variance (MANOVA) comparing the students who played the cooperative versus competitive game. Because students were randomized at the class level, we calculated intraclass correlations (ICCs) for each scale. All of these ICCs were less than .01, thus students were treated as the unit of analysis. Students’ open ended responses were analyzed using content analysis.

Though we had predicted that the cooperative game would lead to greater cooperative attitudes and perspective taking skills, and these effects found were in the expected direction, there were no significant main effects between the cooperative and competitive conditions on either the cooperative attitudes or perspective taking skills \(F(4,84)=0.153, \text{Wilks’} \Lambda=0.993, \ p=.961\). In investigating potential confounding variables, we evaluated the students’ responses to the game conditions, we found that participants in the cooperative condition reported significantly lower enjoyment of game \(t(82.97)=2.76, \ p<.01\). Thus, additional analyses were conducted to see whether enjoyment affected students’ results. Conducting a MANOVA with the game condition and enjoyment as predictors on the same dependent variables, the main effect of game condition was not significant \(F(4,81)=0.964, \text{Wilks’} \Lambda=0.753, \ p=.559\). However, enjoyment of game was marginally significant \(F(4,81)=2.388, \text{Wilks’} \Lambda=0.894, \ p=.059\) and the interaction of game condition and enjoyment was significant \(F(4,81)=3.935, \text{Wilks’} \Lambda=0.837, \ p=.006\). Upon conducting post-hoc tests and adjusting the alpha levels for multiple tests, COOP was not significant \(F(3,84)=2.208, \ p=.09\) though those in the cooperative condition did have higher cooperative attitudes as predicted, PT was significantly affected by the interaction of game condition and enjoyment \(F(11.42, \ p=.001)\), with higher reported enjoyment in the cooperative game condition having statistically significant higher PT than expected from pretest.

Students mostly reported learning game rules and strategies for gameplay in the open-ended response. However, some students in the cooperative game condition also noted that they learned cooperative skills whereas those in the competitive condition more often reported learning deduction or probability skills.

Discussion and limitations
Based on the statistically null main effects of game condition on cooperative attitudes and perspective taking skills, we do not have evidence to support our prediction that cooperative attitudes and perspective taking skills will increase more when playing cooperative as opposed to competitive modern board games. However, further analyses revealed a significant interaction between game condition and enjoyment on perspective taking skills, suggesting that enjoying playing a cooperative board game may be related to increases in students’ self-reported...
perspective taking skills. Those who reported not enjoying the game were likely less meaningfully engaged and/or motivated to fully participate. Differences in enjoyment between games could be due to the theme tied to the mechanics or the physical game components, among other aspects that are game-specific. This finding suggests that the results may not have been solely based on goal structure, but also on other factors tied to the particular games.

Thus, only having one game per condition was definitely a major limitation; utilizing only one game per condition cannot rule out that other games with the same goal structures may lead to different results. Additionally, participants were only exposed to the game for a total of one hour across the three days, which is likely not enough exposure to truly change attitudes or skills. According to Johnson and Johnson (1989), cooperative learning interventions require time. Further, even if these games can affect students’ perspective taking skills and cooperative attitudes, we must keep in mind that these results may not transfer to a formal learning environment.

The next iteration of this study will include a series of different modern cooperative versus modern competitive games, to be played over a series of months, so as to try to better control for enjoyment and provide a more effective dosage. Additionally, we plan to incorporate more observational and qualitative data collection and unobtrusive measures, such as how far apart students sit and how they interact with one another when setting up or cleaning up games.

The findings of this study support that further research in this domain may be warranted. This research has the potential to help students work on social and emotional competencies in an enjoyable and engaging way that may not require as much adult supervision or training. Because board games are low-cost and accessible, they have the potential to help reinforce SEL outcomes in a broad range of adolescents, including under-represented populations who may not have the resources or opportunities for learning SEL outside of the classroom. More generally, connecting with a world of diverse individuals requires strong interpersonal and social skills and knowing how to interact with others can go a long way to bolster successful interactions with diverse others.

References
Playing and Designing Games for Systems Thinking: A Design Based Research Project

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Abstract: Systems thinking (ST) is an important skill for making sense of the complex systems in our world. This design-based research study tested conjectures around students’ understanding of ST in elementary grades. We tested how students learn ST skills through designing and playing digital and board games. We looked for students to identify components of a system, describe interconnections, and explain how those interconnections affect the outcomes of the overall system. We discuss changes to our designs and conjectures over two large design cycles. We hope findings from this study can inform research examining how games support the development of ST and other critical thinking skills.

Introduction

Systems thinking (ST) is an important skill for making sense of the complex systems in our world, including navigating everyday professional and social life (Hogan, 2000). Systems thinking helps people see and experience the relationships “between the various physical and social subsystems that make up our reality” (Richmond, 1993, p. 113). It is considered an important 21st century skill for generating solutions to increasingly complex and interconnected problems (Boardman & Sauser, 2008; P21 Framework Definitions, 2009). ST has received increased attention in educational research (e.g. Goldstone & Wilensky, 2008; Jacobson & Wilensky, 2006; Sweeney, 2010). However, there are few studies focusing on students’ ST learning trajectories, especially in elementary grades.

Hmelo-Silver, Marathe, and Liu (2007) articulated the main aspects of ST that we focus on in this study: components or structures - the elements of a system, behaviors - features of components or descriptions of what they can do, and interconnections or functions - the ways components or behaviors interact and how that impacts the system. Ideally, we’re looking for students to identify components, describe how components and behaviors interconnect, and explain how those interconnections affect the outcomes of the overall system.

We chose to approach ST through designing and playing games for several reasons. First, research clearly demonstrates the benefits of playing games for learning (Barab et al., 2007; Gresalfi & Barnes, 2016; Pareto et al., 2011; Squire, 2006). Research also shows the value of learning through design (Harel & Papert, 1991; Haury, 2002; Kafai & Resnick, 1996), including designing games (Kafai, 1996; Marchetti & Valente, 2014), but more research is needed to unpack how playing and designing games impacts ST (Squire, 2002).

Context and methods

Study context

The data for this project was collected at a summer camp at a southeastern U.S. university during summers 2013 and 2014. Year 1 of the study included two rounds of implementations. There were some revisions to the design between rounds 1 and 2 based on initial findings, then more revisions before year 2.

In year 1, our workshop focused on designing and playing digital games to learn about ST. The workshop lasted one week, followed by a second week with another group of students. The first week had 25 students, and the second week had 23 students including 4 who repeated the workshop. In year 2, our workshop involved designing and playing digital and board games to learn about ST and ratio. We again taught the same week-long workshop for two weeks to two different groups of students. There were 15 students in week 1 and 15 in week 2, with no repeaters. The workshops lasted all day with short breaks for lunch and exercise.

Participants

The students in this study were rising 4th and 5th graders from across the U.S. To qualify for the program, students had to perform at or above the 95th percentile on standardized achievement tests. Once accepted to the camp, students chose to participate in workshops based on their interests and areas with strongest test scores. Therefore, students in our workshops had some interest in games and mathematics. The research team designed, taught, and analyzed each of the workshops.

Data collection
During year 1, we focused data collection on the development of students’ ST skills. We designed and collected pre and posttests for ST, kept copies of the digital games students designed, and took videos of whole class discussions. From year 2, we have copies of students’ digital games and videos of the board games students designed, videos of whole class discussions, and copies of students’ “let’s play” videos, described below.

Analysis
We used the ST framework from Hmelo-Silver, Marathe, and Liu (2007) to code students’ pre and posttests and discussions for evidence of components, behaviors, and interconnections. Test questions and student talk in discussions were coded on a three-point scale. Responses received a 1 if the student only mentioned components, a 2 if he/she talked about behaviors or one interconnection, and a 3 if the solution included multiple interconnections or their impact on the system. We also used the ST framework to count the number of components and connections in students’ digital games. In the digital game designs, each different kind of block or character counted as a component. We then counted connections necessary to win the game. For instance, if there were many enemies in the game and the student chose an avatar (the character the player controls) with a gun, we counted that as one connection because the player needed a gun to get past all the enemies.

Starting points and conjectures
The students in this study identified as “gifted” and tested about two grade levels ahead. They also chose to participate in this workshop, so they were already interested in games and motivated to participate. However, they had very few prior experiences with formal ST skills. Informal interviews indicated students had not spent much time playing or designing games in school. Although all of them played games at home, only a few students had experience designing games.

To understand students’ starting points with ST, we gave pretests in year 1. We coded the tests for evidence of thinking in terms of components, behaviors, and interconnections. The average score on the pretest in the first week of year 1 was 42.8%, and the average score (without the repeat students) in the second week was 45.9%. Students were able to identify components of different systems, but they didn’t understand how those components interacted to affect outcomes of the overall system.

Our initial designs were informed by several conjectures. We thought playing some digital games first would help students generate ideas for their own designs. We planned to talk about the digital games in a whole class discussion, which focused on identifying components in each of the games students played. Next, we wanted students to design their own digital games, which gave them opportunities to plan and explore systems. Students designed in Gamestar Mechanic (https://gamestarmechanic.com/) because the program allows students to easily start the game design process. We also thought that giving students an open goal, such as making the easiest or hardest game in the world, would allow them to explore many different aspects of the game system.

Findings and revised conjectures
Year 1, Week 1
The results after week 1 revealed some limitations of the initial designs. The average pre to posttest change was only 1% (increase from 42.8% pre to 43.8% post), so the tests didn’t reflect any ST learning. In whole class discussions, students mentioned an average of 5 components, 8 behaviors, and 4.7 interconnections per discussion. That means that in each discussion led by a researcher involving all 25 students, only 5 components and about 5 interconnections were mentioned. The numbers are low considering the number of students, the amount of student talk, and the length of whole class discussions (30 minutes or more). We also saw few connections in the games students’ designed. On average, students’ digital games included 7.4 components and only 1.5 connections. A game with 7 components and 1 connection implies there were extra components that didn’t affect the outcomes of the game system. These results led to some changes in the designs for week 2:

- Researchers used ST vocabulary during whole class discussions to help students develop a shared language and understanding of basic ST skills. Researchers used the vocabulary to organize discussions, but students were not required to use the terms in their talk.
- We changed the game design prompt to be “design around an avatar or enemy.” Each student chose an avatar or enemy in Gamestar Mechanic and designed his/her game around that character. This allowed students to think specifically about how components and their behaviors interact with the chosen character to help players win or lose the game.

Year 1, Week 2
Results from the second week of the summer camp revealed some learning gains. First, students’ posttests increased an average of 10% (from 45.9% to 55.9%, ignoring students who repeated the workshop). Looking at students’ talk, we saw an average of 8.7 components, 25.3 behaviors, and 16 interconnections per whole class discussion. This is a large increase from 5 interconnections in week 1. We also saw an increase in the number of connections students used in their designed digital games. Students used an average of 9.1 components and 3.2 connections per digital game.

Year 2
In year 1, we thought the quality of whole class discussions improved when teachers used ST vocabulary to organize discussions. Therefore, in year 2, we added ST terms to the worksheets students used to guide their game designs. We also had students design math board games, and we gave students cards with mathematics problems to use in their games.

While we have not yet completed a retrospective analysis of year 2, I can point to some initial findings based on videos and my own participation in the workshops. First, we found that giving students math cards constrained their game designs. All the student groups incorporated math cards into their board games in a similar manner: a player lands on a particular space that requires them to pick up a math card, and if they get the answer correct, the player collects points or money.

Second, a few students asked to design their digital games in pairs instead of individually. Designing in pairs helped students articulate their ideas and talk more clearly about how the pieces in the games interconnected. In future iterations, we’d like all students to work in small groups.

Third, students created “let’s play” videos of the games. “Let’s plays” are videos people post online showing themselves playing games and talking about strategies to complete difficult sections. Thinking about an audience encouraged students to analyze the difficult parts of the games and how the player interacted with components to win the game. It also forced students to make their thinking explicit. In future workshops, we want to keep using “let’s play” videos as a way to engage students in articulating their ideas.

Discussion
After two years of studying games for ST, we have made some important changes to our conjectures and designs. We now have a better idea of what we can expect from students’ ST skills during each activity and how we can support their learning. I’ve adjusted the hypothetical learning trajectory to build in ST skills more gradually. Rather than expecting students to go from identifying important components to talking about outcomes of a system, the trajectory now includes a set of activities that supports students to think about components, then behaviors, then interconnections and system outcomes. Our findings also point to some ideas about how to support students’ design processes, including using designer worksheets with systems vocabulary, having students play many different games and brainstorm ideas, letting students think creatively about how to use math in their games, and designing digital games around a specific character or component. Table 1 summarizes the updated learning trajectory with design changes to explore in future iterations. We hope findings and design changes from this study can inform research examining how games support the development of ST and other critical thinking skills.

It is important to remember that the context of this study was special: all the students tested above the 95th percentile on state tests, students chose to participate in this workshop, and the workshops lasted all day for a week. However, our designs could be implemented in a regular classroom over a longer period of time. Instead of one week devoted to playing and designing games, the activities could be dispersed over a month or a semester of instruction. As we continue to refine our designs and learning trajectory, it will be interesting to explore how teachers might use these activities to improve students’ ST skills in more diverse classrooms.

Table 4: Updated learning trajectory and designs

<table>
<thead>
<tr>
<th>Systems Thinking Learning Goals</th>
<th>Activity</th>
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<tbody>
<tr>
<td>Recognize important components of the games students play</td>
<td>Students play math board games and digital games. Teachers lead a whole class discussion of the games using systems thinking vocabulary.</td>
</tr>
<tr>
<td>Articulate important components and their behaviors in the games students play</td>
<td>Students make “let’s play” videos about some of the digital games they played.</td>
</tr>
</tbody>
</table>
Recognize important components and how they interconnect to make a game work (focusing on the games students played and their game design ideas)  
Teachers lead whole class discussions brainstorming ideas for math games. Students plan their board game and digital game designs by answering questions (written with systems thinking terms) on a worksheet.

Talk with peers about components and interconnections in students’ designed games  
Students work in groups to design math board games.

Think about components, their behaviors, and how they interconnect in the digital games students make  
Students work in pairs to make digital games in Gamestar Mechanic using the prompt “design around an avatar” or “design around an enemy.”

Talk about components, behaviors, interconnections, and game system outcomes (in terms of digital games, board games, and students’ designs)  
Teachers lead a whole class discussion wrapping-up students’ game playing and designing experiences. They discuss playing versus making games, the different features of digital versus board games, and how digital and board games help people learn or practice mathematics.

References
Forms of Emergent Collaboration in Maker-Based Learning

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Abstract: This paper is a work-in-progress where we discuss the ways in which collaboration can be identified and understood in the context of maker-based activities. While the importance of collaboration is often identified as crucial to successful project-based learning activities, there is not much empirical work that describes: a) what these collaborations look like and b) what happens for learners as they engage in collaborative activities. Here, we draw on data from three different studies of maker-based activities to explore the following question: What forms of collaboration are made possible in maker activities? In asking how collaboration develops through making we shift from collaboration as a design feature of learning environments to both a process and an outcome of learning. We take up an emergent perspective on collaboration focusing on the collaborative interactions that occur naturalistically in maker activities.

Major issue(s) addressed
Learning environments where groups of people are engaged in creative production require collaborative engagement, people and tools working together to produce a piece of work. Creative production affords what Sawyer and DeZutter (2009) call “collaborative emergence,” an activity that has an unpredictable outcome with moment-to-moment contingency, where subsequent actions can change the effect of prior actions, and the process is fundamentally collaborative. Collaborative emergence is distributed across people, tools, and time (Halverson et al., 2015) and can therefore be understood as both a process of making work and an outcome of a work process. We are curious about what happens if we center collaboration as the subject of our empirical inquiry into how learners engage in making activities not as a design feature to “produce learning,” but as a core component of the learning process.

We are interested in collaboration as both a process and an outcome. Typically, in educational settings collaboration as seen as in service of a learning goal whether individualistic or collectivistic, serving as a design feature of learning activities. In maker contexts, scholars have taken up the collaboration-as-design-feature notion whether pairs of people work together to produce individual artifacts, or whether individuals work together to produce a collaborative artifact (Litts, 2017). In the data we analyze for this paper, though, we see that maker activities and spaces afford new forms of collaboration that are not explicitly designed-for. From this perspective, collaboration is not only a method for achieving a goal, but also an end in and of itself.

We characterize this orientation toward collaboration as “collaboration through the air” (Kafai & Harel, 1991), where makers “pick up” an innovative idea by being in the same physical space, working with the same tools, materials, and processes but without explicitly coordinated goals. Kafai and Harel first noticed this phenomenon in their studies of instructional software design projects; they describe a collaborative production style where learners construct their own individual products, yet are working together under the same “umbrella goal” permitting learners to move between individual and collaborative styles as they desire/need. Hall (2015) also documented this phenomenon in studies of a writing lab where participants’ writing was visible through ambient display. Through this display, they co-created an “aesthetic of cohesion” across their writing. Working with what Hall calls an “ambient audience,” he argues that visual representations were passed from screen to screen without explicit conversation or designed collaborative action. In our analysis, we ask what collaboration looks like in maker activities where the learning outcomes for participants are not set a priori and therefore more flexible in terms of the role collaboration can play in the learning process.

Significance of the work
Schoenfeld describes the importance of “ideas in the air” as a mechanism for seeing and solving problems in the scientific community (cited in Kafai & Harel, 1991). When learners are working in the same physical space together, knowledge floats around waiting to be “picked up.” In cases like those described in Hall (2015) and Kafai and Harel (1991), learners need space and time to pick up ideas when they are ready and to drop ideas when/if they need to. This vision for the role of collaboration in learning stands in sharp contrast with the designed-for way we typically incorporate collaboration into a learning environment. We often imagine that in order to collaborate learners need to be told when and how to do so. When we study collaboration in learning environments, we often look at purposeful collaboration such as the impact of role assignment on individual
learning outcomes (De Wever et al., 2008). The significance of this work is to reclassify collaboration as an emergent process and outcome of creative, constructionist learning environments, rather than as a designed-for feature that is built in when the instructor or designer finds it necessary or important.

**Theoretical and methodological approach(es) pursued**
Data for this paper is drawn from our collective research projects that sought to study what people learn through making, how makerspaces function as learning environments, and the design of a school-based makerspace to afford productive learning outcomes for a range of students. Across this work, we attend to the theoretical framings of research in the Maker Movement as described in Halverson and Sheridan (2014): *Makerspaces as communities of practice, makers as identities of participation, and making as a set of activities*. Our research on makerspaces has described the learning arrangements that characterize makerspaces, highlighted individual features of makerspaces and explored how makerspaces foster youth growing and developing their own personal networks of expertise and practice. Our research on makers has demonstrated the habits of mind young makers develop through their participation in makerspaces and in maker activities including agency and resourcefulness. We have also examined the disciplinary outcomes associated with making activities, such as young childrens’ acquisition of knowledge about circuitry. (For citation list of project findings, please see: <https://tinyurl.com/references-collaborativemaking>) The focus on disciplinary knowledge outcomes through participation in maker activities is consistent with other research in the field that occupies the “activities” portion of the Maker Movement research agenda (e.g. Peppler & Glosson, 2013).

We first noticed the importance of collaboration in a pilot test of maker activities that could be used to look at learning processes. We tested an activity where we asked groups of makers to “make flow” as an open-ended making activity. As we watched adults and young people take on this task, we noticed that people were collaborating in a range of ways, though they were not given explicit instructions to do so. For example, when young makers were told to make flow, one participant used a glass jar, cardboard rolls, sugar, tape, and scissors to make a modified hourglass. Another maker, seeing what the first participant had done, took up the same set of materials and created a charming—but frail sugar mill that fit into the city she was already building. In our observations, we were struck by how similar the use of tools and materials was between these two makers who did not know each other and were not working together. Examples such as this motivated us to take a more purposeful look at how collaboration happens across maker activities.

For our analyses, we use data collected (fieldnotes, interviews, and photographs) across three studies: design experiments conducted at three different youth makerspaces, and ethnographic data collected during open-ended making time in a high school-based makerspace. Across cases, makers worked side-by-side and could work together, but were not explicitly instructed to do so. All makers had access to shared tools and materials available in their respective spaces. In some of the design experiments, makers were told what to make (e.g. “Make something that lights up”), while in the open-ended maker experiences they had freedom to make what they wanted. Taken together, these data represent 110 young makers over 16 making episodes. We are currently working through a constructivist grounded theory axial coding process (Charmaz, 2000) through which we identify episodes of collaboration that include “helping” (either peer-to-peer or adult-to-youth), “working together”, and “through the air.” Our goal is to complete an exhaustive analysis of our projects’ making episodes in order to build a theory of collaboration in making. In this paper, we share three paradigmatic examples of collaboration through the air that help to ground our thinking.

**Major findings, conclusions, and implications**

**Collaboration as helping**
Helping is predominant form of collaboration that we see across our data. We noted that collaboration-as-helping took shape in at least two different forms: helping expertise and helping hands. First, in one of our “make flow” design experiments in a library pop-up youth makerspace, Jackson and Shawn teamed up to work with the circuit blocks, which are wooden blocks with motors, lights, switches, and other components with which learners connect using alligator clips to build circuits. Even though they did not previously know each other, Jackson welcomed this collaboration, since it was natural for how he works in the space and because Shawn had circuitry knowledge and expertise that Jackson needed. The two worked closely together to build a large, complex circuit with the blocks, yet in the process they realize the space could use more circuit blocks. So, their task morphed from making a circuit with the blocks to making new circuit blocks for the community space. As a woodworker, Jackson was able to contribute his expertise to building the new circuit blocks. Thus, over the course of this making episode, Jackson and Shawn collaborated through an ongoing exchange of expertise between circuitry knowledge and
woodworking.

In another “make flow” design experiment (part of the same series) that took place at a museum youth makerspace, Charlie and Sarah collaborated toward the end of their making episodes, primarily because they were friends. They both explained that the collaboration was rooted in the fact that Charlie “needed an extra pair of hands” installing the support beam for her racecar track. Over several minutes, Sarah transitioned from her paperclip circuitry experiment to fully helping Charlie: moving her materials to the same table as Charlie, but still working on her experiment; helping Charlie, then returning to her experiment; and finally, solely helping Charlie. Over this episode, Charlie and Sarah’s collaboration emerged from a distant, to side-by-side, to direct collaboration. Charlie reflected on this transition explaining: “I was struggling, I needed extra hands, and then she just came in and she helped like hold things together and gave me suggestions” (Interview, 07/30/2014). Sarah elaborated that “it looked like [Charlie] needed an extra pair of hands, and like she's my friend,” so abandoned her experiment to help keep Charlie’s racecar “steady and stable…helping her through the process of making it” (Interview, 07/30/2014). This making episode emerged as a case of collaboration as helping primarily to give an “extra pair of hands” to a friend, however, over the course of the episode Sarah joined Charlie’s making process more fully.

Inventing technological possibilities
In Nedlam’s Workshop, a 3,500 sq ft. woodshop turned makerspace in a large urban high school in the Northeast, 20-30 students came to the space each day from about 2:30 PM - 4:30 PM (attendance logs) to socialize with friends, to make pancakes and hot chocolate, and to tinker with the digital tools; but, a group of students came specifically seeking opportunities to work with and shape wood. “A group of five Haitian-American girls, three of whom had been in before set about working on mostly wood stuff- with one making a sword, the other making a box…” (Fieldnotes, 10/20/14). Around this time, the extruder for the 3D printer, which had consumed much of the youth’s attention to date, began malfunctioning, and the machine went offline for about a week. This coincided with a what the lead facilitator called a “turning point” (Fieldnotes, 10/27/14) in the youth’s work, where a noticeable interest in making things with wood emerged. Painting, carving, cutting, and gluing or nailing together wood occupied the youth’s attention, where they mostly focused on how they could personalize and/or make something that reflected their interests in the material: “Someone showed Angeline how to use the soldering iron to burn into wood. She made a “P+A” in a heart on a scrap piece. She said that her uncle does a lot of work with wood.” (Fieldnotes, 11/6/14).

This episode marked the emergence of a popular trend of burning designs into pieces of wood with the soldering irons, which is not precisely the intended use for that tool, but a reasonable extension of the tool’s functionality. Within the trend that emerged, some students, Angeline included, began creating religiously-affiliated messages in wood (see Figure 1). Students burned biblical passages, and references to God and their faith. Judeline, a Haitian girl, worked alongside her two sisters and a cousin, borrowing techniques from each other including how to burn certain shapes or how to stain the wood different colors, to create their religious wood burnings. The forms of undirected collaboration that took hold illuminate a complicated intersection of tools, materials, and representations. Initially drawn into the space by the digital tools, youths’ attention shifted to a more familiar medium, wood. They repurposed a maker tool—the soldering iron—to express their own identities and interests in wood. Youth sat and worked together, and these “collaborations through the air” supported how they were able to make their way in a relatively unfamiliar place.

Judeline and her sisters became frequent participants in Nedlam’s over the following 2 years, where their collaborating took the form of seeking guidance from a community volunteer to learn woodworking techniques. Their collaborations evolved from working alongside others, to inventing possibilities for the tools available, to exploring ways of expressing identities, to ultimately seeking help for more complex projects, all of which built the foundation for her sustained participation.

How did you make that flashlight?
During a design experiment at a museum-based makerspace where groups of fifth grade makers were told to “make something that lights up”, a group of 12 students worked at two tables. Makers had access to cardboard, wires, batteries, brads, paper clips, small LED lights, and colored tape. Because this was part of a larger experiment, in this particular group students were taken through the steps of how to connect the parts of their circuit together. Halfway through the making session, DiVonte figured out how to make an on/off button by introducing a brad into the circuit that could be used to break and connect the circuit. As he was working on this, the boys on either side of him noticed what he was doing and asked him how they could do this too. They also used the brad innovation to add buttons to their circuits. When we asked these makers, “What would you want
people] to know about what you made?”, DiVonte wrote: “that I made it light up. I made a swich [sic] go on and off.” Cameron wrote, “That it is a buttin [sic]. There is tape on the wires so it cannot harm you.” Several others in the room referred to their projects as “flashlights”. In an unrelated making episode with blocks later in the session, which was designed for collaboration, these makers “incorporated the flashlights into their blocks” (Fieldnotes, 03/03/15) but did very little collaborating with the blocks themselves. While our prompt for them was “make something that lights up” the addition of the on/off button seems to have floated the concept of a flashlight and gotten picked up by most of the makers in the room without explicit directions or decisions.

At a different table, a group of three other makers were more focused on the aesthetics of their “flashlights” than their functionality. While tape was initially made available for functional purposes (one way to attach pieces together), there were at least six different colors of tape available. Khaliyah starting using the tape to decorate her flashlight. When I asked her about it after the making episode, she said, “I thought it would be pretty cool to decorate it a little bit, to show some color and stuff. And make the colors pop, and make it more interesting” (Interview, 03/03/15). She never articulated this interest during the maker activity, rather she just started using the tape in this way. Emma and Lily followed suit, and each ended up with differently decorated flashlights, all using the colored tape, the only colored material available. Khaliyah put the concept of decorating into the air, Emma and Lily took it up, and it became a collective activity. Interestingly, Khaliyah was also able to help the other two with technical questions, having explicitly connected a prior activity on making robots from her classroom to this activity. Perhaps the informal mentorship role she was playing with the other two makers made the taking up of her ideas more likely.

Forging ahead with collaboration
As designers, our instinct is often to create explicit opportunities for collaboration. If we want learners to collaborate, we have to tell them to, even going as far as assigning roles within the collaboration (De Wever et al., 2008). But this form of collaboration, what we call “designed-for” is in-service of other goals, usually the acquisition of disciplinary knowledge. In this paper, we present an alternative and more emergent perspective on collaboration in making activities. An inherent characteristic of makerspaces is that makers are making together in some fashion. Such spatial designs distribute knowledge throughout the space itself and through proximal interactions with other makers, available to be “picked up” and used when a maker is ready for it. This has clear implications for how we design maker and other project-based activities; rather than using collaboration as a method for acquiring disciplinary content, perhaps we should design for emergent collaboration-through-the-air. This may lead to more productive processes and products that are at the center of constructionist learning.

References
Combining Non-Programming Activities With Programming for Introducing Foundational Computing Concepts

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Abstract: This paper describes the design of non-programming activities aimed at aiding early exploration of hard-to-learn introductory CS concepts (specifically, variables and loops) as well as accompanying bridging programming activities in Scratch. These interactive digital and unplugged activities draw on recent research in dynamic math representations. Empirical research that examines the use of these activities in diverse classrooms shows promise of our unique approach and also points to improvements for future iterations of this design research.

Motivation
Computing is transforming innovation in every discipline through becoming an integral tool that is spurring new ways of doing and thinking. This reality has pushed a rethink of learning in this digital age. “Computational Thinking” (CT) and computer science (CS) skills are now acknowledged as foundational competencies for every child (Grover & Pea, 2018). CS and CT education is scaling in K-12 classrooms in the US and internationally.

Learning to program is a central feature of introductory CS curricula in K-12 classrooms. Scholarly literature from the last three decades documents the difficulties that learners have with deeper conceptual learning of specific concepts integral to programming as well as computing more broadly (e.g. du Boulay, 1986). Recent research conducted in the context of popular block-based programming environments using for teaching CT and introductory CS document that difficulties still persist in the learning of concepts such as variables and loops (Grover et al, 2015). They also suggest that prior mathematics preparation can be a barrier to successful learning of CS (Grover et al, 2016; Lewis & Shah, 2012). We believe that to achieve “CS for All” novel, engaging approaches to introducing learners to these difficult-to-grasp concepts should be attempted and empirically studied instead of the popular (but not always successful) “dive-into-programming-right-away” approach. This current work attempts to achieve this goal by drawing on ideas from past learning sciences and math education research to explore new ways of engaging learners in introductory computing concepts specifically, variables and loops.

Theoretical framework
Trouble understanding variables pervades students’ efforts to use expressions and loops to solve problems in introductory programming (du Boulay, 1989). Middle schoolers working in Scratch have trouble conceptualizing variables and how to use them (especially with loops) and their initial perceptions of variables in programming are influenced by the idea of “unknown thing” as in math (Grover, Pea, & Cooper, 2015; Grover & Basu, 2017).

We are inspired by the powerful idea of epistemological pluralism—multiple ways of knowing and thinking (Turkle & Papert, 1990) for the design of non-programming digital interactives to aid understanding of programming concepts. We also draw on research in math education that has established the important role of dynamic representations in supporting students’ development of conceptual understanding (Drijvers et al., 2009), specifically, innovations in interactive dynamic representations in geometry (Jackiw, 1991). The key insight from that work is that an interactive system can show change over time—often continuously and in response to learner-directed inquiry—to all the values that can instantiate that model. Learning environments also need to account for both individual construction of knowledge and the sociocultural processes that students partake in, in the Vygotskian framing of learning contexts (Cobb (1994). Additionally, constructivist approaches to learning point to providing learners an opportunity to actively construct knowledge by using their intuition and prior knowledge and refining their micro-theories as they interact with artifacts before being provided explanations (Bransford & Schwartz, 1999; Schneider et al., 2015). However, open exploration, especially in the context of programming, often leaves novice learners lost and confused (Mayer, 2004). Exploration thus needs to be designed to provide appropriate levels of constraints and guidance. We also strive to explicitly bridge non-programming activities and subsequent introductory programming activities for mediating transfer (Engle, 2012; Grover et al., 2014).

The following sections describe the features of one unplugged and 2 digital (non-programming) activities aimed at developing students’ early understanding of variables and loops, followed by a brief account of empirical investigations in three public middle school classrooms that used these activities as part of their introductory computer science course. (Space constraints preclude detailed treatment of the designs).
Methods
This section describes the design-based research (DBR) around the design of two digital and one unplugged non-programming activities. These activities were designed as part of a larger effort aimed at exploring novel ways of engaging students in introductory programming concepts, such as variables (along with loops), that novice learners find difficult to grasp. The activities were designed and refined with inputs from teachers (in a participatory design model) and middle-school students (through 2 rounds of piloting involving “thinkalouds”).

Design of curricular activities
Designed as a short and preliminary exploration and introduction to key ideas of foundational concepts (rather than introductory programming constructs) these activities don’t attempt to deliver comprehensive treatments and are designed for one (or two) class periods. All digital activities begin with students exploring the basic phenomenology of the microworld. They are designed as paired exploration along with whole-class discussions.

‘Story Variables’ (unplugged) and ‘Cats & Ladders’ (digital) activities
In Story Variables students work collaboratively in pairs to investigate a series of short “stories” all containing quantities that vary. For example, “Excuse me—last week I bought one of these pens here for $1.50. Are you really telling me they now cost $3?”; “I watched the basketball game last night. At halftime we were tied, but in the end, they beat us 94-90.” Through discussions, students come up with a definition of ‘variable’, practice identifying and naming variables meaningfully, and analyze a variable’s changing values to determine its specific types and expected ranges. Students identify their own real-world scenarios that involve “variables”. As a final activity, they watch a video clip of Pacman and list the different variables they observe. In the Cats and Ladders digital activity (Fig 1), we leverage the popularity of cats! Students rescue distraught cats from the upper floors of various buildings by determining the length of the ladder required to reach them from the ground. The activity is divided into multiple stages, each of which is “unlocked” as the student proceeds through the activity. Learners discuss appropriate names for variables (e.g. “height” or “LadderHeight” is not sufficiently discriminating for the 2 ladders). They also discuss the range of possible values (which are often determined by context), and that different variables may naturally reference different (data) types. Finally, they engage in abstraction through a preliminary exploration of arithmetic expressions and that new variables can be synthesized from existing ones.

‘Graphical Looping’ digital activity and bridging Scratch activities
The Graphical Looping activity sequence (Fig. 2) introduces students to iterated repetitions of a block of actions within a sequence of events, and develops the idea that we efficiently express such a flow of events in terms of a more compact specification of that repetition. Students engage with the idea of action sequences that occur before and/or after a repeating chunk of actions. Graphical Looping makes productive use of comic panels as a proxy for source code in a pre-programming context. Comic strips are atextual (and thus don’t disadvantage ELL students) and contain a formal, and block-structured, grammar for describing action sequences familiar to students. First, students arrange comic panels to tell a “logical story.” They proceed to think about how panels to the story could describe longer swims and identify the “inner story” or “repeating unit”. They discuss how the total length swum increases and the swimmer’s energy decreases with each lap. These ideas are revisited in Scratch programming. The Scratch activities related to loops with variables make explicit connections to Graphical Looping. Learners are introduced to the idea of using a “Repeat” block to swim 3 laps, change the (swimmer’s) Energy value, and also “watch” this value decrease (using the ‘Say’ block) with each lap (or iteration.
of the loop). They then move to the idea of a generalized solution where the number of laps is based on an input from the user that is then used as a variable in the Repeat block (Figure 3).

![Image](image-url)

(a) Swimming Pool Story Arrangement (b) From Arranging to Generating

Figure 2. Screenshots of the Graphical Looping digital activity.

(a) Write a Scratch program using a simple loop to rewrite this code snippet. The swimmer starts with an energy of 1500 calories. You should “say” how many calories are left at each iteration of the loop.

(b) Now, you do not know beforehand how many laps the swimmer will swim. Open the starter program. You will see that there is code that asks the user to enter how many laps the swimmer will swim (a number between 1 and 10). Complete the program so that based on the number the user enters, the program will show how the swimmer’s energy decreases. Show how many calories are left at each iteration of the loop.

Figure 3. Scratch activities using loops and variables that bridge to Graphical Looping.

Study and data measures

These activities were embedded as a 3-to-4 week curricular intervention (length varied by teacher) in a 3 middle school classrooms (N=72; Gr. 6: 17 male, 10 female; Gr. 7: 15 male, 16 female; Gr. 8: 11 male, 3 female) that mirrored the diversity in a large, diverse, urban school district in the U.S. The curriculum was part of an introductory CS course that used Scratch. Three teachers participated in 20 hours of professional development before implementing the curriculum. We conducted mixed method research to: 1) Understand the affordances and design modification needs of these designed activities; and 2) Document and analyze the classroom activity system necessary to support students’ productive engagement with these computing concepts.

Our data measures included (a) Pre-post & formative assessments that were designed using a robust assessment design framework, and included multiple-choice and open response question types and either used snippets of Scratch code, or real-world (narrative) scenarios; (b) Post-survey on students’ reactions to the activities; (c) Interviews & Think-alouds with 12 students (4 per grade) and 3 teachers; (d) Final (open-ended) projects in Scratch: from the 3 classrooms, done (individually or in pairs) analyzed using an elaborate rubric (Grover, Basu, & Schank, 2018). We also analyzed final Scratch projects from ~80 middle school randomly selected from students across the district who were not part of this study (as a comparison).

Results and discussion

Preliminary results (from ongoing analyses) show that all students showed significant gains on the pre-post assessment (Table 1). Preliminary analyses of Scratch projects suggest that students in the sample demonstrated better facility with variables & loops, and their programs were more complex as compared to the comparison projects. Students engaged well with these activities, demonstrating promise of the focus on dynamic representations and relevant examples and contexts. However, the range of students’ readiness to engage and learn and their instructional needs varied considerably both within and across the three classrooms. The 6th graders had the most challenges, whereas the high achieving 7th grade class was able to engage most with the conceptual ideas. This was reinforced from students’ post-survey feedback on these activities. Overall, students found Cats
Ladders to be most engaging and fun ("I liked cats and ladders because it was like a real game"); "It's... to show us about height. And like the variables change. Because like you could change the numbers...It shows us variables. Like how high the ladder could go, like how we could change it.". It was fun and cool.

Graphical Looping activity was found to be lacking in challenge by some "It was too easy"), however students readily made real-world connections ("It teaches you the purpose of what loops do...It reminded like if we go to a grocery store and we could come back and get more food from there and then come back. Like each day you like... it can be from like school, you go back home. And from the home you go back to school") We take these results as constructive feedback to improve upon the designs in the next iteration of this DBR.

Table 1. Student pre-post assessment results

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<th>Grade 6 (n=27)</th>
<th>pre Mean</th>
<th>post Mean</th>
<th>p-value</th>
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Conclusion and future work

"CS for All" in K-12 requires that curricula be designed so all learners succeed in deeper learning of computing regardless of prior academic preparation. This current work attempts to achieve that by exploiting the synergies between key concepts in middle school math and programming, and draw on math education research on the use of dynamic representations to create and examine the use of game-like digital interactives and microworlds that provide early engagement with hard-to-learn computing ideas. While early results are encouraging, they also point toward directions for improvement in future iterations of this design research.

References


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Preschool-Age Children Practicing Science: Intersections of Explanations, Modeling, and Gesture Use

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Abstract: Despite the importance reform efforts have placed on engaging students in science practices, limited research has considered the initial steps young children may take with evidence-based explanations and modeling practices. Following a theoretical perspective that science emerges as it is practiced, we analyzed video of astronomy programs for 3-to-5 year old children in a museum setting. Findings suggest that explanations co-constructed by children ranged in sophistication. Children’s use of modeling practices supported their development of evidence-based explanations. We also found that children often used gestures to develop and communicate their explanations. Our findings demonstrate the initial ways young children’s co-constructed, evidence-based explanations emerge through interactions with educators, peers, and their physical environment.

Introduction

Young children have been referred to as “scientists-in-waiting” due to their notable capacity for scientific reasoning (Gelman et al., 2010). However, this is capacity may not be fully realized without support to develop their abilities. More research is needed that helps us understand the range of ways preschool-age children are capable of doing science (Siry, Ziegler, & Max, 2012). Prior research examines how young children develop an understanding of evidence (Monteira & Jiménez-Aleixandre, 2016) and how the practice of “doing science” emerges in children’s discourse (Siry et al., 2012). Yet, limited research characterizes the ways preschool-age children develop an emergent use of evidence-based explanations or modeling practices. This study helps fill the gap by considering preschool-age children’s initial steps, guided by the following question: How do preschool-age children co-construct science explanations and engage in modeling practices?

Theoretical and conceptual frameworks for “Doing Science”

We focus on how children engage in argumentation from evidence towards constructing explanations and developing scientific models. We draw on sociocultural theory to interpret children’s engagement and learning as situated in the environment (Brown, Collins, & Duguid, 1989) and developed through the interaction of members of a community (Rogoff, 1994). Our theoretical framework also considers science as an emergent process that is generated by those participating together in “doing science” (Siry et al., 2012). This suggests that young children develop understanding of science through interactions with their community, drawing on resources and producing new resources that further their engagement. This perspective on science learning suggests we consider how children’s interactions involve more than just verbal language. Prior research on young children engaged in “doing science” has also taken a multimodal approach, considering children’s discourse and gesture use in the context of science investigations (Siry et al., 2012). Further, studies of older students have considered both gestures and model use as critical to understanding how students convey their understanding of science phenomena (e.g. Kastens et al., 2008; Plummer et al., 2016).

We also define a conceptual framework for evidence-based practices of constructing explanations and modeling. McNeill, Berland, and Pelletier (2017) suggest that in order for children to develop evidence-based explanations in science, children’s explanation should: a) address a question about a scientific phenomenon, b) provide evidence to support the explanation, and c) provide a how or why account for the occurrence of the phenomenon. In these explanations, children use evidence to support a claim - an answer to the question posed about a science phenomenon; they use scientific principles to provide a mechanism for how or why the phenomenon occurs (McNeill et al., 2017). As we interpreted the sophistication of young children’s explanations, we focused primarily on the degree to which they: 1) relied on the educator’s questions about the phenomenon and 2) explicitly included evidence to support their claims. We left open in our coding process whether children would provide mechanistic accounts for the phenomenon, given their age and the complexity of such scientific reasoning. We also consider the extent to which children engaged in two types of modeling practices: 1) when children are thinking about models, they develop or revise models based on empirical evidence in order to better explain or predict a phenomenon; 2) when children are thinking with models, they use or apply models to help them make sense of a phenomenon they have observed (Passmore, Schwarz, & Mankowski, 2017).
Methods
Using a design-based research approach, we worked with an informal science educator to make iterative improvements in the design and implementation of a set of astronomy programs for preschool-age children. The activities were initially selected based on early field-testing indicating their potential to engage young children in evidence-based astronomy explanations. We also selected activities that engaged children with astronomical phenomena through a range of different methods (models, photographs, and directly with phenomena). The four selected activities engaged children in investigating the shadows cast by the Sun, craters on the Moon, surface features of Mars, and the pattern of lunar phases. Each activity was implemented three times by the same early childhood educator, Nora (pseudonym), at a small children’s science museum. The number of children in each workshop ranged from 4 to 25 (average = 12, SD = 5). Children were between 3 to 5 years old. Nora has been educating preschool-age children in formal settings for 40 years and at this museum for 2 years.

Each workshop was video recorded with two cameras to record multiple angles and/or multiple groups of children. Our coding process began using an analytic framework for science practices, developed using literature articulating science practices frameworks (e.g., McNeill et al., 2017; Passmore et al., 2017) and our own ongoing program of research on preschool-aged children’s engagement in science practices in informal settings. We also defined gestures using existing classification schemes: spatial pointing gestures convey location and direction while iconic gestures indicate relationships between objects or spatial information (Alibali & Nathan, 2012; Plummer et al., 2016). One author coded each program to identify instances using these frameworks. The other author reviewed these instances followed by discussion leading to revision in the coding of each workshop timeline. Both authors reviewed all coding to correct for drift in code-use fidelity over time. We looked across the selection of evidence-based explanation codes and modeling codes to look for patterns in the ways children took-up these evidence-based practices through their experiences in this informal setting. And we analyzed how gesture use intersected with our interpretation of their use of these science practices.

Findings
Patterns in the coding led us to three claims, relating to explanations, modeling, and gesture use, describing preschool-age children’s emergent evidence-based practices. Each of these claims emerged through analysis across multiple workshops; we present exemplar episodes from Creating Craters and Moon Phase Matching to illustrate preschool-age children’s emergent practices of “doing science” in museum-based programming.

● Claim 1: Children’s emergent explanations varied in levels of sophistication depending on the degree of use of evidence and degree of support of educator.

● Claim 2: Children engaged in two types of emergent modeling practices: thinking about models and thinking with models.

● Claim 3: Children’s emergent explanations and modeling practices were often dependent on their use of pointing gestures and/or iconic gestures as they developed and communicated those practices.

The Creating Craters workshop began with children discussing observations of lunar craters on a large banner. This was followed by an investigation of how craters are formed. Children worked in small groups to gather data on how craters are made using a model of the Moon’s surface (a tub of sand) and impactors or asteroids (balls of different sizes/masses). Afterwards, children then drew representations of how craters are formed. In this segment, Nathan (5 years) explains his representation to Nora:

Nathan: (Unintelligible) splashes. [Gestures along his drawing showing “splash” of sand.]
Nora: Splashes. How did the splashes get there?
Nathan: I was standing [Nathan passes the paper to Nora, and extends one hand above his head and I threw it down at it [gestures in a quick, throwing motion down towards the ground] and it knocked all the sand [gestures out and away from himself] went flying - [gestures towards where he did his investigation] it made splashes [gestures back from to the drawing]. And it got all over the teacher.
Nora: It came down at great speed and it made a lot of splashes. What kind of crater did it make?
Nathan: It made a really deep one. [Gestures a circle around his crater drawing.] All the way to the bottom. [Starts with both hands above his head, then shoves them down on the word “bottom.”]
Nora: All the way to the bottom of the bin. So what kind of impactor did you use?
Nathan: A metal one.
Nathan generates his explanation with only a few prompting questions from Nora. His claim begins as he combines his drawing with verbal descriptions of descriptions of “splashes.” Nathan’s then uses pointing gestures to link the place where he conducted his investigation to his crater drawing, thus linking his evidence to his claim. He continued to use evidence - his investigation making craters - as he re-enacts, through iconic gestures, how he made a deep crater by throwing the projectile quickly. This allowed him to further develop his claim about how he made a deep crater with “splashes.” It was Nathan’s iconic gesture, and not his words, which indicated to Nora that the ball moved quickly - a concept she verbally stated after observing his gesture.

Nathan’s development of a representation (his drawing of the crater) was an example of thinking about models, as it is based on the evidence he gathered through his investigation of variations in testing impactors made a difference in the size of craters. This is indicated though his description of how his representation shows the creation of “splashes” (the scientific term is ejecta) and the way he gestured to connect the physical location where he conducted his investigation with the paper showing his representation.

In the Moon Phase Matching workshop, children listened to “Papa Bring Me the Moon,” then matched photos of the phases to a banner showing the lunar phases, constructing a representation of the Moon’s cycle from Full to New then back to Full again. Nora led a discussion of the pattern after children organized the phases:

Nora: The Moon looks big and round and then, just like in the story, it seems to get… [Nora points to phases on the banner showing the part of the pattern she is indicating.]
Children: Smaller.
Nora: Until it seems to - [Points to New Moon.]
Mae (4 years): Disappear! Another child: New!
Nora: Disappear. And then back up in the sky its [points along the phases] it seems to get -
Mae: Crescent. / Another child & Nora: Bigger.
Children: Bigger, bigger, bigger - [Nora points at phases leading up towards Full.]
Nora: Until it is a - (Children: Full) a full Moon again. [Pointing at Full.]

This is a less sophisticated example of children co-constructing an explanation than the previous episode as it is highly guided by the educator, and all of the evidence is “in-the-moment.” In other words, children draw on evidence for their claim about the pattern of the lunar phases implicitly from the banner as they describe it getting smaller and bigger. This initial claim about the pattern was built on later in the workshop as children observed the Moon in a computer simulation and considered how it changes day after day. They used the evidence from the banner’s representation to co-construct a new claim:

Nora: We noticed the moon is getting bigger so we must be heading towards the -
Children: Full moon.
Nora: Then after full moon we’ll head back and it will start to get -
Mae: Smaller, smaller to new moon!

Here, the children are thinking with models; they have used a representation they developed by matching Moon phase photos to a banner showing the cycle of lunar phases, to support the construction of their claim. The representation supports the children in making sense of how, but not why, the pattern of phases occurs. The use of a representation, rather than a causal model, allowed children to co-construct an emergent explanation (one that lacked scientific reasoning).

In the previous segment, children did not use gestures while co-constructing explanations, but they were guided by Nora’s gestures. Her use of pointing gestures supported their analysis of the representation. In other Moon Phase Matching workshops, we observed children using gestures to support their construction of explanations. This segment picks up after Nora responds to Nathan’s idea about the Moon’s appearance:

Nora: … made it appear smaller, smaller, disappear [pointing at New moon on the Moon phase banner].
Bryce (4 years): Smaller, smaller, smaller! [He places his fingers as if holding something very small.]
Nora: And then appear, what does it appear to do? [Nora is pointing, just beyond the New moon.]
Bryce: And then it turns smaller, and smaller, like this [shrinks his fingers down so that they are pinched together] and then it disappears full up this place [holds his hands above his head].
Nora: OK, it’s disappeared, and then what happens?
Nathan: It reappears [uses both hands to open out in an expansive gesture].

Both Bryce and Nathan use gestures to indicate how changing size is important their claims about the Moon.

Conclusions and implications
Our findings suggest that preschool-age children have the capacity to engage with evidence-based practices as a form of “doing science,” consistent with a trajectory towards more sophisticated use of these epistemic forms. Our analysis indicates that young children, with the support of their peers and educators, can engage in emergent forms of scientific explanations. Their simple claims were often guided by the educator, and the evidence was used either implicitly, such as making claims based on recent observations without verbal description, or they drew on data that they were currently observing, as indicated through verbal or gestured cues. Our findings extend research on how young learners begin to take up science practices as a way to understand their world through interactions with peers and the physical environment (Monteira & Jiménez-Alexandre, 2016; Siry et al., 2012).

Modeling practices and gesture use served as support for children as they co-constructed evidence-based explanations for astronomical phenomena. Children’s use of modeling practices, both thinking with and thinking about models, was central to their engagement with evidence-based explanations. Models (and representations) provided opportunities for children to either refine their understanding of their evidence or produce evidence for their claims. Children used models to generate data and observe patterns which provided evidence for co-constructing claims, such as the representation used in Moon Phase Matching. Children also used evidence gathered from their own investigations to generate representations used to construct explanations for phenomena, such as during Creating Craters. Thus, children used models both as tools for thinking and tools for generating data (Passmore et al., 2017). Attending to children’s gesture use was critical to understanding how they co-constructed explanations and engaged in modeling practices. Children used pointing gestures to attach evidence from their own personal investigations to claims and used iconic gestures to represent concepts central to their explanations. Gestures allowed children to go beyond what they might otherwise be able to express verbally, externalizing aspects of their developing knowledge (Alibali & Nathan, 2012).

References

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Dynamic Exploration on Self-Explanation Prompts in Complex Tasks

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Abstract: This study explored the effects of the focus (inference or inference followed by integration) and assistance level (less vs. more) in self-explanation (“SE”) prompts on learning outcomes measured by procedural- and conceptual knowledge and whether these improvements persisted over time. A total of 129 South Korean students who enrolled in economic instruction were randomly assigned to one of four conditions: IF-LA, IT-LA, IF-MA and IT-MA. The results revealed that there was an interaction effect of the focus and level of assistance of SE prompts on delayed conceptual knowledge. Prompts that focused on inference followed by integration resulted in significantly higher immediate conceptual knowledge test scores than prompts that focused only on inference. These findings indicated that SE prompt must be designed considering these two factors according to target knowledge.

Introduction

Being equipped with a highly systemized set of knowledge, (i.e. Economics), is in other words to be able to solve various problems in different situations in an equally systemized manner, (Feltovich, Prietula, & Ericsson, 2006), and this is only possible when the core concepts of such problem-solving process is understood completely (Van Gog, Paas, & Van Merriënboer, 2004).

SE is the generation of explanations for oneself to understand the principles of the learning material and each problem-solving steps (Chi, Leeuw, Chiu, & LaVancher, 1994), and self-explanation prompts are best suited to stimulate learning outcomes within certain domains. In their notable study, Berthold, Eysink, and Renkl (2009) developed assisting SE prompts that induce a focused processing of conceptual aspects of mathematical probability. While prompts were irrespective of procedural aspects, they could foster procedural knowledge. The assisting SE prompts allows enough cognitive capacity to concentrate not only on the prompts-induced conceptual aspects but also on the problem-solving process. While it was expected for them to induce conceptual knowledge, self-explanation prompts seem to hinder the acquisition of procedural knowledge. Several scholars (Berthold, Röder, Knörzer, Kessler, & Renkl, 2011) argued that, under complex learning circumstances, prompts that attract learner’s attention to a certain aspect would impede the deeper processing of other important aspects. Therefore, meticulously designed prompts are needed for facilitating both procedural and conceptual knowledge to solve a complex task. This study explores the ways to design the focus and level of assistance of SE prompts in economics for enhanced learning outcomes (procedural and conceptual knowledge) and persistency of such improvements.

SE promotes learning in two primary ways (Rittle-Johnson & Loehr, 2017). First, SE encourages inference generation on a material that they do not fully understand. Nokes, Hausmann, VanLehn, and Gershman (2011) argued that gap-filling prompts are particularly efficient for the development of problem-solving schemas. Second, SE empowers learners to integrate pieces of new information and to combine them with prior knowledge. When studying texts with problem-solving examples, learners’ SEs often link solution steps with prior knowledge or information in the text (Atkinson, Renkl, & Merill, 2003). In this study, we hypothesized that integration-based prompts (i.e., generating inference followed by integration) would enhance performance for complex tasks. Since learners were not only required to generate inferences from simple tasks, but also needed to integrate their inferences with prior knowledge to complete more complex tasks (Morrison, Bol, Ross, & Watson, 2015; Van Merriënboer & Kirschner, 2012). Chi et al. (1994) also suggested that the prompts were designed to reflect a range of difficulties (e.g., category 2 and 3 questions).

Although prompting SE has been recognized as a way to improve learning process, sometimes, even when prompted, learners are unable to generate reasonable explanations as they do not know how to engage in SE. Providing a structured SE format is an instructional technique for improving the quality of SE (Rittle-Johnson & Loehr, 2017). Yet, previous studies on various SE-assisting procedures have shown mixed results (, since an incomplete SE bears the risk of disturbing learners’ constructive activities. Thus, it is important to identify the appropriate level of prompting assistance that elicits SE and foster meaningful learning. As an alternative, Berthold et al. (2009) suggested that assisting SE prompts, like fill-in-the-blank followed by open-ended questions, should be provided when assistance is necessary. However, learners should build their own schemas rather than relying on external resources to learn how to organize complex learning process (Van Merriënboer &
Kirschner, 2012). This study attempted to see whether providing learners with keywords with open questions followed by open-ended question prompts, or less assisting SE prompts, affected learning outcomes.

As discussed above, previous research has demonstrated the effect of the focus and assistance level of SE prompts independently. To date, little research has been done about the effect that the combination of the focus and assistance level of SE prompts have on learning outcomes for complex tasks. The main research questions addressed: 1) what are the effects of the focus and assistance level of SE prompts on procedural knowledge? (immediate and delayed test), and 2) what are the effects of the focus and assistance level of SE prompts on conceptual knowledge? (immediate and delayed test)

Method

Participants and research design
This study was conducted in a high school in Suwon, South Korea. The participants were 129 tenth grade students (female: 55%) who had already learned about the concept of exchange rates through their regular curriculum. A 2×2 experimental study was conducted using the factors of (a) the focus of SE prompts – inference (“IF”) vs. inference-generating followed by integration (“IT”); (b) the assistance level of SE prompts - less assistance (“LA”) or an open question with keywords followed by open questions vs. more assistance (“MA”) or fill-in-the-blank questions followed by an open question. Participants were randomly assigned to one of four conditions: LA-IF (n = 29), LA-IT (n = 26), MA-IF (n = 36), and MA-IT (n = 38).

SE prompts embedded in learning materials
The research team and economic teachers with 3 to 5 years of experience each developed experimental materials based on previous research (Van Gog et al., 2004). All learning materials were paper-based and provided process-oriented worked examples because such examples showed learners the correct way to perform a complex task while explaining why it was done that way (Van Merriënboer & Kirschner, 2012). Three examples of gradually increasing complexity that showed the participants how to determine the impact of exchange rate fluctuations on the economy, were used: (Task 1) ‘Predict changes in international currency exchanges from an analysis of domestic economy.’ (Task 2) ‘Analyze the impact of exchange rate fluctuations on an export company.’ (Task 3) ‘Analyze and evaluate an import company’s financial losses from exchange rate fluctuations.’ The solution step was omitted from example to execute the fading strategy. The prompts were given in place of the solution step and the learners were required to answer one prompt for each step of the example (Fig. 1). The “IF” prompt corresponded to the one in the study of Conati and VanLehn (2000), and was focused on generating inferences to fill the gaps (e.g., ‘The answer is correct because...’). The “IT” prompt was adapted from another study (Chi et al., 1994), and was designed to facilitate an integration between prior knowledge and new information (e.g., ‘What is different from the previous task?’ or ‘How does it relate to what you have already seen?’). The “LA” prompt was again an open-question but with keywords for Task1 and 2 and more open-ended question for Task 3. The “MA” prompt was same as the one used by Berthold et al. (2009) and consisted of a fill-in-the-blank question for Task 1 and 2, and an open-ended question for Task 3.

Measurement
The pretest examined the participants’ knowledge on the concept of exchange rates through questions. The posttests assessed both procedural and conceptual knowledge and conducted immediately after the learning session and on the following week. The immediate test included 9 items for assessing procedural knowledge and 3 items for conceptual knowledge, while delayed test included 3 and 5 items, respectively. Questions for procedural knowledge included, “Calculate the change in export value of $30,000 when the exchange rate rises from 1,000 KRW to 1,200 KRW,” and for conceptual knowledge, questions such as “Look at trends in exchange rates and write reasons why certain trends would be favorable to exporters or importers” were asked.

Procedures
The experiment was composed of two sessions. The first session included a 7 minute-long pretest, the learning phase, and the immediate posttest. During the learning phase, the participants studied 3 complex tasks with
process-oriented worked examples for 10 minutes each. The participants then completed their respective SE activities for each prompt for 10 minutes each. The fist posttest lasted 10 minutes, while the second session took place a week later for 15 minutes.

**Results**

To ensure homogeneity among four experimental groups with regard to prior knowledge, a one-way ANOVA test was conducted ($F(3, 125)=1.626$, $p=.187$). The group means, standard deviations were analyzed (Table 1).

| Table 1: Means and standard deviations of learning outcomes across groups |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| Aspect            | IF-LA M, SD       | IT-LA M, SD       | IF-MA M, SD       | IT-MA M, SD       |
| Immediate         |                   |                   |                   |                   |
| procedural        | 4.50, 2.15        | 5.11, 2.39        | 5.31, 2.48        | 5.46, 1.77        |
| conceptual        | 4.64, 3.21        | 6.61, 2.99        | 5.24, 3.42        | 6.42, 3.24        |
| delayed           |                   |                   |                   |                   |
| procedural        | 3.08, 2.43        | 4.11, 2.02        | 4.14, 2.03        | 4.38, 2.11        |
| conceptual        | 7.53, 4.16        | 9.05, 3.30        | 9.76, 3.33        | 7.23, 2.93        |

Two-way MANOVA was conducted to examine the effects of focus and assistance level of self-explanation prompts on learning outcomes. Box’s M test for homogeneity of covariance matrices (Box’s M=20.482, $F=6.42$, $p=.934$) and Levene’s F tests of equality of variance matrices were not significant for learning outcomes ($p$ ranged from .051 to .929). Utilizing Wilks’ Lambda criteria, the interaction effect was significant (Wilks’ $\Lambda =.917$, $F(4,122)=2.777$, $p=.030$, $\eta^2=.083$) and the main effect of the SE prompts’ focus was significant (Wilks’ $\Lambda =.894$, $F(4,122)=3.628$, $p=.008$, $\eta^2 =.106$). However, the main effect of SE prompts’ level of assistance was not significant (Wilks’ $\Lambda =.963$, $F(4,122)=1.182$, $p=.322$, $\eta^2=.037$).

**Effects on Procedural knowledge**

Follow-up ANOVAs, concerning immediate and delayed procedural knowledge, the main effect of the SE prompts’ focus was not significant ($F(1, 125)=.903$, $p = .344$, $\eta^2=.007$, $F(1,125)=2.703$, $p=.103$, $\eta^2=.021$, respectively). There was also no interaction between level of assistance and focus of SE prompts ($F(1,125)=2.703$, $p=.103$, $\eta^2=.021$).

**Effects on conceptual knowledge**

Follow-up ANOVAs, for immediate conceptual knowledge, the main effect of the SE prompts’ focus was significant ($F(1, 125)=7.60$, $p = .007$, $\eta^2=.057$), implying that IT prompts condition obtained significantly higher scores on immediate test than IF prompts condition (mean difference =1.57, ES(d)=.49). Yet, there was no interaction effect ($F(1,125)=.472$, $p=.493$, $\eta^2=.004$). For delayed conceptual knowledge, there were no main effect of the SE prompts’ focus ($F(1,125)=.644$, $p=.424$, $\eta^2=.005$), but an interaction between the focus and level of assistance of SE prompts ($F(1,125)=10.516$, $p=.002$, $\eta^2=.078$), as shown in Fig 2. The simple main effects showed that focus and assistance level of SE prompts had a significant effect on delayed conceptual knowledge in the IF prompts group ($F(1,125)= 5.484$, $p=.04$), meaning that MA prompts group had higher score than LA prompts group (mean difference=2.23, ES(d)=.61). On the other hand, focus of SE prompts had a significant effects on delayed conceptual knowledge among LA prompts group ($F(1,125)= 8.828$, $p<.001$), implying that IT prompts group had significantly higher score than IF prompts group (mean difference=2.53, ES(d)=.69).

**Discussion**
The results reveal that the focus and assistance level of SE prompts affect learning outcomes depending on the target knowledge, and three conclusions can be drawn from these results. (a) There was an interaction effect between focus and assistance level of the SE prompts on delayed conceptual knowledge (See, Fig. 2). Or, in using inference-based prompts, a learner would establish a strong problem-solving schema and correct domain knowledge through generating inference with the help of more assisting self-explanation prompts in the initial learning phase. In this case, despite increasing task complexity, a learner would have no need to compare or integrate his/her understanding. In contrast, using the integration prompts that are less assisting in early stages of learning, makes a learner to build a relatively weak problem-solving schema through the inference generation. Therefore, as learning phase progresses, a learner finds it necessary to integrate what is understood and revise any incorrect knowledge. These results suggest that the focus of self-explanation prompts could be designed in various ways depending on the level of assistance of the self-explanation prompt. (b) Contrary to the hypothesis, the different types of prompts showed no significant difference in their influence on procedural knowledge, and the result is also contradictory to the aforementioned findings of Berthold et al. (2009). This could be due to lack of learners’ prior knowledge, as the learners only had a very basic concept of exchange rate. In other words, the learner could not spare his/her attention to the acquisition of other types of knowledge including procedural knowledge, because the assisting prompts have drawn attention to a particular type of knowledge (Berthold et al., 2011).

This research calls for further studies to address the following two limitations and to conduct more experiments, in order to broaden the universality of the implications presented so far. (a) This study excluded an experimental condition of providing only structured SE prompts while some study proved their efficacy for learning performance higher than open-question SE prompts (e.g., Gadgil, Nokes-Malach, & Chi, 2012). Thus, future research would need to include this condition. (b) The measures for learning consisted of a short list of questions. Further research would need to scrutinize procedural and conceptual knowledge with more extensive set of tests to take a closer look at the impact of self-explanation prompts on learning outcomes.

Reference

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Abstract: This paper examines the efficacy of drawing for supporting learning from digital media, such as dynamic visualizations. Extant research on the efficacy of drawing for promoting learning from dynamic visualizations is contradictory. The discrepancy in these findings has been attributed to the differences between drawing and dynamic visualizations. While dynamic visualizations emphasize spatiotemporal transformations, drawing emphasizes static spatiotemporal structures. Thus, drawing may impede learning from a dynamic visualization when the target learning objective relates to dynamism as it may bias the learner to focus on structure at the expense of transformation. Here, we present our developing findings that drawing provides an effective learning scaffold for learning from dynamic visualizations more so than self-explanation prompts, and that drawing biases learners to attend to fewer spatiotemporal structures.

Introduction

There has been an increased emphasis on supporting science learning with drawing activities, despite relatively little evidence that drawing is generally an effective learning scaffold when deployed in the science classroom. While several studies (for a review see Van Meter & Firetto, 2013) have shown that drawing can effectively support learning from text, it is not clear that drawing produces the same benefits with other instructional materials. Although it has been argued that drawing is likely to improve learning from dynamic visualizations (e.g., Ainsworth et al., 2011), the empirical evidence demonstrating a reliable effect of drawing remains outstanding. Some early studies have reported evidence that drawing improves learning from animations (Mason, Lowe, & Tornatora, 2013; Zhang & Linn, 2011) and simulations (Stieff, 2011); however, Plötzner and Fillisch (2017) recently demonstrated no significant benefit of drawing for learning from a complex animation.

In contrast to prior claims, these authors argue that dynamic visualizations emphasize complex spatiotemporal transformations (i.e., changes among spatial relationships), but drawing emphasizes the construction of a static representation that highlights spatiotemporal structures (i.e., geometric entities). Because of the different emphasis of drawing and dynamic visualizations, they suggest that drawing may only improve learning from dynamic visualizations of simple physical systems that focus on spatiotemporal structures. Although the results of this study suggest that drawing biases learners to attend to static features, that work did not include a complex, interactive visualization, nor did the researchers contrast drawing with an alternative scaffold. Here, we compare the efficacy of drawing with and without a dynamic visualization with a highly interactive visualization that enriches the verbal learning material and a study design that included an active comparison group to investigate whether drawing selectively biases learners to focus on transformations.

Present study

The present study examines whether learning from dynamic visualizations is improved by constructing drawings while reading a science text with a complementary visualization. Half of the sample population interacted with a dynamic visualization about chemical equilibrium from The Connected Chemistry Curriculum (Stieff et al., 2012) while reading. To identify the interactive benefit of drawing and visualization, these groups were further divided into two groups that either made self-explanation summaries or self-explanation drawings.

Our comparison of interest is the interaction between the two factors: does drawing improve learning from a visualization as much as it improves learning from a science text but not as much as summarizing? Based on prior research from learning with texts that demonstrate a positive effect of drawing, we predicted that drawing would improve learning from the dynamic visualization as much as it improved learning from the text only. Because the visualizations used in this study were highly interactive (i.e., students were directed to manipulate system variables and observe system results), we also predicted that students who construct drawings while learning (with text alone or visualizations) would construct more conceptually accurate drawings that depicted spatiotemporal transformations relevant to the chemical system under study.
Participants
127 students from a mid-sized research-extensive university in Germany participated on a voluntary basis for payment (12€). Students were recruited from a range of liberal arts majors including science and non-science fields. Data from 7 participants were excluded because they did not finish the procedure within the allotted time.

Materials
All participants received an instructional text on chemical equilibrium with five main ideas: the concept of dynamic chemical equilibrium, LeChatelier’s Principle, the effect of pressure, temperature, and concentration on the equilibrium position of a reaction. The text was taken from a popular US secondary chemistry textbook (Holt, 2002) and translated into German by a native speaker. The 1875-word text was presented with no accompanying figures and had a Flesch-Kinkaid readability score of 44 on the German readability scale.

In addition to the text, one half of the participants were provided with an interactive simulation from The Connected Chemistry Curriculum (Stieff et al., 2012). The simulation presented a reversible chemical reaction at equilibrium. Participants could interact with the simulation to alter the system temperature, pressure, and reactant concentration. The simulation would respond to any manipulation of these parameters with a probabilistic model that restored the system to dynamic equilibrium and a new equilibrium position. The display included not only a dynamic visualization of particle interactions, but dynamic plots of concentration over time.

Embedded within the instructional text were five self-explanation tasks that asked students to explain in their own words the main idea of each section of the text related to the five main ideas. One half of the participants received directions to provide a self-explanation in the format of a written summary and the other half received directions to instead make a sketch for their self-explanation. Participants who received the supporting simulation were instructed to interact with the simulation immediately before generating each self-explanation (drawing or summary) to help them better understand the main idea of the text; participants without the visualization were encouraged to reflect on what they read to respond to the question.

Measures
Chemistry prior knowledge
To control for individual differences in chemistry knowledge, prior knowledge of chemistry was measured with a subset of 10 relevant items of the Chemistry Concepts Inventory, which has been found to be a valid and reliable measure of general chemistry knowledge acquired in secondary education (Barbera, 2013).

Learning outcomes
Learning outcomes were assessed with a summative achievement assessment from The Connected Chemistry Curriculum. The 14-item instrument assessed participants’ declarative knowledge related to chemical equilibrium, models of dynamic chemical systems, and ability to predict how chemical systems would respond to external stressors (Cronbach’s alpha = .85).

Procedure
Participants were tested in groups of up to six, and were randomly assigned to one of four conditions (i.e., text-summary, text-sketch, text+visualization-summary, text+visualization-sketch). Each participant worked individually at a private desk with provided paper, a pen, and a computer, if necessary.

Participants first completed a demographic questionnaire before completing the Paper Folding Test (3 min.), the reading comprehension test (4 min.), and the chemistry prior knowledge test (10 min.). Following the three tests, participants were allotted 45 minutes to complete the learning phase in which they read the text, completed the self-explanation tasks, and interacted with the visualization, if required. Participants were allowed to work through the material at their own pace and were stopped at 45 minutes.

Results
Performance on all measures was determined by calculating and norming the number of correct responses on each measure. The average time to complete the learning phase was 40 minutes and the average number of tasks completed was 4.7. We observed no statistical difference in completion time or the number of completed tasks between groups. After completing the learning phase, the learning outcomes measure was administered with a 20-minute time limit. No differences in reading comprehension or spatial ability between groups was observed.

We qualitatively analyzed the five self-explanation tasks with three binary codes: (1) accurately represents the relevant main idea, (2) references spatiotemporal structures (e.g., particle composition), 3) represents spatiotemporal transformations (e.g., dynamic system changes). Figure 1 illustrates the application of
the coding scheme with drawings from two participants. The sketch on the left demonstrates a particle-level representation where the learner has used geometric shapes to demonstrate (inaccurately) changes in particle identity but does not represent how the system changes with increased pressure. The sketch on the right demonstrates a particle-level representation and accurately illustrates how the depicted system would respond to increased pressure with two images that depict the entire system before and after pressure is applied.

**Figure 1.** Two sketches from participants illustrating the effect of pressure on dynamic chemical equilibrium.

**Does drawing improve learning from dynamic visualizations relative to summarizing?**

Post-test achievement was compared with a 2 (text v. text+visualization) x 2 (summary v. sketch) ANCOVA while controlling for prior knowledge. Prior knowledge significantly correlated with learning outcome, $F(1,120) = 5.26, p = .02, \eta^2_p = .05$. Although a difference was trending, we observed no main-effect of media, $F(1,120) = 3.13, p = .07$. As seen in Figure 2, average student performance was higher in the two conditions with sketching scaffolds than those with summarizing scaffolds. No significant interaction was present in the model, $F < 1$.

**Figure 2.** Mean accuracy on post-test assessment of the learning material.

**How do learners’ self-explanations differ between scaffolds embedded in the learning material?**

We analyzed qualitative differences in the participants’ self-explanations using three independent 2 (text v. text+visualization) x 2 (summary v. sketch) ANCOVAs, controlling for prior knowledge. First, we analyzed the self-explanations for an accurate depiction of each main idea. We observed no significant differences between scaffold types or learning media and no interaction (all $F$s < 1). Second, we analyzed the self-explanations for references to spatiotemporal transformations, such as changes to the system state. We observed that references to transformation information differed significantly between conditions. We observed a main-effect of scaffold ($F(1,120) = 6.04, p = .015, \eta^2_p = .05$) but no main-effect of learning media or interaction ($F < 1$). As seen in Figure 3, average occurrences of transformation information were higher with summarizing scaffolds than with sketching scaffolds for both types of media. Third, we analyzed the self-explanations for representations of spatiotemporal structures, such as particle composition. We found that references to structural information differed by scaffold, $F(1,120) = 50.0, p < .001, \eta^2_p = .30$ and by learning media ($F(1,120) = 7.51, p = .007$) and a trending interaction, ($F(1,120) = 3.56, p = .06$). As seen in Figure 3, the average occurrence of structural information was greater with summarizing scaffolds than with sketching scaffolds and greater in text only conditions. The trending interaction suggests that participants who had access to a visualization were much more likely to focus on structural information when they made summaries than when they made sketches.
Discussion and conclusions
While evidence is increasing that dynamic visualizations benefit learning, it is unclear whether this benefit is moderated by the act of drawing. Here, we tested the prediction of Plötzner and Fillisch (2017) by analyzing the content of student-generated representations. We aimed to identify whether drawing supports learning from a visualization and whether drawing biases learners to focus on static features of a visualization. We found that sketching better supports learning from a visualization relative to summarizing. In contrast to prior work, we observed learners represent concepts equally well verbally and pictorially, yet emphasize structural information when learning without a visualization. Understanding whether and how drawing supports learning remains an important target of educational research to support the incorporation of drawing into curriculum reforms. Here, our preliminary analysis suggests that drawing can yield improvements in learning about systems-level processes in science contexts and may improve learning from complex visualizations of those processes.

References

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Making Learning Journeys Visible: Towards Supporting Collective Reflection on Graduate Attributes

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Abstract: Although some computer-based systems exist to facilitate the management of capstone projects, it is not really clear how learners can be supported to reflect on the connection between their (past and ongoing) learning experiences, and the graduate attributes (GAs) they are intended to develop. This paper proposes a technological infrastructure, and the epistemic and social scaffolding, for students to collectively reflect on how each of their learning products generated across different units of study contribute to the development of their GAs, in light of a final capstone project. We illustrate the feasibility of our approach through the authentic deployment of the toolset in an immersive environment for supporting teams of final year students to reflect on their GAs development.

Introduction and related work
Capstone projects and units of study are one common to higher education (HE) degrees across universities as they provide students the opportunity to demonstrate their capacity to integrate knowledge and skills acquired and apply them to real-world problems (Holdsworth et al., 2009). Capstones are commonly conducted in the final year of a degree to provide the culmination of theoretical and applied work to support learners in successfully joining an increasingly uncertain, evolving and competitive workforce (Dunlap, 2005). Thus, capstones often become critical for integrating previous learning (Fernandez, 2006), assessing progress (van Acker & Bailey, 2011), and reflecting on the graduate attributes (GAs) development (Ras et al., 2007). GAs are a set of generic skills that universities define for developing work ready graduates by providing coherence across all the units of study within a degree (Hager & Holland, 2007). A critical and productive activity identified by Hage and Holland (2007) to develop GAs is to induce learners to reflect on their previous learning experiences which can enable them to make visible the tacit knowledge generated by (sometimes) unconscious actions during (apparently isolated) learning tasks, in light of the current practical work and learning context.

Figure 1. Left: Participatory Timeline collaborative interface as a high-level view of learners’ posts across units of study. Right: Tablet interface to see blog posts details and associate them to specific GAs.

According to Learning Sciences and classic educational literature, reflection is multi-faceted. For example, reflecting on previous learning experiences allows the learner to revise or even change the interpretation of the meaning of those experiences (Mezirow, 1990). Reflecting on past learning experiences can also promote learners’ complex sensemaking through the extraction and articulation of both the content and the skills that were built, which can then be transferred to future situations if similar conditions are likely to be faced (Kolodner et al., 1998). Whilst some reflection is best done individually (Boud et al., 1985), reflecting as a social activity is also enhanced, particularly when learning was facilitated in that social context (Bell & Davis, 2000). It is thus fair to say that it makes sense for capstone experiences to have a strong reflection component because learners are expected to apply what they have previously learnt to contexts beyond the original situations in which learning happened (Holdsworth, et al., 2009; Ras, et al., 2007). In fact, several tools and pedagogical approaches are commonly put in place for encouraging learners to reflect in capstones, including keeping journals (Hmelo-Silver,
2004), creating wiki pages (Ras, et al., 2007), or writing reports (Holdsworth, et al., 2009). However, whilst these may work well for promoting individual reflection, it has been stated that more scaffolded mechanisms are needed to ensure effective collective reflection (Hmelo-Silver, 2004). Similarly, there exist tools that support the mapping of curriculum and the learning designs with GAs (Thompson, 2007), but these are often focused on mapping assessment tasks with GAs rather than focusing on promoting learners’ reflection. In sum, it is not clear how students can reflect on the connection between their previous learning experiences and the development of their GAs, particularly in their final year, once they have passed through various units of study that sometimes may appear disconnected from a learner point of view.

In this paper, we describe our first steps towards providing the toolset and the epistemic scaffolding to make learning evidence across units of study visible, interactive and traceable for promoting collective reflection in terms of GA development. We present a fully functional prototype which was designed in close collaboration with the coordination team of a university degree and deployed in an authentic final year capstone experience. The contribution of the paper is the rationale behind the design of the tool and its associated pedagogical scaffolding. We illustrate the potential usefulness of the tool by briefly describing the preliminary experience of a team of final year students reflecting retrospectively and prospectively on their GAs development, with the tool being deployed in a technology-rich immersive environment.

Learning context and participatory consultation

Although capstones are orchestrated differently in each HE degree, we decided to understand and define the reflection needs of learners in a specific learning context: a Master’s degree of Data Science offered by the University of Technology Sydney (UTS). This is a 2-year full-time degree aimed at equipping graduates with an understanding of the potential of analytics to transform practice through industry experiences, real-world projects and self-directed learning. The degree features two final year capstone units of study where learners are asked to be involved in independent online work, mentoring, peer feedback and industry experience. A common practice in this degree is that learners are asked to keep a (WordPress) personal blog during their whole degree. Blogging has been increasingly used in HE to facilitate student collaborative learning (Kuo et al., 2017), thus this is not an uncommon pedagogical practice. In this degree the learning designs of most units of study include various blogging-based tasks. At the beginning of their enrolment, learners get access to an open peer-sourced WordPress multisite platform where they can individually produce educational resources, generate academic reports, comment on each other’s pieces of work, or share reflections. The blogging platform is also intended to function as a repository of community-knowledge; and as an environment for engaging peers and industry contacts to showcase the development of the five GAs of this degree. Close consultation with the degree coordinator and the team of teachers in charge of the final year capstone projects led to the identification of the following considerations that the design of the reflection toolset and pedagogical scaffolding must consider:

1. It is critical for learners to engage with peers while reflecting on past learning experiences given the highly collaborative active participation that most units of study encourage.
2. It is critical for learners to show how their key work supports the development of the GAs and, also to gain awareness of the GAs that may be less developed.
3. There is a need for learners to rapidly visualise and navigate through all the content they have generated across units of study to be more mindful about their learning journeys in light of the capstone experience.
4. There is a need of a tangible final product of the reflection that learners can take away or share with others.

Toolset design

As a result of the design considerations listed above, we created a fully-functional prototype that we call the Participatory Timeline which includes a collaborative and an individual interfaces (Figure 1, left and right respectively). The collaborative timeline highlights milestones or critical events recorded by the learners. In this case, it connects to the WordPress API to get all the content from specific learners’ blogs and displays them according to the time they were published. This way, learners can scroll and rapidly and visually navigate through all the content they generated in the past years or months. Each blog is presented in the timeline as a container of the original title, text and keywords chosen by the learner. Learners can interact with this Participatory Timeline directly via a web browser on their personal computer or via a large screen for group exploration. Additionally, we designed the timeline to be also be displayed in an immersive facility located at UTS called the Data Arena (see Figure 2, left). This is a state of the art 360-degree immersive data visualisation facility that is purposely built to allow groups of people to interact with data. It is a 10-meters of diameter cylindrical space where the timeline can be displayed continuously around the learners. The space is also equipped with an omnitrack, optical motion...
capture system consisting of 12 infrared movement cameras. We took advantage of this facility to enhance the exploration of learners’ blogs by also designing an individual interface pictured in Figure 1 (right) that can be operated from a tablet device. This tool allows learners to walk around the Data Arena space, each holding a tablet device, to explore a blog’s content in detail. Learners can select blog posts from a list automatically filtered according to their physical position in relation to the timeline. This is achieved by attaching infrared trackers to the tablets that serve to track the learner’s position. In this way, learners interact with the timeline, initially, using their body’s proximity in relation to the timeline (see Figure 2, right-above). Then, learners can tap on a specific blog to read the textual content, and look at the images, graphs and media they or other learners created. The interface allows them to tag each blog post according to the GAs that they consider that post contributes to. The Participatory Timeline can also run on an interactive tabletop placed at the middle of the Data Arena space (see Figure 2, left). This tabletop version features a set of filters that can be used by learners to hide and show posts according to the GA tagging that they have performed using the tablet interface (see buttons at the left of Figure 1, left).

Epistemic design and authentic pilot study
The teaching team designed a scaffolded reflection task within the final capstone unit of study for learners to collaboratively reflect on how the learning activities performed as part of the degree (across units of study) matched the GAs they were intended to develop. Learners were asked to respond the following focus question: “How do the posts I/we have created in [the WordPress platform] during the previous year can serve as evidence of my/our Graduate Attributes development?” This task was subdivided into three subtasks.

**Part 1- Exploration and gathering (5-10 min)**, learners were asked to individually hold one of the tablets and walk around the Data Arena to explore to identify the location of particular posts written by themselves or others that can serve as evidence of GAs development as a preparation for the next part.

**Part 2 - Collective matching of GAs (20 min)**, learners were asked to work with the rest of the team to define a strategy to specify what posts provide evidence of GAs development. For this, they had to explicitly associate the selected posts with specific GAs using the tablet tagging functionality (see Figure 1, right).

**Part 3- Collective reflective screen casting (20 min)**, learners were asked to develop a coherent story demonstrating the development of their GAs over time. Then, learners were asked to highlight both the GAs that have been strongly and weakly developed thus far, the actions that can be taken forward, and the potential role and limitations of reflecting on the blog posts. The intended output is a collaborative screencast recorded at the Data Arena using the interactive tabletop located at the centre of the learning space (see Figure 2, right-below).

**Authentic deployment example**

![Figure 2. Left: The Participatory Timeline deployed in the Data Arena. Right: a learner interacting with the timeline through his proximity to posts and the tablet. Right-below: a team of four learners recording a collective screencast.](image)

The prototype and the pedagogical practice are being deployed as part of the final capstone experience of the Master degree mentioned above. We illustrate the potential usefulness of the system by showcasing the preliminary experience of one team composed of four master students, who successfully completed the reflection task described above. For this session, the content from their four blog sites was loaded onto the Participatory Timeline in the Data Arena. This preliminary exploration suggested that learners found it useful that the task was scaffolded. In words of one of the learners, “scaffolding the task into three distinct phases guided us through a gradual progression, giving me time to think before starting to discuss on how to match GAs with particular blogs”. Moreover, although the Data Arena space is intended to foster collaboration, actual collaboration occurred mostly at the tabletop. For example, while exploring the interface using the tablets, the team naturally split in two,
interacting in pairs (e.g. see Figure 2, left), sometimes sharing one tablet to explore the same content. One of the learners explained this as follows “the timeline allowed us to explore different blog posts. Doing the same in a large screen would have forced all of us to comment on the same post at the same time as we did for recording the reflective screencast. In the timeline, each of us could decide to individually explore posts but also we could keep awareness of what others were doing, make comments and show things to others”. At the tabletop, learners spent some time to reflect among themselves before pressing the record button to produce the final reflection output. Learners agreed that this discussion was the “the core of the collaboration exercise” (as stated by one learner) since it allowed them to reach common understanding of the state of each of their GAs development journeys. Learners generated a collective screencast successfully after just one attempt. They expressed lots of interest in getting this as a digital artefact (see final output of this team in https://youtu.be/VuxKr7v1zL4) to make it available to the wider community of students. Learners also appreciated the possibilities facilitated by the immersive physical space, described by one student as follows: “being able to see the posts spread on a timeline was fantastic, plus the interactivity via our body location, was great”. Overall, results of these preliminary explorations towards supporting learners to collectively reflect on their GAs development are encouraging. The intention was nicely summed up by one of the learners as follows: “this exercise is good to understand how our blogs reflect certain GAs. If I would be using only the current online system I wouldn’t have been able to connect blogs to the GAs properly”.

Conclusion and future work
Making the connection between learning tasks and GAs is, in many cases, made explicit in the teacher’s design, but not necessarily easily grasped by learners in practice. The development of reflective and critical thinking skills is vital for the current uncertain and evolving professional workforce. Thus, this work should be seen as an initial step towards much work that needs to be done in this area. Future work in this line of research certainly includes exploring the strategies to scale up this approach. Currently, the Participatory Timeline can be accessible online 24/7 via any device desktop, tablets, mobiles. The main challenge is how it can scale up to support other learning scenarios that may use additional sources of learning evidence beyond blogging. Current work is exploring how to integrate other sources of student’s learning outputs (e.g. concept maps, reports, presentations) and learners’ media footprint (such as twitter, slack channels, etc).

References
Researcher or Fellow Citizen?
Looking for a Role Model in the Humanities
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Abstract: The idea of a team of researchers working at advancing knowledge represents a strong role model for STEM education. The article suggests that an alternative role model – a community of fellow citizens engaged in solving problems of how to better live together – can be an equally compelling model for the Humanities. Mode 1 knowledge building rooted in learning within the disciplines is compared with a mode 2 focusing on context-specific knowledge, transdisciplinarity and collaborative rationality as essential ingredients of a new role model for the humanities: The fellow citizen. Two cases – a collaborative investigation carried out by an ethics committee and a literature course in a conflict-ridden area – are presented as examples of the fellow citizen in action, which build on cultural humility as a key value and dialogic literacy as an overarching learning goal.

Introduction and overview of this paper
In the Knowledge Building approach, the work of students is primarily valued in terms of contribution to the community, which in turn is modelled on the ethos, goals and processes of knowledge-creating organizations as scientific research groups and industrial design teams (Scardamalia & Bereiter, 2014). The researcher working in teams thus represent a strong role model in an approach that is becoming a ‘signature pedagogy’ (Shulman, 2005) for the STEM disciplines. Nearly all educational interventions quoted by Scardamalia & Bereiter (2014) or presented at ISLS and CSCL conferences focus on STEM. This role model is instrumental in defining the criteria for assessing learning outcomes, as the extent to which learners adopt the mindset of a researcher, as reflected in their use of terminology (Zhang et al., 2011). This theory-developing article acknowledges the importance of role models in designing educational interventions and builds on the idea of contributing to the community as overarching goal for collaborative learning, but proposes that a group of fellow citizens engaged in processes of ‘collaborative rationality’ to solve problems of how to better live together (Innes & Booher, 2010) represent an additional role model that is productive for conceptualizing learning in the humanities.

Differences of in pedagogy between STEM and Humanities can to a certain extent be ascribed to differences in ontology, epistemology and methodology. Another important difference is the scope and goals of research in STEM versus Humanities between what has been called the nomothetic and the ideographic. The former seeking to constitute theories in the mathematical formulation of natural laws of general necessity, while the latter seeks to create specific forms out of the mass of historical material available to convey in vivid images the variety of human life in their unique forms (Windelband 1894). The differences in disciplinary perspectives leads to explicit or implicit pedagogies to educate the senses of the students to conform to the goals of research. Kuhn (1962) mentions how a specific ‘gestalt’ of the individual scientist is the outcome of education within a paradigm or disciplinary matrix consisting of methods and theories to which the student gets acquainted in the course of solving standard problems and doing research under the supervision of a researcher working within the paradigm. Both Windelband and Kuhn focuses on what can be called ‘basic research’ understood as “experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.” (OECD, 2002, p. 77). They are both aware that science–being a human endeavor–always stands in a specific relation to society which supports it. Science needs to be justified and this justification cannot be explicated from knowledge alone but only from the utility of that knowledge broadly conceived in relation to society. Bridging the prevalent but simplistic notion of a divide between the intrinsic motivation of knowledge production for purely scientific reasons and the extrinsic utilitarian production of knowledge for commercial gain or practical application Stokes (1997) proposed a mode of research resulting in “use-inspired basic research” combining the two motives of knowledge production. He further suggested that this has become a significant mode of scientific research resulting from the interest of those funding research and in the overall justification of science to the general public. In describing the emergence of this new mode of research it can be helpful to distinguish between education for what Gibbons et al. (1994) termed knowledge production in ‘mode 1’ and ‘mode 2’. Following the development in mass higher education and the diffusion and proliferation of different sites of scientific knowledge production it seems appropriate and justified that the students of humanities should gain
insights and competences within mode 2. In order to frame this within the humanities a new role model is needed. The fact that only a small fraction of candidates will become PhDs, an even smaller part will venture to become postdocs and fewer still will get tenure to become a full-time professional academic highlights the need to supplement the traditional role model of the researcher. In this article, we propose the notion of the fellow citizen as a new role model in the humanities. To this goal, we first discuss the elements of knowledge production associated with the role model, that aims at better defining the contribution of the humanities for advancing knowledge within a community. Two cases are presented that foster community growth, are rooted in the conceptual tools and practices of the humanities and that exemplify the role model. Finally, we propose cultural humility and dialogic literacy as respectively the key value and the key competence.

Building knowledge in mode 2

In distinguishing between the two modes Gibbons et. al. (1994) contrast mode 2 with the more traditional mode 1 that focuses on basic research and has the knowledge building paradigm as signature pedagogy and the researcher as role model. The differences can be highlighted by focusing on five distinctive but connected aspects: 1) contexts; 2) range of perspectives; 3) diversity in sites of production; 4) reflexivity and 5) challenges regarding quality control and peers. These aspects are further elaborated in the following.

1) Generated within contexts of application and evaluated in contexts of implication mode 2 differ markedly in relation to mode 1 where the practical implications of the results are of little importance. The context of application is the total environment in which the problem arises and where appropriate methodologies are developed and outcomes disseminated. This can be contrasted with the idea of the partial and controlled environment of the scientific experiment or the theoretical work of hypothesis generation in mode 1 within the natural sciences. External validity in mode 2 depends on the use-value of the knowledge.

2) Mode 1 often takes as its point of departure problems arising within the discipline and follow a process of puzzle-solving that Kuhn (1962) termed ‘normal science’. Since the context of application in mode 2 is the total environment theories need not be derived from existing disciplines in order to be applied. Transdisciplinarity involves the creative mobilization of theoretical perspectives and practical methodologies to solve problems and to offer new perspectives. The characteristics of transdisciplinarity is “knowledge which emerges from a particular context of application with its own distinct theoretical structures, research methods and modes of practice but which may not be locatable on the prevailing disciplinary map” (Gibbons et al., 1994, p. 168). Solutions in mode 2 are transdisciplinary in the sense that they can’t be derived from any single discipline. In the course of problem solving and a degree of formalization transdisciplinarity may even evolve into a research program that is different from the disciplinary nomenclature of the traditional universities, nanotechnology and environmental studies being prominent examples of this (Weingart, 2010).

3) Diversity in sites of knowledge production is another characteristic of mode 2. The breakdown of boundaries and hierarchies of knowledge is a result of the proximity and embeddedness of knowledge production to practice. New technologies and new ways of organizing knowledge allows for a high degree of openness to the public sphere. Examples are creative commons licenses and open-access journals, even cannibalistic appropriations (Bar et al., 2016) such as torrents and illegal sharing of restricted journals allow for others to join the research game. The diffusion and distribution of new sites also includes organizations ranging from private consulting firms, think tanks, NGOs and CROs (Contract Research Organizations).

4) Mode 2 is highly reflexive replacing the ‘objective’ interrogation of subject-object relation with a more inclusive dialogical relation. Research becomes a dialogic process between research actors and research subjects whereby the area of accountability is widened to include the anticipated–predicted and unintended–consequences of research. Knowledge needs to be ‘socially robust’ because its validity is no longer determined solely, or even predominantly by scientific communities, but by a wider community of producers, disseminators, traders, practitioners, politicians and users (Nowotny et al., 2003). Feedback loops, iterations and moderations are an integral part of mode 2 processes.

5) Mode 2 challenges traditional systems of quality control with peer-review, because it does not possess a stable taxonomy of disciplines from which to find scientific peers. Over time such a taxonomy can be established and even come to form a new discipline but this is the exception to the rule of mode 2. But what the knowledge might lose in scientific rigor it may gain in the applicability in practice, because quality control lies with the users which constitute the peers.

While the traditional researcher working within a discipline is an important role model, we argue that it needs to be supplemented with the role model of the fellow citizen working in collaboration with practitioners, stakeholders, policymakers and citizens outside university settings. It is important that the new role model is underpinned by pedagogical strategies and equipped with contexts of application. Furthermore, the role model
Collaborative rationality

Collaborative rationality (henceforth CR) (Innes & Booher, 2010) stands out as an epistemology and methodology for knowledge production in mode 2 which is especially designed to tackle ‘wicked problems’ about how to better live together. CR aims at producing robust, legitimized knowledge and identify three conditions for a successful process: 1) all relevant actors must be included in the process, thereby securing the necessary diversity without which collaboration would yield solutions that are poorly informed, infeasible or unjust; 2) the actors must need each other to achieve their goals, because without interdependence, they would have no reasons for collaboration; and 3) actors must engage in authentic dialogue. CR represents an emerging paradigm for developing innovative solutions to societal challenges and in doing so making communities more resilient and adaptive to future change. CR is important for a community of researchers working in mode 1, as suggested by the centrality of open-ended yet goal-directed dialogue in the KB process (Scardamalia & Bereiter, 2014), but CR nearly constitute a prerequisite for mode 2. CR is essential to the role model of the fellow citizen. Moreover, the idea of a community of diverse and interdependent fellow citizens in dialogue may better capture the learning context and the competences required for solving problems and developing new knowledge.

Community and knowledge building: two cases

In the two following cases participants – including teachers and facilitators – worked together at the edge of their understanding, while at the same time working towards strengthening their community’s cohesion and resilience. To us they represent strong cases of the fellow citizen in action and may serve as ideal type exemplars of a practice to support both community and knowledge building in mode 2.

The Danish Council of Ethics and coercion in psychiatric care

In 2011 the Danish Council of Ethics was asked by the parliament to develop guidelines on the use of coercion in psychiatric care (Waldorff, Sørensen & Petersen, 2014). Instead of building on its traditional approach – that is, collecting expert advice and discussing it behind closed doors – the committee decided to establish a community of inquiry involving representatives of psychiatric patients and their families in addition to health professionals, and to gradually open up the discussion to public scrutiny and debate. With the help of a consulting firm hired to facilitate the process, experiences of patients and their family were staged by actors and transformed into short fictional films, portraying for example the meetings of former patients with their former caregivers. The prolonged process eventually led all the involved actors to agree in reframing coercion in psychiatric care from being primarily a matter of managing resources (which was the initial point of view of health professionals) to being primarily a matter of culture in the caregiving institutions. The committee’s final report was widely appreciated and managed to initiate institutional change due to an enhanced legitimacy grounded in the committee’s reputation for competence and in the openness and inclusivity of the inquiry process (ibid., pp. 82–86).

A literature classroom for Israeli and Arab teachers

Since 2005, at a college of education in northern Israel, Yahel Poyas has taught a course of literature as part of a teacher education master’s program in multidisciplinary teaching of the humanities attracting students from various disciplines with both Israeli and Arab background. During the course, the students read and discuss literary works. In the process, they meet and interact with one another in a context were members of the Arab and Israeli communities, while inhabiting the same territory, watch different television channels and read different books and newspapers (Poyas, 2016). Literature in Poyas’ classes is the point of departure for creating an ‘in-between space’ and metaphoric domain between the external reality and the inner world of the reader. This space stands in a complex, dialogic relation with the external world and the literature allows for discussion on issues of power, identity, gender and human conduct in times of conflict and anxiety, while at the same time enables reflecting on the role of language and narrative in building imagined worlds (Poyas, 2016). Poyas’ role in designing the course primarily consisted in choosing the texts, which in itself involved negotiating issues of language, aesthetics and politics. This contestation was witnessed most clearly through a conflict with one of her students, where both students and teacher had to explore the foundations of their own understanding both in their role as fellow citizens of a conflict-ridden country and as learners in the humanities. In the process, they enhanced their understanding of other fellow citizens, as well as of literature as a powerful tool for patterning our expectations, fears, desires and behaviors (Raskin, 1983).
**Discussion and conclusions**

Participants in the two examples never take the role of truth-owning experts, but act primarily as fellow citizens with a personal involvement with the issue and topic. Teachers or facilitators have a responsibility for organizing and managing the process, but should be in no position of power in discussing the problem at hand. This is painfully evident in the case of Yahel Poyas, who takes full responsibility for managing the classroom and the ensuing conflicts by reserving for herself a role of a fellow citizen with special obligations to self-restrain in order not to let her own views prevaricate others. The same type of cultural humility as a “commitment to self-evaluation and replacing inherent hierarchical power imbalances [...] with a collaborative learning model” (Nomikoudis & Starr, 2016) seems to be one key value in the successful work of the Danish Council of Ethics. Thus, dialogic literacy as a dual principle for advancing knowledge and for nurturing relationships (Caviglia et al., 2017) seems to be an essential part in establishing the new role model. It is therefore suggested as an overarching learning goal of educational intervention based on collaborative rationality. The pedagogy fostering the role model therefore needs to incorporate the conditions of CR: diversity, inclusion and interdependence of actors with the goal of dialogic literacy. Achieving this in the learning context of humanities means first and foremost to promote the epistemology of mode 2. The fellow citizens can be a role model for the Humanities as strong as the role model of the researcher is for STEM education. Indeed, integration of the additional role model of the fellow citizen may prove conducive to the development of a curricula focusing on knowledge building in mode 2.

**References**


“But We Don’t Have Beta-Cells”: Agent-Based Models to Support Health Education

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Abstract: This paper seeks to support science learning within the health-related education, the diabetes education domain. With this aim, we evaluated the impact of deep biochemical understanding on behavioral patterns of young patients with type 1 diabetes. The findings propose, a strong significant correlation between youths causal biochemical understanding to their behavioral patterns of glucose self-regulation. Consequently, in order to promote this biochemical understanding, we introduce an agent-based learning environment (SimDCell) which supports exploration of glucose equilibrium interactions that facilitate relation and connection of the biochemical processes to youth with type 1 diabetes own body functioning and to their daily based medical decisions.

Introduction
Health-related education has thus far occupied a modest space in the learning sciences (e.g. Reeve & Bell, 2009; Ching & Schaefer, 2015). To encourage additional learning sciences research in health education and to demonstrate the potential of applying existing approaches in this space, this paper presents an agent-based modeling approach to teaching the biochemical processes relating to the treatment of type 1 diabetes.

Type 1 diabetes mellitus (T1DM) is a life-threatening, chronic illness that affects youth and requires lifelong insulin therapy. The youth and their families must develop new routines for monitoring and tracking of blood glucose data (Lee, Thurston & Thurston, 2017). To maintain the delicate balance of blood glucose levels, adolescents must quickly learn to apply complex disease-related knowledge to daily self-treatment decisions. Much is still unknown about how learning interventions could better support type 1 diabetes management, a known problem for adolescent youth.

In response to this problem, we hypothesized that increased causal understanding of the biochemical processes underlying blood glucose might improve adolescents’ glucose self-regulation. Based on the cross sectional study results, described below, this hypothesis appears to be supported. In light of this finding, we have developed an agent-based modeling environment, the Simulated Diabetes Cells (SimDCell), as a tool to support youth with type 1 diabetes examine and learn more about biochemical processes related to their disease. In this paper, we present vignettes from a single youth with type 1 diabetes interacting with this tool to illustrate the kinds of connections and discoveries characteristics that could be made with such an environment.

Simulated Diabetes Cells (SimDCell) learning environment
The SimDCell learning environment was designed in NetLogo (Wilensky, 1999), an agent-based modeling (ABM) environment, which is extensively used to model complex systems in science and to support learning about systems in classes (e.g., Dubovi, Dagan, Sader-Mazbar, Nasar & Levy, 2018; Jacobson & Wilensky, 2006; Levy & Wilensky, 2009). Complex systems are comprised of numerous micro-level entities, whose interactions emerge into a higher-order behavior, a macro-level phenomena. The diabetic process and its medical treatment is a prime example of a complex system. Many different molecules interact with one another, with drug molecules, and with normal body processes leading to the emergence of therapeutic or toxic effects. Medications are aimed at restoring physiological factors that maintain equilibrium in the body. However, equilibrium, as a complex phenomenon, is difficult to teach and to understand (Zion & Klein, 2015), since it encompasses dynamic processes that take place while the system is at a constant state.

The SimDCell learning environment is comprised of multiscale biochemical models embedded in a pedagogically-supportive e-learning management system (Figure 1). These agent-based models simulate the relevant anatomy of glucose equilibrium. Two central representations were used: 1) cell models (pancreas cells, muscle cells and liver cells), and 2) plots showing the numbers of various molecules. Each cell model includes the main organelles and molecules that participate in the metabolic processes and insulin mechanisms that maintain blood glucose equilibrium. The models are used to demonstrate the effects of various activities and diets on both healthy and T1DM body functioning. Participants can add different doses of insulin-based medications,
manipulate multiple characteristics and habits (such as fasting or sport activities), and observe the subsequent body reaction. The plots show the number of insulin and glucose molecules in the various relevant body parts. The use of multiscale models enables participants to zoom in on each type of cell separately or to zoom out to view how the different types of cells work synchronously for a more comprehensive exploration of glucose equilibrium.

![Figure 1](image.png)

Figure 1. A screenshot of SimDCell environment and a picture of adolescent learning with the environment.

**Methods**

**Research design and participants**
A mixed methods approach was used to understand the relationship between adolescents' biochemical knowledge and glucose control effectiveness. We conducted a cross sectional employed research with type 1 diabetes adolescents between 12 and 18 years old (n=55) who are treated at the diabetes clinic in a large hospital in northern Israel. The sample comprised of patients who are treated with either insulin pump (n=34; 61%) or with multiple injections (n=21; 39%), and lived with T1DM for an average of 5±3.4 years. To examine how adolescents might use the SimDCell environment to learn about their disease, we employed case study methods with a 13-year-old female participant, “Michelle”.

**Data collection instruments and data analysis**

**The cross sectional study**
*Diabetic biochemical knowledge.* We designed three open-ended questions to evaluate adolescents’ knowledge about biochemical processes of glucose equilibrium. The first question asked participants to describe the role of insulin within human body by using terms such as cell, receptor, transporter, energy, ATP, etc. The second question presented the case of “John”, who has T1DM and is currently experiencing high blood glucose levels. The participants were asked to explain whether high blood glucose levels enable John’s cells to produce more energy compared to a healthy body. The third question asked the participants to describe the differences between insulin secreted from a human pancreas and insulin administered as a treatment. The content of the items was reviewed by diabetes experts to ensure accuracy. The language of the items was compared to school science curricula to ensure they were written at an appropriate level for the young participants. The responses were coded as correct or incorrect, and the total score was calculated as the percentage of correct answers.

*Glucose control.* Glycosylated Hemoglobin (HbA1C) is a blood test which estimates the glucose level average over a period of 2-3 months. HbA1C was obtained from the patients’ medical records. In order to prevent diabetic complications, the clinic guidelines’ recommendation for all adolescents is to keep HbA1C below 7.5% which is equivalent to a blood glucose level of 169 mg/dl.

**Case study**

For the case study, we used screen recording software to capture Michelle’s interactions with the SimDCell learning environment. While leaning with SimDCell, Michelle was asked to use a think aloud protocol, with additional information elicited by a supporting researcher. A video-based discourse analysis was conducted to explain the interaction between the young participant, the learning environment, and the researcher (Jordan & Henderson, 1995). The researchers carefully transcribed then coded each video entry. The resulting codes were compiled into a codebook for illuminating how the participant used the provided data representations, how she interpreted the processes depicted, and how she resolved conflicts raised when comparing the SimDCell representations with her own bodily experiences.

**Results**
The association between biochemical knowledge and glucose control

A significant negative correlation was found between the level of biochemical knowledge and the glucose balance as measured by HbA1C (Pearson $r = -0.57$, $p<0.001$) among adolescents who used the insulin pump for treatment. Hence, the higher the biochemical understanding the lower HbA1C, which means better metabolic control. No significant difference was found among adolescents using treatment based on multiple daily injections (Pearson $r = -0.23$, $p=0.29$).

Learning with multiscale biochemical models

When introduced to the SimDCell learning environment, Michelle quickly began to manipulate the model cells. The learning environment was designed to expose the sophistication of the cell models gradually. On the first screen, only a single muscle cell is displayed; on subsequent screens, users can manipulate new characteristics and new organelles and cells are revealed. Michelle was eager to explore the new features of the model to advance through the screens. After exploring the muscle cell, Michelle moved to another screen to explore a beta (pancreas) cell. After a quick inspection of the cell model, Michelle's attention fell quickly to the presence of insulin in the cell representation.

Michelle: [pointing to the beta cell model] So, if this cell is not insulin dependent, why does it still have an insulin inside it?

Researcher: Please try to switch to the muscle cell, and then compare between the cells, between the beta and the muscle cells.

Michelle: I see… The beta cell produces insulin and then secretes it. While the muscle cell uses this insulin as a mediator for glucose entrance within the cell.

Researcher: [pointing to the beta cell] Now try to add glucose by clicking inside the model and see what happens.

Michelle: [clicks rapidly on the screen, which creates multiple glucose molecules] It’s fun! See… I filled it with glucose. [pauses for observation] More insulin is secreted now. Ah, I see, that’s actually what is happening within a healthy body. But we (people with type 1 diabetes) don’t have beta cells, so we don’t secrete insulin. Here they called it bolus, we also call our injections “bolus”. Only here it’s a bolus of insulin in a healthy body.

By giving Michelle the opportunity to explore the function of muscle and beta cells and compare them, SimDCell prompted Michelle to compare the representations and the interactions to the function of her own body. Moreover, she was able to comprehend that the insulin bolus that she receives multiple times a day is actually a mimic of the insulin bolus secretion from a healthy pancreas. The understanding of normal beta cell function helps to clarify reasons for the T1DM insulin regimen, which includes different injections during the day. In the next excerpt, Michelle explores the function of another molecule she had used in her treatment—glucagon.

Michelle: [exploring the liver cell at the model] I understand now. When insulin is attached to its receptor on the liver cell membrane, then the glycogen is constructed from glucose. And when glucagon is attached, it causes the breakdown of glycogen.

Researcher: So then, why do you think you have to carry glucagon injections with you?

Michelle: So, when I am passing out, the glucagon takes the glycogen out of the liver cell and breaks it down to glucose molecules, and then the blood glucose level will rise.

Researcher: I hope you won’t pass out.

Michelle: But if we, people with diabetes, have normal glucagon in our body, why do we need these injections of glucagon if we already have it?

Researcher: Try it with the model. See what happens when the model cells are in hypoglycemia.
Exploration of cells models in the SimDCell environment gave Michelle the opportunity to relate complex understanding of glucose equilibrium toward her own body and make sense of treatments that she is receiving (e.g., glucagon kit that she carries with her).

Discussion and conclusion
This study among adolescents with type 1 diabetes provides preliminary results showing the importance of young patients having causal biochemical knowledge about their disease (Lee et al., 2017). Our findings show that adolescents’ glucose levels, measured by HbA1C, were significantly and strongly associated to the adolescents’ causal understanding of biochemical processes. That is, when the level of biochemical understanding was higher, the glucose balance was better, i.e., the HbA1C was lower. A closer look at our data suggests this effect is true only for patients whose treatment is based on the insulin pump. This can be explained by the greater number of decision-making processes that insulin pump users have to make compared to treatment with multiple daily injections. Administration of insulin through multiple daily injections is based on blood glucose levels only, while insulin pump treatment also requires increased glucose monitoring, counting dietary carbohydrates and judging the impact of exercise on insulin infusion rates. This additional consideration illuminates the importance of causal biochemical understanding for such complex daily decisions.

The current study also builds upon previous research regarding the value of exploring computer models for science learning (e.g., in physics: Sengupta & Wilensky, 2009), by extending it to understand how models based on a complex-systems perspective may support adolescents learning to self-regulate their diabetes. The SimDCell environment is a novel approach in diabetes education and helps adolescents draw connections between pathophysiological-biochemical processes and their application to diabetes treatments. As they explore dynamic cell models, young people are able to relate the processes represented in the models to the functions of their own body and improve their mechanistic understanding about diabetes. More research is needed to explore the relation of casual biochemical explanations of a disease management and consequent health outcomes.

References


Acknowledgements
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Failure to Replicate Using Dialogue Videos in Learning: Lessons Learned from an Authentic Course

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Abstract: Previous laboratory studies have found that students learned significantly more from dialogue videos compared to monologue videos. However, these studies were conducted in laboratory conditions, which do not adequately reflect the characteristics of an authentic course environment. Therefore, we replicated the study in an actual blended biology course to test if the benefits of dialogue videos still remain. Contrary to laboratory studies, no significant difference was found in students’ learning between the two groups. We then posited that the integrated content, choice of tutees, and students’ preference to monologue videos may have caused the discrepancies in the findings. Relevant evidence was provided to support our hypotheses. Implications and limitations were also discussed.

Learning by observing others learn is a promising instructional approach for learning. Studies conducted on this approach have demonstrated the effectiveness with respect to learning gains of having students observe an expert tutoring a novice as they working through a problem compared to the conventional style of only an expert working through a solution in a monologue format (Driscoll et al., 2004). We henceforth call the first type of videos as dialogue videos, and the second type of videos as monologue videos.

Videos are the most common instructional approach in online learning or blended learning (Kay, 2012). With the dramatic growth of online or blended learning in higher education, it is imperative to investigate the potential benefits of the application of dialogue videos in an online/blended college-level course environment. However, most of the previous studies were conducted in lab conditions, which were not an accurate representation of an authentic learning environment. The current paper aims to fill the gap in the existing literature by presenting a replication of using dialogue videos in an authentic blended STEM course.

Relevant literature

Learning from observing dialogues

For decades, numerous studies have been carried out to prove that individuals can learn actions or behaviors from observing others. For instance, aggressive behaviors can be learned by observing others displaying them; novices can learn work-related skills via observing experts performing work activities; children can imitate behaviors by observing adults acting.

Can one also learn cognitive-related skills from observing? Observing just the overt outputs of learning alone presents many challenges. One would not see the underlying many-to-one cognitive processes that underpin learning (Chi & Bjork, 1991). For example, when an expert is solving a math problem, some covert reasoning processes cannot be demonstrated by her overt behaviors. To overcome the many-to-one cognitive processing issue, one possible solution is that the expert explains her thinking while solving the problem (Collins, Brown, & Holum, 1991). However, studies have shown that experts are notorious for not being able to convey their entire thinking process to novices (Nisbett & Wilson, 1977), and novices cannot learn very well from hearing experts’ didactic-like explanations (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001). One reason why a novice cannot learn well from an experts’ didactic-like explanations is because the expert cannot gauge the novice’s understanding level (Chi, Siler, & Jeong, 2004).

Observing dialogues between an expert tutoring a novice to solve problems poses a possible solution. Engaging a novice in dialogue with expert can force the expert to bring their cognitive level down to level of the novice as they exchange ideas, thus reaching a common ground by which a student can observe both the outputs and cognitive processes that accompany expert-level thinking. During the dialogues, the misconceptions expressed by the novices and the correcting information provided by the experts enable observing students reflect on their understandings, and thus learning occurs (Chi, Kang, & Yaghmourian, 2017).

Previous studies of observing dialogue videos

Dialogues between a teacher and a student are critical in observers’ learning (Cox, McKendree, Tobin, Lee, & Mayes, 1999). Observers who watched the dialogue videos in dyads learned substantially more than those who...
watch monologue videos in solo or in dyads (Chi et al., 2017). Several studies have shown that even when the observers watch the dialogue videos in solo, they still can learn more in comparison than the observers who watched the monologue videos individually. For example, Driscoll and colleagues (2004) found that students who overheard the dialogues between a virtual tutor and a tutee wrote significantly more content than those students who were in monologue condition. Similar results were found in two other studies (Muller, Bewes, Sharma, & Reimann, 2008; Muller, Sharma, Eklund, & Reimann, 2007), in which observers watched dialogue videos outperformed those observers who watched monologue videos. However, all of these studies were conducted in laboratory conditions. It is necessary to replicate these studies in an authentic course, and to investigate if the benefits extend to the online and blended learning environments.

Methods

Participants and study site
This study was conducted in an upper level biology class. Two-hundred and ten students consented to be enrolled in the study, in which 49.1% of the students were Caucasian, and the following were Hispanic (19%), Asian (18.1%), and African American (4.0%). The rest of the students indicated their ethnicity as other. The majority (87.2%) of the students declared their major as Biology (Medical) Science, with 3.5% students in Genetics, and the rest of the students were either from Psychology or the Public Health department.

Video creation and procedures
Eight dialogue- and eight monologue-videos were filmed. In the dialogue videos, the course instructor tutors a tutee who works through a set of biology problems, asking questions. Four students who completed the course in the previous year were recruited as tutees for creating dialogue videos. Each tutee filmed two videos: one from a first set of four and one from a second set of four. The monologue videos only present the instructor solving the same set of biology questions. Therefore, both dialogue- and monologue videos use the same set of biology questions. Each week, a worksheet containing the same questions in the videos was handed out to each observer student. Observer students watched the assigned videos and completed the worksheets on Thursday as pre-class assignments, and attended a recitation on Fridays. Students were randomly assigned to two groups, each observing one type of video for the first four weeks and the other for the second four weeks. That is, one group of students watched dialogue videos for the first four weeks, and monologue videos for the second four weeks. The other group of students first watched monologue videos and then switched to dialogue videos. The topics covered in the videos including Homeostasis, Information Flow, and Adipocyte Cells, etc.

Measures
Eight quizzes were created by the instructor to measure students’ learning from the videos. Each quiz consisted of 10 to 12 multiple-choice questions, totaling 89 questions. Each week, the first ten minutes of Friday recitation were devoted to in-class quizzes. At the end of week 8, students were asked to indicate their preferences for the videos, and explain why.

Results
Because all students viewed both monologue and dialogue videos, we used a repeated-measures model to compare students’ aggregate dialogue scores to their aggregate monologue scores. To address the issue of missing data, we used a mixed model to estimate parameters with maximum likelihood estimation and a compound symmetry covariance structure specified to make the model an analogue of a repeated measures ANOVA. We found no significant difference between student performance when using monologue videos (M = .80, SD = .09) and dialogue videos (M = .790, SD = .10); F = 2.26, p > .05.

Prior laboratory studies suggested that the dialogue videos were more beneficial to learning the tasks that require higher-order thinking skills (Muller et al., 2008, 2007). Therefore, to further test if the dialogue videos influenced on students’ performance on higher-order cognitive tasks, 16 questions that required students to transfer their knowledge to new scenarios were identified by two experts together in biology field. However, using the same statistical model specified above, the results revealed a significant trend, in which the monologue group (M = .88, SD = .12) performed better than the dialogue group (M = .86, SD = .13); F = 3.90, p = .05004.

Possible reasons of a failure and implications
Why would the studies in laboratory conditions favor the dialogue videos but in an authentic course yield a failure? Our discrepant findings may be attributable, in part, to several factors, including the nature of authentic courses,
design of the dialogue videos, and students’ reactions to the videos. In this section, we attempt to discuss the possible reasons and their implications.

Integrated content
Unlike a laboratory experiment, the learning content in an authentic course is always more likely to be integrated. That is, the content presented in later videos was more likely to be built upon previous videos. Students may have already established clear understandings of the concepts from other learning materials or the previous videos, thus diminishing the main benefits of the dialogue videos (i.e., reflect on misconceptions).

In comparison to Muller and colleagues' (2007, 2008) studies, in which the dialogue videos were used for Newton’s First and Second Laws which are notoriously difficult to learn, the content that covered in our videos was relatively less difficult. Due to the difficulty, Newton’s First and Second Laws easily evoke misconceptions (Mayer, 2004), and a clear understanding cannot be easily established. The dialogue videos provided great opportunities to the students in Muller and colleagues' (2007, 2008) studies to reflect on their misconceptions. Therefore, we proposed that dialogue videos should be used for introducing novel concepts that are more likely to be misunderstood and require higher-order cognitive processes to maximize their benefits.

Video design
Including tutoring in videos aims to elicit more dialogues between experts and novices, and hence scaffolding the cognitive process for problem solving. Observing students can thus learn from the process of an expert correcting errors made by a novice. However, the tutees in the dialogue videos for the current study completed the course in the previous year. Compared to the observing students, the student tutees in the videos were more familiar with the concepts covered in the videos. Therefore, the number of questions asked by the tutees were less than what one would expect the observing students would ask. We thus proposed that the discrepancy in the findings of this study and the literature may have arisen from the dialogue level between the instructor and the students in the videos. To test our hypothesis, we analyzed the dialogue videos based on the instructor-student interaction levels. Each of the videos was segmented into episodes based on the questions (i.e., each video consisted of two to six episodes). The episodes were coded as no interaction, less interaction, and rich interaction. Only one question and one feedback between the instructor and the student was coded as less interaction, whereas the episodes contained at least two questions and feedback were coded as rich interaction.

Two researchers coded the first two dialogue videos independently, and then met to discuss any discrepancies in their coding until 100% agreement was achieved. The rest of the six videos were analyzed by the second researcher. A total of 36 episodes were identified from the videos. Seventeen episodes (47.2%) were categorized as rich interaction, 17 episodes (47.2%) were less interaction, and two episodes (5.6%) had no interaction. We, therefore, posited that the benefits of dialogue videos may have been minimized due to only less than half of the videos containing rich interactions. In future research, to maximize the advantages of dialogue videos, two approaches can be taken. First, students who have never taken the course and are not familiar with the topics in the course should be recruited as tutees for the videos to promote richer interaction that better matches the mastery levels of the observing students enrolled in the course. Second, the dialogue between instructors and students in videos can be specifically scripted so that more rich interactions can be included in the videos (Muller et al., 2007).

Preference of monologue videos
Among the students who indicated a preference for the types of videos they observed, 59.9% (N = 124) of the students reacted favorably to the monologue videos, and only 20.3% (N = 42) of the students favored dialogue videos. For decades, a substantial body of studies have evidenced that positive affect improves students’ performance on higher-order cognitive tasks (see Isen, 2008, for a review). We posited that the strong preference of the monologue videos may have influenced students’ cognitive processing. Therefore, no learning differences between the two groups were detected.

To find out if this is true, we analyzed students’ responses to the “why” question for their preferences. Two researchers applied thematic analysis on the responses independently (Braun & Clarke, 2006), and met to discuss the discrepancies in their codes until 100% agreement was reached. The two main factors that influenced students’ preferences were: 1) the monologue videos were more straightforward (N = 69), and 2) the dialogue videos were more likely to create confusion when students in the videos made mistakes (N = 42). However, confusions can actually inspire greater depth of cognitive processing if appropriately regulated (Craig, Graesser, Sullins, & Gholson, 2004). A failed confusion regulation is more likely to yield negligible learning (D’Mello, Dale, & Graesser, 2012). In our study, when confusion occurred, there was no direct channel for the students to immediately resolve it. A possible solution to overcome this issue can be allowing students to observe the dialogue
videos in dyads. Therefore, when confusion occurs, students will have peers to discuss and to resolve the confusion immediately.

**Conclusion and limitations**

The goal of this paper was to replicate laboratory studies of using dialogue videos to enhance observing students’ learning. However, no significant difference in learning was found between the dialogue group and the monologue group in this replication. We therefore provided three possible reasons to explain why there was a discrepancy in findings between prior laboratory studies and our replication study. We proposed possible solutions to overcome these issues for future research.

In addition, we need to highlight some limitations of this study. One pressing concern is that there is no log data of the students. No instructional material can be beneficial if students do not utilize it. Due to the lack of log data, the analyses for student learning outcomes were based on the suppositions that all students have watched the videos. Second, since students were enrolled in the same course, there are chances that students from the two groups discussed their video types. Thus, a threat to internal validity of the study may exist.

**References**


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Blending Mathematical and Physical Negative-ness

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Abstract: Expressing physics problems in the form of a mathematical model is one of the most important stages in the problem-solving process. Particularly in algebraic symbolization, understanding the meanings of signs and being able to manipulate them becomes a challenging task for students, especially when more than two elements in the mathematical expression could carry a negative sign. We use Conceptual Blending theory to investigate how students attribute emergent meaning to the signs and how they articulate different signs in their algebraic symbolization. The data for this research is drawn from oral exams of students enrolled in upper-division physics. The results shed light on students’ understanding of algebraic symbols and their competence in formulating and manipulating them.

Introduction
Mathematics is the common language of science, including physics. By the time university students take intermediate physics, they normally have mastered algebra and practiced calculus in the prerequisite math courses. Accordingly, the mathematical difficulties they usually encounter are appropriately ascribed to the link between mathematical expression and the physical meaning that they are trying to make. Considerable research in physics education research (PER) is devoted to investigating the relationship between math and physics, especially how students use math to express physics concepts and tell physical stories. Conceptual blending (Fouconnier & Turner, 2002) provides a framework where the idea and structure from multiple input domains are blended to generate new meaning, and thus helps us to investigate how students blend mathematics and physics conceptual knowledge. Previous research on math in physics contexts (Bing & Redish, 2007; Hu & Rebello, 2013) argues that students can construct more effective blends through better mapping. Thus, student difficulties might not be because of lacking prerequisite skills but rather because of the inappropriate blending of math, physics knowledge, and the physical scenario at hand. Other work (Gire & Price, 2014) also uses blending theory to show how students make conceptual meaning of electric field vectors. The difficulty occurs when students’ represented vector fields in space are also attributed to the clash between input spaces; that is, when an input element (e.g., spatial extent) could represent two meanings simultaneously (distance in coordinate space and magnitude of the field).

In this study, we focus on students in an upper-division Electromagnetism I course with heavy use of mathematics to understand electric and magnetic fields. As a group, their mathematical skills and physics intuitions are substantially more advanced than introductory students, but they still encounter algebraic difficulties with negative signs. The negative sign and its associated concepts in learning and teaching have been studied extensively in k12 contexts back to 1972, but not with upper-division, math-heavy science students. When it comes to electromagnetic topics, the negative sign could be affiliated with different possible elements, such as the charge, vector field, etc. We use conceptual blending theory to account for the meaning that students associate with the sign and to explain the difficulties they face when they manipulate all negative signs at the same time.

Methods
We collected video data of oral exams done by students in an undergraduate upper-division Electromagnetism I course which enrolls about 20 senior physics students and covers the theory of electric and magnetic fields in vacuum and matter. Our data are drawn from the first oral exam in the fourth week of class, after the class has covered major topics such as Coulomb’s law, Gauss’ law, and the method of separation of variables.

In an oral exam (Sayre, 2014), students individually work on the board and are encouraged to talk and explain their reasoning to the instructor as they move through the problem. The problem they are exploring is finding the electric field on an axis caused by two equal and opposite charges located on the same axis. The problem appears superficially easy -- it is often given to introductory students -- but requires careful attention to the sign of algebraic expressions and high expectations of consistency among different directions, values, and signs. Four students (all male; three white, one Asian) solve this problem as part of their exam and none of them succeed on their first attempt. The similar struggles across all students become a salient point requiring investigation of students’ competence to deal with algebraic signs. We perform moment-by-moment analysis to investigate students’ reasoning and construct multiple blends to obtain different emergent meanings that student endow the sign with. In this paper, we introduce a case study on one student whose reasoning is typical of his peers and who eventually arrives successfully at the correct answer.
Blending between directionality and sign

Conceptual blending theory accounts for how people formulate meaning. Blending, the central action of the theory, is a mental operation of a mental network that generates new meaning. The network consists of at least two input spaces containing information from discrete domains, a generic space containing the common structure and information between input spaces, and a blended space where the new information, whose structure does not exist in any input, emerges. A blending process of generating new meaning has three stages (composition, completion, and elaboration), mostly happening at the subconscious level.

We propose three different blends among the directionality and the algebraic signs, which lead to three different emergent meanings that cover the situation at hand. Because these two input spaces may produce different blends that lead to different conclusions about the physics, we contend that this problem is difficult because selecting the appropriate blend is difficult, not because of an inherent difficulty in choosing input spaces or building each blend. Because vectors have both magnitude and direction, a full analysis of students’ blending as they figure out electric fields would require blends for both the magnitude of the vectors and their direction. Observationally, we notice that students tend to treat magnitude as a separate problem as direction, so for brevity we focus only on their directionality reasoning here.

In each blend, there are two input spaces which are main characters in our problem, directionality and sign. The first blend runs when a space-fixed problem is involved, for example a coordinate axis in a one-dimensional problem. The axis could be positive leftward or rightward. From directionality, rightward and leftward map to positive and negative (respectively) from sign, projecting forward the convention that leftward is negative and rightward is positive. Running the blend yields a vector \( \vec{x} \) which is positive when it points to the right. This is the usual convention for one-dimensional space-fixed coordinate systems in physics.

Alternately, one could select away and towards from directionality to map to positive and negative in sign (respectively). This is common in body-fixed coordinate systems: moving away from me is positive velocity and moving towards me is negative; radial vectors are positive away from the source. In the case of the electric field caused by a charge, we add the effect of the sign of the charge into the blend with directionality and sign. In this further blend (not pictured) a positive charge maps to the positive-away part of the blended directionality-sign space, generating a blend where the electric field of a positive charge points away from the charge.

Another significant emergent meaning of the sign comes from the relative direction of two vectors, shown on the right in Figure 1. The characteristics of directionality are now “sameness” or “differentness”. In a one-dimensional system, “different” and “opposite” are the same, so we kept the label of the more general case. Formally, the association with the sign might come from the mathematical property of the inner product of two vectors; the inner product of two opposite vectors is negative. Apart from comparing the sign of \( \vec{x}, \vec{E}, \) and \( \vec{R} \), (the distance vector from the point charge to the field point), the meaning emerged from this comparative blend also sometimes shows up when students consider the interference of two fields. For instance, \( \vec{E}_1 \) and \( \vec{E}_2 \) are destructive if their directions are opposite and thus one can insert a negative sign accordingly to account for that destructiveness in the expression for the total field strength. Noting that, the constructiveness and destructiveness are inherently affiliated with the relative direction meaning. Therefore, using these associations requires consistency and care to not double account for this meaning.

Example and analysis

Oliver, our case study student, uses math explicitly to show exactly what he thinks of each element in the expression. Additionally, he is also good at thinking out loud and expressing his thoughts in detail.

The problem is given to Oliver in both verbal and diagrammatic forms. “Suppose we have two charges at -a and +a [as per the charges in figure 2]. What does the electric field look like along the x-axis?” The problem

Figure 1. Three blends between directionality and sign. From left to right: for space-fixed coordinates, for body-fixed coordinates, and for comparing the signs of vectors.
is typically solved by dividing the whole region into three regions: left of both charges, right of both, and the region between them. The electric field contribution from each charge varies in each region both in direction and magnitude and is commonly drawn like the arrows in figure 2. The total electric field will obey the principle of superposition in all regions.

Table 1: Oliver’s solution

<table>
<thead>
<tr>
<th>Time</th>
<th>Mathematical expression</th>
<th>Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 7:56</td>
<td>( \vec{E} = E_{-q} + E_q = k\frac{-q}{(x+a)^2} \hat{x} + k\frac{q}{(x-a)^2} \hat{x} )</td>
<td>Blend for body-fixed coordinate, blend of comparing ( \hat{x} ) and ( \vec{R} )</td>
</tr>
<tr>
<td>2 10:53</td>
<td>( E_1 = k\left[\frac{-q}{(x+a)^2} - \frac{q}{(x-a)^2}\right] \hat{x} )</td>
<td>Blend of comparing ( E_q ) and ( E_{-q} ) (destructiveness)</td>
</tr>
<tr>
<td>3 12:18</td>
<td>( E_1 = k\left[\frac{-q}{(x+a)^2} + \frac{q}{(x-a)^2}\right] \hat{x} )</td>
<td>Blend of comparing ( E_q ) and ( E_{-q} )</td>
</tr>
<tr>
<td>4 13:15</td>
<td>( E_1 = k\left[\frac{q}{(x+a)^2} - \frac{q}{(x-a)^2}\right] \hat{x} )</td>
<td>Blend of comparing ( E_q ), ( E_{-q} ), and ( \hat{x} )</td>
</tr>
<tr>
<td>5 15:36</td>
<td>( E_2 = k \frac{q}{(x-a)^2} (-\hat{x}) + k \frac{-q}{(x-a)^2} (-\hat{x}) )</td>
<td>Blend for body-fixed coordinate, blend of comparing ( \hat{x} ) and ( \vec{R} )</td>
</tr>
<tr>
<td>6 17:56</td>
<td>( E_2 = k\left[\frac{q}{(x+a)^2} + \frac{1}{(x-a)^2}\right] \left(-\hat{x}\right) )</td>
<td>Blend of comparing ( E_q ), ( E_{-q} ), and ( \hat{x} )</td>
</tr>
<tr>
<td>7 19:30</td>
<td>( E_3 = k \frac{q}{(x+a)^2} (-\hat{x}) + k \frac{-q}{(x-a)^2} (-\hat{x}) = k\left[\frac{-q}{(x+a)^2} + \frac{q}{(x-a)^2}\right] \hat{x} )</td>
<td>Blend of comparing ( E_q ), ( E_{-q} ), and ( \hat{x} )</td>
</tr>
</tbody>
</table>

Oliver starts by writing down the superposition formula of the total electric field: \( \vec{E} = E_q + E_{-q} \), and moves to define each contribution using Coulomb’s Law, as is appropriate to the problem (Table 1). It takes him a long time to decide what the denominator looks like so that it is consistent with the definition of \( \vec{R} \). The formula of the electric field due to a point charge \( \vec{E} = k\frac{q}{R^2} \vec{R} \) suggests Oliver should blend the charges’ value with the direction of the electric field vector and compare the distance vector \( \vec{R} \) to \( \hat{x} \). Then, as Oliver thinks that “\( \vec{R} \) is along \( x \) direction”, a positive sign which is commensurate with the “sameness” in \( \vec{R} \) and \( \hat{x} \) direction is added while he replaces \( \vec{R} \) by \( \hat{x} \). Oliver concludes that the total electric field along the \( x \) axis will be as shown in line 1. We see that Oliver could have arrived at the correct answer if he defined correctly the relationship between \( \vec{R} \) and \( \hat{x} \) for each charge. However, as vector \( \vec{R} \) is not clearly shown on the diagram, this output from the blend of comparing \( \vec{R} \) and \( \hat{x} \) leads to an array of confusion and conflict with other blends that he uses later.

\[ \vec{E} = \frac{kq}{\left[(x-a)^2\right]} \hat{x} + \frac{kq}{\left[(x+a)^2\right]} \hat{x} \]

**Figure 2.** Diagram with the two charges on the \( x \)-axis at \( +/- a \). Regions 1-3 and the origin \( O \) are marked, and the blue arrows designate the direction of the electric field in each region.

Noticing that the electric field of the positive charge does not always point in the \( \hat{x} \) direction as shown in his mathematical expression, Oliver decides to divide the given region into three smaller ones and defines the field vectors on the diagram, as shown in Figure 2. With the diagram, the blend of comparing the vectors, especially \( \vec{E} \) and \( \hat{x} \), can be run easily and becomes more trustful to Oliver compared to other blends. Later, we observe him trying to fit the sign coming from other blends with this one.

In region 1, Oliver quickly realizes that the contribution of the negative charge to any field point is greater than that of the positive charge. He inserts a negative sign between the two terms accounting for the effect of destructiveness of two component fields as they are in opposite directions. He concludes: “It would be this term \( E_{-q} \) minus this term \( E_q \)” (line 2). However, as he is halfway through recording the expression on the board, Oliver expresses suspicion because both terms are now negative. This result clearly conflicts with their relative direction because he has double associated their opposite direction with inappropriate application of destructiveness. Oliver tries hard to determine where another negative sign could come from, such as the denominator, to cancel one negative sign for the whole term. Finally, he decides to absorb the destructive meaning of the sign into the opposite-direction meaning of the electric field vector and changes the second negative sign of the whole term back into the plus sign (line 3), which supports the fact that they are in opposite directions.
However, Oliver has not considered the sign commensurate with the relative direction of $\vec{E}$ and $\hat{x}$, leading to his solution having the opposite sign to the correct answer.

Reading off the physical sense of Oliver’s mathematical expression again, the instructor points out that $E_q$ is pointing in the $\hat{x}$ direction. Oliver starts getting frustrated. He knows that the final solution should have a negative sign in $E_q$ to be consistent with the blend of comparing $\vec{E}$ and $\hat{x}$ that is obviously shown on the diagram. However, Oliver gets stuck manipulating the signs coming from all the sources and ascribes a general meaning to the final sign left in the expression. Eventually, Oliver changes the sign of the terms such that they agree with the emergent meaning of comparative blend between $\vec{E}$ and $\hat{x}$. Oliver confirms his final solution (line 4) and explains his line of reasoning: “Because… see the charges, I should have just figured it out […] which direction it is. This is exactly what is changing the signs, not necessarily the sign of the charge.” In other words, Oliver has successfully affiliated the sign’s meaning of the effect of charge on the field and the superposition into the sign’s meaning of the relative direction among component electric fields and $\hat{x}$.

Moving to the other two regions, we observe Oliver encounter the same struggles with multiple meanings of the sign; however, he's faster at selecting productive blends. Rewriting the mathematical expression in such a way that the minus signs are put next to the elements they belong to (line 5) helps Oliver better distinguish and understand the meaning of the signs. Eventually, deciding to be consistent with the blend of comparing the relative direction of component electric field and $\hat{x}$, Oliver arrives at the correct answers for regions 2 and 3, noting that he should “not worry about the sign [of charge], just worry about the field point [field direction]” (line 6, line 7).

**Discussion and conclusion**

As shown in the case study, the problem of two charges appears easy but requires effort and consistency in considering where the signs belong and their meaning. Oliver typically struggles with combining ideas which seems to be easy. Using conceptual blending, we look at the fine-grained structure of the sign and thus, explore his reasoning meticulously, and how he successfully blends the physical and mathematical sign.

We have associated the algebraic sign with three different meanings in this electrostatics problem, which emerges from three blends of directionality with signs. In the cases of electric field with interference, the sign charge input and the constructiveness or destructiveness also play a role in the blend. We argue that the challenging part of this problem is attributed to the complexity of selecting different blends for sign and directionality. The sign could be affiliated with the relationship among $\vec{E}$, $q$, $R$, and $\hat{x}$, or with any of them individually. The student in this case study shows his strong competence in negative number arithmetic, for example, operation of multiplication. However, to successfully deal with algebraic signs, the student has needed to recognize these different blends and productively select among them. In the literature of using conceptual blending theory in science education research, this difficulty could be explained by the clash between different input spaces, where a sign, either positive or negative, could carry multiple meanings in a comparative blend.

The sign is not the only problematic algebraic element in this problem. The other students in our data also struggled with determining the distance from the two point-charges to field point in different regions. However, as we are interested in how students work on the meaning of the negative sign, we purposefully picked Oliver, who had much less confusion about the distance, and focused on his reasoning on charge and directionality.

The problem of introductory level problems when introduced to intermediate-level students helps expose students’ understanding of mathematics and their competence in using mathematics to express physical concepts. The salient algebraic complexity of this problem has suggested these types of problems could be an interesting electromagnetism problem in physics education research, leading to greater insight into student algebraic thinking.

**References**


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Exploring Design Trade-offs in Incorporating Making Activities Into High School Science Curriculums

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Abstract: This study seeks to explore design tensions in introducing making activities into high school physics classrooms by examining making in semi-informal settings. Through participation in an after-school program and/or summer internship, high school students used Arduino-compatible hardware and software to develop their own scientific instruments for use in classroom physics laboratories. Here we present findings on students’ roles as co-designers and how that influenced their learning and engagement. Furthermore, we discuss issues of accessibility in designing activities in terms of physical and computational affordances. Regardless of prior experience, students were more engaged using pre-assembled robots with defined projects compared with materials and methods traditionally utilized in makerspaces. Additionally, the graphical programming language associated with these robots was more accessible than script-based languages generally used to program Arduinos. This suggests, that to provide equitable access to—and engagement with—electronic making, more material and computational scaffolding are required than what is generally provided in conventional makerspaces for implementation in high school classes.

Introduction
Efforts to improve U.S. students’ educational outcomes have often focused on improving their engagement, performance, and retention in science, technology, engineering, and mathematics (STEM) disciplines. One way of improving students’ STEM outcomes is through “making” (e.g., Blikstein, 2013). In making, individuals design, build, modify, and/or repurpose objects using electronics, hardware, and tools. Advocates of making suggest that it is a powerful way to promote learning as students seek out STEM knowledge (e.g., Barton, Tan, & Greenberg, 2016). Making engages students in science and engineering practices (Koh & Abbas, 2015) and supports development of 21st century skills, such as problem-solving and critical thinking, which are essential for success in STEM fields (Martin, 2015). Making has also been suggested as an avenue to breaking down barriers of learning and attainment in STEM. “Anyone can make…anyone can change the world” (Hatch, 2014, p.14).

Although makerspaces are now common in a variety of informal and out-of-school contexts, there is little evidence that the maker movement has been successful in involving a diverse audience. These activities continue to be dominated by white men who have resources to invest in technology and materials (e.g. TASCHA, 2012). Likewise, many out-of-school makerspaces present barriers to entry (Lewis, 2015), such as a lack of computing experience (e.g., AAUW, 2000), the vague purpose of these venues, and the absence of a clear goal (Lewis, 2015). One way to mitigate these barriers is to move making activities into the regular school day, where they can be made accessible to all students. Yet, moving making from informal into formal high school settings presents significant challenges of its own, such as the pressure to align activities with curricular standards, to assess learning outcomes, and to work within time constraints imposed in schools.

In this study, we examine the feasibility and challenges associated with introducing making activities into high school physics classes through extracurricular activities. Using methodological principles of design-based research (DBR; Design-based Research Collective, 2003), we explore ways to bridge the divide between the playful exploration of informal making activities and the structure of traditional schooling, all while providing students with exposure to tools and skills relevant for success in STEM careers. We asked high school students and a physics teacher to act as co-designers and design a set of making activities to be adopted within a typical high school physics curriculum. Specifically, students were given an open-ended charge to explore ways to use Arduino-based hardware and software to design and program scientific instruments that could be used by other students to collect data and test scientific concepts during physics laboratory experiments (after Resnick, Berg, & Eisenberg, 2000). Our goal is to explore the design tensions in introducing making activities into high school
physics classrooms and understand the implications for student engagement and learning, ultimately providing insights for others who seek to bridge the informal-formal divide.

Methods

Phase one: After-school “Arduino Club”

Seven eleventh and twelfth-grade boys participated in the “Arduino Club” after-school program. The program met for one hour, once a week, for one school year. Students were recruited for the club by our partner teacher from his advanced level physics class. The group consisted of one Hispanic student, one Asian student, and five Caucasian students. All had prior computer programming experience, but only one student was familiar with Arduino programming language.

The aim of the program was to design scientific instruments using an Arduino microcontroller and various sensors. To examine what kinds of hardware and software were best suited for this purpose, students attempted to design instruments using different equipment in two separate iterations. The first iteration included the following equipment: Arduino Starter Kit, Elego UNO Project Super Starter Kit, and Kuman Project Complete Starter Kit. These kits contained a few pre-planned activities users could actualize using the Arduino. Pre-written, editable script in the Arduino programming language was also provided. The second iteration equipment was from Makeblock. Makeblock produces Arduino-based, programmable, robotic equipment for kindergarten through high school students (see Figure 1). Kits provide instructions on how to build specified robots that collect data and carry out tasks using different sensors (e.g., a motion sensor, an accelerometer). Robots and sensors are programmed using mBlock software, a graphical programming medium modeled off Scratch 2.0 (MIT) (see Figure 1).

Figure 1. Students in the after-school club work first with Arduino kits (left) then later with Makeblock kits (right).

To examine the process and challenges associated with designing the instruments, data was collected using both “visor cameras” (see Figure 1) and a stationary video camera. The visor cameras (small cameras attached to the brim of a tennis visor) captured point-of-view audio and video from each student. The stationary camera captured interactions across the entire group. Additionally, researchers took ethnographic field notes focusing on students’ use of the technology, problems encountered, and supports or scaffolds utilized to address those problems. Furthermore, background questionnaires and researcher interviews were completed to understand students’ prior technological experience and their interest and engagement with regards to the assigned materials and tasks.

Phase two: Summer internship

During the subsequent summer, six high school students participated in a forty-hour internship. Students were recruited for the internship using an application process developed by our partner teacher. Participants were selected to try and replicate the demographics and skill level of a regular high school class. Student interest, prior technological experience, and their availability to attend the internship were also considered during the selection
process. As a result, participants included two girls and four boys. Of those, two students were Black and four were White. The girls had no prior programming experience, while all four boys reported some experience.

Students were divided into two tri-stratified groups based on prior programming experience. Each group was composed of one student with no prior experience (i.e., novice), one student with some programming experience (i.e., intermediate), and one student familiar with Arduino programming language (i.e., advanced). Working with the partner teacher, students were asked to create physics labs (and write associated lesson plans) that utilized Makeblock robots and add-on sensors (e.g., light and gas sensors). Researchers used identical methods as in Phase One to collect data.

Findings
Using the iterative principles of DBR, we examined whether the open-ended Arduino equipment or the Makeblock robotic equipment would provide the most amenable hardware and software for designing scientific instruments to be used in high school science classes. Our observations through the after-school club revealed that open-ended and unstructured equipment traditionally incorporated in making activities were too difficult for students to learn to use within time constraints of one-hour blocks. In line with traditional makerspaces, students were provided no guidance on how to use the equipment to design their scientific instruments. The lack of structure in the activities resulted in students not knowing how to proceed with the tasks using hardware and software at hand. For example, one student said, “I don’t have much I can do until I go home and can read about the sensor [in the manual],” indicating the student needed more time to understand the materials than what was provided. Furthermore, students struggled to use the script Arduino programing language, saying things like, “I’m learning C++...Alright I don’t know what’s going on.”

Due to a lack of structure in activities and challenges associated with using script coding, we observed that student interest in working with open-ended equipment waned. Throughout the year, five out of six students ceased to attend “Arduino Club” until Makeblock robots were introduced. Once this new equipment was utilized, the same students, who had expressed frustration while using the previous equipment stated, “Now we actually get to do stuff.” This reaction suggests students felt they faced a functional block when working with fully open-ended equipment.

After observing challenges associated with the open-ended Arduino equipment, we focused on finding equipment that was more accessible and engaging to students. Thus, we tried Makeblock robotic equipment because of the scaffolding their graphical programming interface provides and the novelty and excitement generated from working with and building robots (e.g., Khanlari, 2013). Also, because these kits had more explicit instructions on how to use hardware to carry out specific tasks, we suspected that this would help students focus on how to use sensors and robots to design experiments relevant to high school physics, rather than spending their time understanding the utility of the equipment. When Makeblock robotic kits were introduced to “Arduino Club”, students expressed greater enthusiasm for working with these kits than for the open-ended equipment. One of our advanced level participants was even inspired by Makeblock equipment to create a novel instrument using additional materials from Phase 1.

The mBot graphical programming language used to program Makeblock robots made designing with Arduinos accessible to students with all levels of programming experience. This accessibility was demonstrated through the summer internship, as one of our novice students stated, “I think being a beginner [block-based coding] was better, because you could see the flow of things, and everything had a color, and you could input it.” Students with little to no exposure to computation were able to create code that programmed robots to collect specific data using sensors. For example, one physics lab the summer internship students created, called “Jakob’s Mega Murder Mystery,” used the concept of evaporation, a Makeblock robot, and a gas sensor to determine how an imaginary individual “Jakob” died. A novice student who had an avid interest in forensics connected that interest with the sensors and code to formulate this creative and engaging lab.

Additionally, we documented that robots were exciting for both genders, regardless of prior knowledge. One of the girls in the summer internship stated, “I think just being able to feel confident um or having seen something outside of what [I’m] normally doing helped me think about it in a different way. So I think having robots would have been incredibly beneficial…I think [it] would have shown me a world where you can apply this.” Our partner teacher also noted that robots could be more engaging for students than the traditional labs. “Robots are cool and throughout the school year we had that after school thing…the whole robot notion, it just grabbed their attention…not everyone [will be interested] but I think it’s more interesting to try than just using a stopwatch and a meter stick.” This indicated that even advanced students, with a great deal of prior knowledge were engaged.
Moreover, allowing students to formulate their own lesson plans, as co-designers, led to an increased sense of agency and ownership of their own and their peers’ learning. Allowing students to be experts on creating lessons that they could learn from led to them to think about the conceptual hurdles in learning new physics concepts and the technological tools used to investigate those concepts. For example, one student reflected on how important it was to her to ensure the activities she was designing were accessible to students with little programming knowledge, “If you're good at coding it's like riding a bike and once you learn how to ride a bike … you don't forget how to ride a bike, so you forget what it's like learning how to ride a bike. Or the trivial things to you are not trivial to someone else…They [coding learners] literally need the step by step to see it happen...”

Finally, mixed-experience groupings and collaborative work were important scaffolds for students when it came to programming the technology. When asked how students worked together within their groups, one student, who had no prior computer programming experience stated, “I think we worked really well together. It was nice having like, uh someone who knows a lot about [computer programming] and someone who’s in the middle. Um so it was helpful letting us learn from them and it was nice having a group with different levels and we all came together with our own ideas and stuff.” Our second novice student added that, “They [my other group members] explained it really well to me, which is hard to do.” This indicated that intentionally grouping students with a range of prior knowledge provided all participants with the benefits of relative expertise documented by Penney, et al (2016). Our partner teacher noted the relative expertise served as an effective group scaffold, “[a novice student was] curious and able to bombard them [her group members] with the questions that she had and that’s how she got what she needed…for someone who is new to this, to be able to talk it through, is very vital.”

In summation, using robotic kits, the associated sensors, and the mBlock programming language, students in the summer internship successfully created seven lesson plans covering topics including momentum, friction, acceleration, velocity, ultrasound, and electromagnetic radiation. The defined projects and kit constraints provided students with the structure necessary to deduce how to use the hardware and software available to create lesson plans, while implementing basic coding that would be accessible to all students in a high school physics classroom.

Conclusions and implications
Overall, our findings indicate a path forward for moving making activities into the regular school day, as part of required science classes, and demonstrate many potential advantages in doing so. Through a design-based research process, engaging students and our partner teacher as co-designers, we discovered activities and equipment that are not only interesting and engaging to students, but also fit within constraints of a high school curriculum. These activities simultaneously exposed students to sets of tools and activities (designing instruments to investigate scientific queries) that are more authentic to practices of professional scientists than labs typically done in science classes (Chinn & Malhotra, 2002).

The findings also challenge some assumptions of the maker movement and suggest important directions for future work. For example, despite arguments for a democratizing impact of making, our inability to recruit girls for the after-school club and the small number of girl applicants for the summer internship adds to the growing body of evidence suggesting that informal making contexts may not be perceived to be appealing and/or welcoming places for women. Furthermore, in contrast to open-ended, unstructured, activities advocated by many making enthusiasts, we found that some amount of structure and scaffolding is optimal, particularly for students who have less experience with relevant skills and materials. These findings suggest that it is not only possible to move making activities into high school science classrooms without destroying their benefits for learning and engagement, but that doing so (and doing so in ways that layer structure and scaffolding into the experience) may have democratizing effects that making experiences offered solely in informal spaces do not. Our research also demonstrates benefits of engaging students and teachers as co-designers in the DBR process to design activities that balance student interest and engagement with constraints inherent in moving making into schools.

Selected References
Achievement Goals and Team Leadership in Online Small Group Learning

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Abstract: Group learning is a common used learning approach in online education. However, there are limited studies addressing how to support online groups from the perspectives of motivation and team leadership. This study attempts to understand how achievement goals and leadership styles could influence collaboration experience and individual performance. The results showed that learners who adopted mastery goals tended to engage in group learning through promoting member relationships and group cohesion whereas leaders who adopted performance goals tended to concentrate on helping group complete tasks. High level of relationship-orientated leadership made performance-approach goal orientation a significant predictor of collaboration experience and reduced the negative effect of performance-avoidance goals on final grade. This study finally provides insights to online group activity design.

Introduction
Small group learning is a commonly used instructional approach in online education. There are a few challenges that have been discerned such as the reduction of social and contextual cues, trust issue among team members, feeling of isolation, and technical uncertainty (DeRosa, Hantula, Kock, & D’Arcy, 2004). From a team leadership perspective, research has found that virtual team leadership is necessary for quality team performance, however at the same time how leaders or leadership functions in virtual teams is still under exploration (Avolio, Walumbwa, & Weber, 2009; Hertel, Geister, & Konradt, 2005). What makes the challenges even more critical is that leadership in online classrooms are sometimes not explicitly specified by the instructor. In this scenario, leadership roles are little structured and group process is weakly scaffold by the instructor. Informal leadership will gradually emerge in effective online groups, whereas some other groups might stay leaderless towards the end of the group life. The goal of the current study is to understand how emergent leadership in formal online educational settings affect group healthiness as well as individual academic achievement.

Motivation in individual and group learning
In academic settings, students’ achievement motivation is strongly associated with how they engage in learning activities and further academic performance. Goal orientations refer to the reason why students study. The classic model differentiates three goal orientations: mastery, performance-approach (PAP), and performance-avoidance (PAV) goal orientation (Middleton & Midgley, 1997). Mastery goals represent students’ main focus on understanding subject content and developing competence, whereas performance goals reflect the focus on demonstrating competence and how ability will be judged relative to others. The main difference between PAP and PAV goals is striving to outperform others versus striving to avoid doing poorly than others. Research has found a volume of benefits of adopting mastery goals for its positive influence on learning interest, persistence, psychological well-being, and so forth (e.g., Linnenbrink-Garcia & Pintrich, 2000). Particularly, students adopting mastery goals are more likely prefer group collaboration than those who adopt performance goals (Elliot et al., 2016). On the other hand, PAP goals are associated with lower performance, superficial learning strategy use, and fear of failure. Online education has shown its advantages in reducing social comparison among learners which is promising in terms of encouraging mastery goal adoption.

Leadership as engagement in group learning
In earlier literature studying leadership in face-to-face teams, there is a classic dichotomous model viewing leadership as functional acts: task-oriented and relationship-oriented leadership (e.g., Stogdill, 1969). In non-academic settings, a typical task-oriented leader (T-leadership) focuses on completing tasks and tends to be more directive, autocratic, and critical, whereas relationship-oriented leader (R-leadership) tends to be considerate, permissive, democratic, and person-oriented. Research has shown the contingency effect of the two leadership style on team effectiveness. Generally, T-leadership style would be more effective in extreme team situations (e.g., members are not very close or very close to each other), whereas R-leadership styles are more effective than T-leadership when member relationship is intermediate (Strube & Garcia, 1981). This model has
also been applied in a computer-mediated communication environment (e.g., Yamaguchi, Bos, & Olson, 2002; Xie, Sun, & Lu, 2015; Xie, Hensley, Law, & Sun, 2017). Particularly, in online groups without formal leaders, multiple group members can act like both task- and relationship- oriented leaders. At the same time, group members may not actively engaged in leadership roles. Therefore, under the perspective of leadership as shared leadership roles among group members, this study attempts to understand how leadership as an active investigation in group learning could affect collaboration experience and individual learning outcomes.

**Research Questions**

Synthesizing theories and empirical findings, this study attempts to study the following research questions:

1. Can goal orientations predict leadership styles, group cohesion, and individual learning outcome?
2. Does leadership moderate the effect of goal orientations on group cohesion and individual learning outcome?

**Methodology**

**Context and participants**

The study was conducted in an undergraduate-level online course at a large public university in the Midwest United States during spring and summer 2013. The seven-week-long course covered the topics of learning strategies such as note taking, reading, studying, presentation skills, and resilience in order to help students improve college course achievement. There are in total 171 students from 32 groups and six sessions of the course participated. Most of them were professional and continuing education students. Through group discussion, students shared ideas and received feedback from groupmates for creating individual learning portfolios. Online discussion posts and portfolios were both graded based on the quality and the quantity.

**Measures and data collection**

*Achievement goals* were measured by the achievement goals questionnaire (Elliot & Church, 1997). *Leadership styles* were measured by two scales of which each measuring a specific form of leadership, adapted from Stogdill’s (1969) Leadership Behavior Descriptor Questionnaire. R-leadership scale measured the degree to which students perceived themselves as facilitating positive interactions among group members, whereas T-leadership scale measured the degree to which students perceived themselves as helping the group attain goals. The *group cohesion* scale (Chin, et al., 1999) measured a sense of belonging to and having connectedness throughout the group. All items focused on the specific context of the course and were measured on a seven-point scale. Achievement goals were measured at the beginning of each class, whereas other variables were collected at the end. All scales exhibited acceptable levels of internal consistency (Hair, Black, Babin, Anderson, & Tatham, 2006). See Table 1 for details of variables.

**Table 1. Variables and descriptives**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample Item / Formula</th>
<th>Mean</th>
<th>SD</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mastery goals (6 items)</td>
<td>I want to learn as much as possible from this class.</td>
<td>4.87</td>
<td>1.31</td>
<td>.86</td>
</tr>
<tr>
<td>PAP goals (6 items)</td>
<td>It is important for me to do better than the other students.</td>
<td>4.47</td>
<td>1.52</td>
<td>.86</td>
</tr>
<tr>
<td>PAV goals (6 items)</td>
<td>I just want to avoid doing poorly in this class.</td>
<td>4.37</td>
<td>1.31</td>
<td>.76</td>
</tr>
<tr>
<td>T-leadership (5 items)</td>
<td>I gave directions about how to do the online discussions and portfolio assignments.</td>
<td>4.00</td>
<td>1.49</td>
<td>.87</td>
</tr>
<tr>
<td>R-leadership (4 items)</td>
<td>I suggested how we could all work together.</td>
<td>3.97</td>
<td>1.41</td>
<td>.88</td>
</tr>
<tr>
<td>T-leadership level</td>
<td>Score &gt;=4.5 was coded as 1, otherwise 0 using regression tree to determine the threshold (Breiman, Friedman, Olshen, &amp; Stone, 1984).</td>
<td>.66</td>
<td>.47</td>
<td>na</td>
</tr>
<tr>
<td>R-leadership level</td>
<td>Score &gt;=3.6 was coded as 1, otherwise 0 using regression tree to determine the threshold.</td>
<td>.39</td>
<td>.49</td>
<td>na</td>
</tr>
<tr>
<td>Group cohesion</td>
<td>I feel I belong to my group</td>
<td>4.46</td>
<td>1.38</td>
<td>.90</td>
</tr>
<tr>
<td>Grade (transformed)</td>
<td>5-Int(FinalGradePercent+102.1365)</td>
<td>2.89</td>
<td>.80</td>
<td>na</td>
</tr>
<tr>
<td>Group mastery goal level</td>
<td>Average scores of mastery goals among group members</td>
<td>4.51</td>
<td>.65</td>
<td>na</td>
</tr>
<tr>
<td>Group PAP level</td>
<td>Average scores of performance goals among group members</td>
<td>4.50</td>
<td>.54</td>
<td>na</td>
</tr>
<tr>
<td>Group PAV goal level</td>
<td>Average scores of performance-avoidance goals among group members</td>
<td>4.37</td>
<td>.64</td>
<td>na</td>
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<td>Group T-leadership level</td>
<td>Average scores of T-leadership among group members</td>
<td>4.14</td>
<td>.79</td>
<td>na</td>
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<tr>
<td>Group T-leadership</td>
<td>Average scores of R-leadership among group members</td>
<td>4.07</td>
<td>.74</td>
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</table>
Results and discussion

Predicting individual-level outcomes

First, can goal orientations predict leadership styles? Two multiple linear regression models (Model 1.1 and 1.2 in Table 2) were built with the two leadership styles as the dependent variable of each. Results showed that PAP goals played the strongest predictor role of T-leadership ($t=4.86$, $df=111$, $p<.001$); mastery goal orientation significantly predicted R-leadership ($t=3.52$, $df=111$, $p=.001$). PAV goal orientation negatively predicted both leadership styles with weaker effect size on R-leadership (Coef. = -.18, $t=-1.87$, $df=110$, $p = .06$, 95% CI = [-.36, .01]) compared to T-leadership (Coef. = -.21, $t=-2.16$, $df=111$, $p = .03$, 95% CI= [-.40, -.02]). The results were consistent with the previous research results on the matching effect of goal orientations and leadership styles (Xie & Huang, 2014).

Second, can goal orientations predict individual collaboration experience? We use individual perceived group cohesion as the measure of collaboration experience. Multiple linear regression analysis (Model 2.1) suggested that only mastery goal positively predicted perceived group cohesion ($t=5.13$, $df=167$, $p<.001$).

Does leadership play moderation role in the effect of goal orientations on collaboration experience? Multiple linear regression analysis (Model 2.2) showed that PAP goals failed to significantly predict collaboration experience, however, its interaction term with R-leadership level was a significant predictor, controlling the effect of mastery goal ($t=5.33$, $df=167$, $p<.001$). In other words, only higher level of R-leadership would make PAP goal a significant predictor of collaboration experience.

Regarding individual performance which was measured by final grade of the course, Model 3.1 suggested that mastery goals positively and PAV goals negatively predicted final grade. Both PAP goals and group cohesion has no significant impact on individual performance. Beyond these general relationship between goal orientations and learning performance, does leadership plays moderation role in the effect of goal orientations on grade? Among the three goal orientations, mastery goals and PAV goals were the two significant predictors of the final grade. Model 3.2 showed that T-leadership level significantly reduced the negative effect of PAV goals on final grade ($t=2.96$, $df=167$, $p=.003$), although the main effect of PAV goals was still negative, controlling the effect of mastery goal. In other words, only higher level of R-leadership would make PAP goal orientation a significant predictor of collaboration experience.

In sum, we found consistent findings of the close relationship between mastery goals, R-leadership style, and group cohesion as well the tight relationship between PAP goals, T-leadership style, and final grade. R-leadership helped strong PAP goal to affect collaboration experience, whereas T-leadership played slightly reduced the negative effect of PAV goal on learning performance. However, in this course, collaboration experience was found to neither hinder nor facilitate individual performance. This gives a heads-up for instructional design, advocating for integrating group learning to the path to individual growth rather than a stand-alone class activities.

Table 2. Summary of models

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model omnibus test</th>
<th>$R^2$</th>
<th>Independent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1.1 T-leadership</td>
<td>F(3,167)=11.95, $p&lt;.001$</td>
<td>.17</td>
<td>Mastery goal, PAP goal, PAV goal</td>
</tr>
<tr>
<td>Model 1.2 R-leadership</td>
<td>F(3,167)=9.63, $p=.001$</td>
<td>.20</td>
<td>Mastery goal, PAP goal</td>
</tr>
<tr>
<td>Model 2.1 Group cohesion</td>
<td>F(3,167)=14.99, $p&lt;.001$</td>
<td>.21</td>
<td>Mastery goal, PAP goal, PAV goal</td>
</tr>
<tr>
<td>Model 2.2 Group cohesion</td>
<td>F(3,168)=40.51, $p&lt;.001$</td>
<td>.33</td>
<td>Mastery goal, R-leadership level * PAP goal</td>
</tr>
<tr>
<td>Model 3.1 Final grade</td>
<td>F(3,167)=11.37, $p&lt;.001$</td>
<td>.17</td>
<td>Mastery goal, PAP goal, PAV goal</td>
</tr>
<tr>
<td>Model 3.2 Final grade</td>
<td>F(3,167)=14.72, $p&lt;.001$</td>
<td>.21</td>
<td>Mastery goal, T-leadership level * PAV goal</td>
</tr>
</tbody>
</table>

Predicting group-level outcomes
Although the sample size at group level is small, the model was statistically significant with the omnibus test at the alpha = .05 level (N=32, F=2.65, df=7, 24, p=.035). There was 43% of variance in group cohesion explained. The correlation between group-level T-leadership and R-leadership was too strong to avoid multicollinearity problem. The final model therefore only contained R-leadership and other predictors according to theoretically closer relationship between R-leadership and group cohesion. Not surprisingly, the average level of group cohesion was best predicted by group-level R-leadership (t=3.25, p=.003, 95% CI=[.1825815, .8175336]). Interestingly, heterogeneity of PAV goals negatively predicts group cohesion (t=-2.02, p=.054, 95% CI=[-3.408462, .0327989]). In other words, members sensed the group belongingness more strongly when they had similar level (high, medium, or low) of PAV goals. There was no other patterns found about goal orientations and average group cohesion. On the other hand, none of the group-level variables significantly predicted either group level T- or R-leadership.

Significance and limitations
By examining leadership in small online group, the role of group learning experience on learning outcomes was tested. Regarding the limitations, group-level analysis was conducted with small sample from specific context, which restricts the generalizability. Future investigation would use multivariate linear models considering group-level and individual-level variables at the same time.

References
Learning with Multi-Representational Texts in a Second Language: An Eye-Tracking Investigation

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Abstract: Integrating verbal and pictorial information is fundamental in learning multi-representational materials and is reported to correlate with various positive outcomes of learning. To investigate how non-native English readers engage with multi-representational texts, the eye movements of 32 university students were examined while they read a multi-representational text in their second language (L2). The role of prior knowledge, L2 vocabulary knowledge and L2 reading comprehension ability was also investigated. No significant correlations emerged between eye-movement patterns and individual differences but there were significant correlations between eye-movement patterns and learning outcome. This study found partial support that greater integration between text and pictures by non-native English readers was associated with a better learning outcome. Text-dominant processing and text-guided integrative processing appear to be equally important when reading multi-representational texts in the L2.

Keywords: Multi-representational learning, integrative processing, eye-movements, reading in a second language, learning from text

Introduction

The nature of reading multi-representational texts
Most studies that involve native readers learning with multi-representational texts suggest that their reading is text-dominant. Readers predominantly attend to text and sometimes neglect to devote sufficient amount of attention at inspecting corresponding pictures. Multimedia researchers argue that pictures should not be neglected as successful comprehension of multi-representational texts necessitates the readers to integrate information from both representations. Text-picture integration is fundamental as it allows readers to construct a coherent mental representation of the learning content (Mayer, 2005). Eye-movements indicative of the text-picture integration process are associated with various positive outcomes of learning. Readers who make more and longer attempts at integrating perform better in several learning tasks than those who make less and shorter attempts. This more strategic behavior is characterized by more frequent integrative transitions between text and picture, longer text re-reading time while re-inspecting picture and longer picture re-inspection time while re-reading text (Mason, Tornatora & Pluchino, 2013, 2015).

Despite the plethora of studies published, surprising little attention has been given to people reading multi-representational texts in their second language (L2). Studies comparing first language (L1) and L2 reading have found that reading in L1 and L2 differs. L2 reading patterns for instance are usually characterized by longer sentence reading times, more fixations and shorter saccades (Cop, Drieghe & Duyck, 2015). This present study therefore argues for the importance of studying the non-native readers since their experience with multi-representational texts may differ from their native-reader counterparts. Their difficulty in comprehending the verbal information may lead them to ignore the pictures as they focus on the reading in a less familiar language. Alternatively, it may guide them to use the pictures as a source, allowing them to gain a deeper understanding of the text.

We also examined individual differences that are commonly linked to the engagement with multi-representational texts: prior knowledge and reading comprehension ability. Empirical support regarding their role in facilitating learning of multi-representational texts suggests positive associations with learning outcomes (Mason, et al., 2015). Additionally, prior knowledge is shown to correlate positively with text-picture integration (Mason, et al., 2013). Reading comprehension on the other hand is argued to facilitate text as well as image comprehension (Scheiter, Schüler, Gerjets, Huk & Hesse, 2014). For people reading in their L2, vocabulary knowledge is known to play an important role (Droop & Verhoeven, 2003).

The present study
To explore the non-native English readers’ reading of a multi-representational text in English, their eye-movement behavior was examined. We specifically examined their text-picture integration since it is integral to comprehension and learning successfully from multi-representational texts. To this end, two research questions were addressed in this study:

1. Is the eye-movement pattern of non-native English readers reading an authentic multi-representational text in English related to their English vocabulary knowledge, English reading comprehension ability and their prior knowledge in the subject matter?

2. Is the eye-movement pattern of non-native English readers reading an authentic multi-representational text in English related to their learning of the multi-representational text?

Method

Participants
Fifty undergraduates and postgraduates who used English as their L2 were recruited. However, due to calibration problems and drifts in gaze data when reading a long authentic text for an average of 4.84 minutes, only the data of 32 participants could be analyzed. Participants had not studied science since the age of 17 to ensure the material they were reading was not already over-learnt, had normal or corrected-to-normal vision and were at most ‘good’ users of English. Their English proficiency was determined by their performance in an English proficiency test such as IELTS or TOEFL. In addition, the reading direction of their L1 matched that of English, i.e. left-to-right, and top-to-bottom, as this may influence how readers look at text and pictures.

Reading material
The reading material was a single two-page spread from a science textbook for Year Seven (Levesley, Johnson & Gray, 2008) that discusses the properties of solids, liquids and gases. It was chosen after piloting as it includes a number of representation types which serve different functions and whose integration was expected to be important for learning. The material consists of chunks of text and several types of graphic representations (photograph, diagrams). For eye movement analyses, the material was divided into 28 areas of interest (AOIs). Each is classified as either a text or a picture AOI. There are 21 text AOIs made up of paragraphs, headings and questions. Each graphic representation is an AOI in itself, accounting for 7 picture AOIs.

Measures

Vocabulary knowledge in English
The English vocabulary task used was the Lexical Test for Advanced Learners of English (LexTALE) which assesses English vocabulary knowledge. The test involves an un-speeded visual lexical decision task in which each participant was presented with 60 letter strings and they had to decide whether or not each letter string was an existing English word.

Reading comprehension ability in English
Participants’ reading comprehension ability was assessed with the Gray Silent Reading Tests (GSRT).

Prior knowledge of the topic
The participants’ pre-existing knowledge regarding the properties of solids, liquids and gases was assessed with 10 multiple-choice items. Each has four options with one correct answer. All items were adapted from a list of assessment items available on the American Association for the Advancement of Science Project 2061 Science Assessment website, under the topic Atoms, Molecules and States of Matter.

Learning outcomes
The post-test was a paper-and-pencil task assessing the participants’ recall and comprehension of the reading material. It comprised eight open-ended questions reproduced from the question section of the reading material. The last question however was slightly different from the original. In addition to describing “the movements of the particles in solids, liquids and gases” in just words, the participants were also asked to describe them through drawing(s). This additional element assessed the participants’ recall and comprehension of the pictorial information, in particular. Answers to all eight questions were scored according to their correctness and completeness to provide a maximum post-test score of 30 (of which 16 points were from the final question which included drawing). The answers were independently scored by two raters.
Eye movement measures
Because the way in which the non-native English readers integrate verbal and pictorial information in the text is essential for this study, we collected several measures that are normally used to measure this process. The measures were based on the gaze shifts between text and picture AOIs. Integrative transition is a frequency measure indicating the number of attempts at integrating verbal and pictorial information (Mason, et al., 2015). Two temporal measures were also calculated to identify the total time spent on integrative processing during the re-processing of the material. Look-from text to picture fixation time refers to the total time spent re-inspecting a picture AOI while re-reading a text AOI, whereas look-from picture to text fixation time refers to the total time spent re-reading a text AOI while re-inspecting a picture AOI. These second-pass reading measures were examined because it is assumed to reflect a more intentional and purposeful processing of the material (Mason, et al., 2015). Additionally, the total times spent making text-to-text and picture-to-picture integrations during second-pass reading were also calculated. Look-from text to text fixation time refers to the total time spent on a text AOI while re-reading another text AOI, whereas look-from picture to picture fixation time refers to the total time spent on a picture AOI while re-inspecting another picture AOI.

Apparatus
Eye movements were collected using the Tobii Pro TX300 eye-tracker (Tobii Technology, Stockholm, Sweden) with a 300 Hz sampling rate. The stimulus was presented on a 23-inch TFT monitor with a 1920 x 1080 pixel-resolution. Data were recorded with Tobii-Studio software. The eye-tracker allows the participants freedom of head movement at 37 x 17 cm or 15 x 7”.

Procedure
All participants were tested individually. The study comprised three stages; pre-experimental, experimental and post-experimental. All were carried out in a single session. The pre-experimental stage involved the administration of GSRT and the prior knowledge test. In the experimental stage, the participants sat in front of a monitor with the built-in eye-tracking system and were asked to read the stimulus silently and carefully as they would have to answer questions afterwards. The participants read at their own pace. Before the experiment commenced, the system was calibrated on a nine-point grid. All participants finished reading the stimulus under 10 minutes. The post-experimental stage entailed the administration of the post-test, LexTALE and a background questionnaire. The participants completed all three stages under 1 hour and 45 minutes.

Results and discussion
The descriptive values are displayed in Table 1.

Table 1: Means and standard deviations for readers’ individual difference measures

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>English vocabulary knowledge (min. = 0, max. = 100)</td>
<td>73.36</td>
<td>15.18</td>
</tr>
<tr>
<td>English reading comprehension ability (min. = 0, max. = 65)</td>
<td>50.25</td>
<td>5.15</td>
</tr>
<tr>
<td>Prior knowledge (min. = 0, max. = 10)</td>
<td>7.47</td>
<td>2.23</td>
</tr>
<tr>
<td>Learning outcome (min. = 0, max. = 30)</td>
<td>17.95</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Eye-movement behavior and individual differences
One of the aims of the study was to examine whether non-native English readers’ eye-movement patterns are related to their individual characteristics such as prior knowledge or reading comprehension. A correlation analysis however did not find significant associations between any of the individual differences and any measure of eye-movements (see Table 2).

Table 2: Correlations between eye movement and individual difference measures

<table>
<thead>
<tr>
<th></th>
<th>English vocabulary knowledge</th>
<th>English reading comprehension ability</th>
<th>Prior knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrative transition</td>
<td>.219</td>
<td>.188</td>
<td>.250</td>
</tr>
<tr>
<td>Look-from text to picture fixation time</td>
<td>-.021</td>
<td>-.025</td>
<td>.245</td>
</tr>
<tr>
<td>Look-from picture to text fixation time</td>
<td>-.129</td>
<td>.194</td>
<td>.224</td>
</tr>
<tr>
<td>Look-from text to text fixation time</td>
<td>.108</td>
<td>.022</td>
<td>.126</td>
</tr>
</tbody>
</table>
Look-from picture to picture fixation time | .071 | .189 | -.044

*All ps are above .05

This is rather surprising especially with regard to prior knowledge which has been argued to facilitate text-picture integration (Mason, et al., 2015; Scheiter, et al. 2014). The non-native readers’ English reading comprehension ability and English vocabulary knowledge as well as what they have already known about the subject matter therefore cannot explain how they read and processed the multi-representational material.

Eye-movement behavior and learning
To investigate whether the non-native English readers’ eye-movement behavior is associated with their learning of the material, correlations were calculated between the eye movement measures and learning outcome. Learning outcome ($M = 17.95$, $SD = 3.5$) correlated positively with integrative transitions ($r = .411$, $p = .020$), look-from text to picture fixation time ($r = .426$, $p = .015$) and look-from text to text time ($r = .388$, $p = .028$). However, it did not correlate with two other measures; look-from picture to text fixation time ($r = .266$, $p = .142$) and look-from picture to picture fixation time ($r = .137$, $p = .456$). Thus, it seems that those who performed better in the post-test were readers who integrated verbal information for a longer time during the re-processing of the material. They also integrated verbal and pictorial information to a greater extent during the learning episode. However, this was only partially supported because look-from picture to text fixation time did not correlate with learning outcome. This suggests that similar to L1 readers, the L2 readers also have text-dominant processing and text-guided integrative processing (indicated by look-from text to text fixation time and look-from text to picture fixation time) and so were just as important for learning from the multi-representational material.

Conclusion
This study aimed at extending current research on multi-representational learning by exploring readers’ engagement with a multi-representational text in their L2. We examined their eye-movement behavior when reading and processing the text and found that the individual differences examined could not explain this behavior. We were also particularly interested in how these readers integrated the text and pictures and found support for the importance of integrating both representations to learn successfully from multi-representational texts. It appears that text-dominant processing and text-guided integrative processing are equally important. Because the participants were reading in their L2, they needed more time to process the text. Hence, they benefited more from authentic multi-representational textbooks by not only integrating verbal and pictorial information to a greater extent but also by using text to guide this process. Thus, it seems that successful L2 readers are as equally dependent as L1 readers on text-guided interpretation and integration of pictures. How different these processes are in L1 and L2 reading and how it could contribute to learning from multi-representational texts may be of interest for future research, as the number of people studying in their L2 continues to grow.

References
Examining Virtual Reality Based Learning Design for Children with Autism via Seasonal Index Analysis

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Jewoong Moon, Florida State University, jmoon3@fsu.edu

Abstract: This mixed-method study aims to examine the design features and effectiveness of virtual reality (VR) based, social skill learning tasks that aim to promote the social competencies development of children with high-functioning autism. These tasks support both steered and creative role-playing, collaborative design, and virtual gameplay among the target children. Nine 10-14-year-old children with high functioning autism participated in the study over 16-31 intervention sessions. A time-series, seasonal index analysis was conducted with participants’ longitudinal social interaction performance during and across various VR learning tasks. The study findings indicated that the design features of the simulated scenarios and learning tasks in the VR-based learning environment mediated the intervention effects on different social interaction performance.

Introduction
Prevalence rates suggest that 1 in 68 American children are diagnosed with autism. Those diagnosed with high-functioning autism (HFA), in particular, may be the fastest growing segment (Rao, Beidel, & Murray, 2008). Children with HFA lack critical social skills such as initiating and maintaining social interactions, sharing affective experience or understanding the perspectives of others, cooperation and negotiation (Macintosh & Dissanayake, 2006).

Virtual reality (VR) has emerged as a promising platform for social skills learning. Via a 3D simulation of real-world experiences, VR based learning enables the practice of social interaction skills in a non-threatening sandbox setting before testing them out in the real world (Schmidt & Schmidt, 2008). Supporting multisensory interactions for multiple users across a distance is another promising feature of VR based environments because the learning can be extended to multiple settings. Yet prior reviews of the educational applications of VR suggested that its affordance for learning still needs to be studied together with other mediating factors, such as instructional strategies and learner characteristics (Mikropoulos & Natsis, 2011).

This mixed-method, multi-case study aims to examine the salient features of VR based learning tasks that contribute to the social competencies development of children with high-functioning autism. Specifically, the research question to be addresses is: What VR-based learning tasks and scenarios would reinforce social interaction performance of children with high-functioning autism?

Literature review
Theory of executive dysfunction and weak central coherence in autism
An important theoretical account of autism is executive dysfunction (Denckla, 1996). Executive functioning (EF) is defined as the ability to initiate and maintain a set of problem-solving behaviors for attainment of a future goal, such as planning, intentionality (e.g., ability to create and maintain goal-directed behaviors), cognitive flexibility (e.g., shifting attention between stimuli/response sets), and inhibition (of irrelevant responses or impulse) (Ozonoff, Pennington, & Rogers, 1991). Adopting this theoretical perspective, a core intervention design and research hypothesis in this study is that designing and arranging environmental stimuli and problem-based learning tasks that purposefully motivate, scaffold, and instill the practice of executive functioning should promote the social competencies development of learners with autism.

Naturalistic interventions for children with autism
Although there are some common diagnostic features, there is still great heterogeneity associated with autism. Hence it is critical yet challenging to design an intervention that will be effective and versatile for diverse learners with autism because their specific needs will vary. Recent reviews of social skill interventions with individuals with autism proposed a reduction of direct intervention for naturalistic intervention, and the transferring of control for prompting social interactions from teacher verbal antecedents to self-monitoring or naturally occurring stimuli (e.g., Rao et al., 2008). A naturalistic intervention is usually conducted in loosely controlled contexts and incorporates the target child’s preferences into the social skills training.
In spite of their promise, naturalistic and adaptive interventions for children with high-functioning autism are still understudied but worthy candidates for further development and testing (Rao et al., 2008). A recent review on the interventions of social skills learning (Authors, 2017) reported that prior research typically lacks a purposeful investigation of instructional procedures and learning activities in the intervention, and it is difficult to determine circumstances in which the intervention is impactful, or to extract findings that may contribute to the design heuristics and theoretical insights that will guide future intervention development.

**Virtual reality for naturalistic social skills training**

Research also showed that children with autism tend to enjoy computerized intervention programs and have made significant learning gains using various technology-integrated training packages, such as cartoons, video modeling, computer-assisted instruction, and computer games (Beaumont & Sofronoff, 2008). In comparison with other computerized programs, virtual reality supports high-fidelity role-playing to facilitate the transfer of skills between taught and real contexts, and provides a multi-user, open-ended design space for real time collaboration. VR has intrinsic appeal as an instructional tool for children with autism who are typically visual learners (Mitchell et al., 2007). Yet empirical research examining the design and instructional characteristics of a VR-based social skill training program is still limited. Previous VR-based social skill interventions were typically multimedia direct instruction or highlighting a single social scenario (Laffey, Stichter, & Schmidt, 2010; Mitchell et al., 2007). Extending prior research, we investigated the design and affordance of a variety of VR-based social problem-solving scenarios and tasks, including agent-facilitated and peer-enacted role-playing, collaborative artifact design, and virtual gaming, in motivating and enhancing the social interaction performance by children with autism.

**Methods**

**VR based social skill learning environment**

Using OpenSimulator, we constructed a 3D virtual world that simulated the residential community, a virtual school, amusement parks, and various resorts. This virtual world supports social role-playing, collaborative design quests, and virtual gaming. Non-player characters were developed as interactive pedagogical agents that provided structured prompts based on the triggering events. Two virtual facilitators, incarnated into a variety of social characters via a voice-morphing software, provided adaptive scaffolding. The prompts and scaffolds focused on activating and guiding learners’ involvement in executive functioning during the aforementioned learning tasks. The intervention program was aimed to promote the performance of responding, initiating social interactions, interpersonal negotiation, cognitive flexibility (e.g., switching between solutions, multiple tasks, or perspectives), and positive self-identity manifestation.

**Participants and procedure**

A mixed-method multi-case study was conducted to examine the potential association between the virtual scenario and learning task design features and learners’ social interaction performance. Nine 10-14-year-old children who had a formal medical or educational diagnosis of high functioning autism, including one girl and eight boys, participated in the VR-based learning program at home. Each child went through the program over 16-31 intervention sessions (.75 to 1 hour per session), based on each child’s progress and availability. Participants’ social interaction performance was measured at 3-5 baseline sessions. When all baseline data are stable by level, trend, and variability, the VR-based social skill intervention was introduced to child 1. The other participants remained in the baseline condition. When the measures of child 1 gained stability over consecutive sessions during the intervention, child 2 began the intervention while other children continued in the baseline condition. This process repeated for each child until the last one. The sequence of participation was random and the frequency of participation was customized based on each participant’s progress and schedule.

**Data collection and analysis**

Behavioral data was collected from the participants via screen recording and onsite observation of their participation actions and reactions. We then conducted behavioral analysis with the recorded social interaction performance (215 .75-1hr sessions), using time sampling (per 30 seconds) as the primary unit of coding. The coding focused on the manifestation and frequency of positive and negative enactments of the targeted social competencies. The coding followed a structured protocol proving the operational definition and examples of each performance measure, and was supported by an observational data gathering application that enables real-time collection and coding of data obtained from infield and video-based observational processes. Three trained coders independently coded a randomly-selected 20% of the recordings. The interrater reliability was .86. After
more formal discussion and reaching 100% agreement on the frequency and occurrence contexts for every core performance measure and their exemplified events, two trained coders then coded the remained recordings.

Based on the social interaction behavioral coding results, we then calculated the average frequency of successful enactments of each targeted social interaction competency (i.e., average counts of successful enactments of each competency in a selected 3-min interval) in each baseline and intervention session. The type of learning task and simulated social problem scenario (setting) of each intervention session were also coded. To better examine participants’ longitudinal social interaction performance during the progression of learning tasks and scenarios, we adopted the time series analysis approach (Jebb, Tay, Wang, & Huang, 2015) to integrate temporal dynamics in salient pattern detection. We calculated a seasonal index using the following formula for each participant with each VR-based social learning task and setting in order to examine the association between the type of VR-based learning tasks/scenarios and a participant’s social interaction performance.

\[
S\text{-index} = \frac{\text{The average frequency of each social skill enactment within each setting (or task)}}{\text{The average frequency of each social skill across all settings (or activities)}}
\]

If a simulated social scenario (setting) or a learning task’s S-index is higher than 1, this specific setting or task has a privileged intervention effect in comparison with others, whereas a smaller-than-1 S-index represents an underprivileged intervention effect. We also conducted a visual analysis of time series cross-participant graphs (i.e., graphing the data collected and visually inspecting the differences among simulated scenarios and tasks within and across participants) to further examine whether there is a functional relation between the scenario and learning task design features and the outcome variables.

**Results**

Table 1 provided a summary of average seasonal indices of VR-based learning tasks. Across participants, the activity of virtual world exploration reinforces responding and interaction initiation more than higher-order social skills of negotiation, positive self-identity expression, and cognitive flexibility. Among virtual gaming tasks, the chess game showed a differing intervention effect from virtual sports games on the performance of three higher-order social skills. In the social games that learners voluntarily initiated (e.g., racing game and scavenge hunting), the intervention effect was balanced for various social skills. VR-based digital story telling had two forms – creative storytelling using fantasy-themed 3D visuals versus social storytelling based on emulated historical characters. The former fostered self-identity while the latter better facilitated negotiation. Role-play tasks, whether agent-facilitated or peer-enacted, reinforced social interaction performance consistently. The task of acting as a waiter in a virtual amusement-park fish/chip shop, in particular, promoted the performance of initiation as well as higher-order social skills. In comparison with creative building, client-solicited artifact building had an underprivileged intervention effect on self-identity expression.

### Table 1: S-indices of intervention effects of VR-based learning tasks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Responding</th>
<th>Initiation</th>
<th>Negotiation</th>
<th>Self-Identity</th>
<th>Cognitive Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>1.37</td>
<td>0.92</td>
<td>0.47</td>
<td>0.69</td>
<td>0.75</td>
</tr>
<tr>
<td>Math Game</td>
<td>1.05</td>
<td>0.94</td>
<td>1.00</td>
<td>1.16</td>
<td>1.09</td>
</tr>
<tr>
<td>Chess Game</td>
<td>0.96</td>
<td>0.93</td>
<td>1.69</td>
<td>0.30</td>
<td>2.12</td>
</tr>
<tr>
<td>Sports Games</td>
<td>1.04</td>
<td>0.70</td>
<td>0.24</td>
<td>1.06</td>
<td>0.67</td>
</tr>
<tr>
<td>Racing Game</td>
<td>1.19</td>
<td>1.21</td>
<td>1.47</td>
<td>1.02</td>
<td>0.49</td>
</tr>
<tr>
<td>Scavenge Hunting</td>
<td>0.99</td>
<td>1.13</td>
<td>1.09</td>
<td>0.83</td>
<td>0.98</td>
</tr>
<tr>
<td>Creative storytelling</td>
<td>1.18</td>
<td>0.91</td>
<td>0.73</td>
<td>1.97</td>
<td>0.90</td>
</tr>
<tr>
<td>Social storytelling</td>
<td>1.08</td>
<td>1.10</td>
<td>3.39</td>
<td>0.97</td>
<td>1.19</td>
</tr>
<tr>
<td>Dietitian Roleplay</td>
<td>1.15</td>
<td>0.87</td>
<td>0.90</td>
<td>0.88</td>
<td>1.15</td>
</tr>
<tr>
<td>Librarian Interview</td>
<td>1.12</td>
<td>1.07</td>
<td>1.07</td>
<td>0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>Park Worker Roleplay</td>
<td>0.97</td>
<td>1.02</td>
<td>0.93</td>
<td>1.15</td>
<td>1.08</td>
</tr>
<tr>
<td>Waiter Roleplay</td>
<td>1.32</td>
<td>1.64</td>
<td>0.98</td>
<td>1.00</td>
<td>1.04</td>
</tr>
<tr>
<td>Client-solicited Building</td>
<td>0.97</td>
<td>1.02</td>
<td>1.07</td>
<td>0.67</td>
<td>1.06</td>
</tr>
<tr>
<td>Creative Building</td>
<td>1.23</td>
<td>0.97</td>
<td>0.98</td>
<td>1.03</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Table 2 summarized the average S-indices of simulated social scenarios/settings in the virtual world. In general, the scenarios where the participants got to roam the virtual land and approach objects freely (e.g., the sandbox, village, amusement park, a Lego kingdom, and an underwater resort) were underprivileged in fostering the performance of negotiation or cognitive flexibility. In comparison, in a scenario where participants’ agency was lessened (e.g., school nurses office), the performance of negotiation and cognitive flexibility improved whereas that of initiation and self-identity expression decreased.
Table 2: S-indices of intervention effects of VR-based social scenarios/settings

<table>
<thead>
<tr>
<th>Scenario/Setting</th>
<th>Responding</th>
<th>Initiation</th>
<th>Negotiation</th>
<th>Self-identity</th>
<th>Cognitive Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandbox (Open World)</td>
<td>1.14</td>
<td>0.81</td>
<td>0.81</td>
<td>0.69</td>
<td>0.73</td>
</tr>
<tr>
<td>School Classroom</td>
<td>0.97</td>
<td>0.91</td>
<td>0.89</td>
<td>0.79</td>
<td>0.83</td>
</tr>
<tr>
<td>School Cafeteria</td>
<td>0.95</td>
<td>0.83</td>
<td>0.90</td>
<td>0.85</td>
<td>0.77</td>
</tr>
<tr>
<td>School Nurses Office</td>
<td>0.94</td>
<td>0.47</td>
<td>1.33</td>
<td>0.60</td>
<td>1.24</td>
</tr>
<tr>
<td>Village</td>
<td>1.28</td>
<td>0.93</td>
<td>0.40</td>
<td>0.86</td>
<td>0.54</td>
</tr>
<tr>
<td>Amusement Park</td>
<td>1.04</td>
<td>0.92</td>
<td>0.34</td>
<td>1.04</td>
<td>0.75</td>
</tr>
<tr>
<td>Fish &amp; Chip Store</td>
<td>1.54</td>
<td>1.65</td>
<td>1.05</td>
<td>0.81</td>
<td>1.08</td>
</tr>
<tr>
<td>Lego Kingdom</td>
<td>1.07</td>
<td>0.81</td>
<td>0.58</td>
<td>1.05</td>
<td>0.84</td>
</tr>
<tr>
<td>Western Town Resort</td>
<td>0.96</td>
<td>1.04</td>
<td>1.10</td>
<td>0.84</td>
<td>1.24</td>
</tr>
<tr>
<td>Underwater Resort</td>
<td>0.87</td>
<td>0.94</td>
<td>0.62</td>
<td>0.83</td>
<td>0.84</td>
</tr>
<tr>
<td>Snow Resort</td>
<td>1.01</td>
<td>1.01</td>
<td>1.14</td>
<td>1.42</td>
<td>1.05</td>
</tr>
</tbody>
</table>

The finding on the differential effects of the VR-based learning tasks and social scenarios on each social competency suggested that participants with different social learning needs would benefit from them differently. This implication was validated by the visual analysis of time series cross-participant graphs.

**Conclusion and implications**

The current study findings indicated that the designers of VR-based learning should dynamically adapt the design and presentation of VR-based learning tasks and simulation scenarios based on the targeted competencies and the in-situ reactions of learners. The study findings will enrich the research of inclusive and adaptive e-learning by illustrating the design of naturalistic, design- and play-mediated social skills training. The project will also offer theoretical and empirical guidance for the future design of a computer-assisted, versatile, and immersive learning experience for learners with special needs.

**References**


Emergent Leadership and Its Influence on Collaborative and Individual Reasoning

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Abstract: Collaborative discussions that feature argumentation have been shown to benefit children’s reasoning skills and provide an optimal environment for children to strengthen their social skills including emergent leadership. As these social skills develop, it is unclear how they impact the cognitive benefits that children yield from participating in the collaborative discussions. This study examined the immediate and delayed impact of children’s emergent leadership on their reasoning at both the group and individual level. Results showed that among different leadership moves that emerged during collaborative discussions, topic control significantly influences whether the discussion group and individual children consider both sides of a controversial issue. The study implies positive influence of emergent leadership on children’s cognitive development during collaborative discussions.

Introduction
Collaborative learning is widely recognized as an instructional format that promotes socialization and learning among students of different levels in a variety of subjects (Mercer & Littleton, 2007). Research has shown that, when compared to direct instruction, peer-led collaborative discussions that foster argumentative dialogue can lead to children’s better comprehension of the text, development of critical and analytic thinking, and improved argumentation skills which further transfer to their writing (Rezniskaya et al., 2009).

Argumentative dialogue is a type of classroom discourse that can shape how learners reason about a topic. Based on the Vygotskian principal of internalization, argumentation has been used as a framework to promote higher-level reasoning and critical thinking skills (Andriessen, 2006). It is believed that, during argumentative dialogue, students first learn to reason out loud with their peers and then internalize the process. When children reason together, they hear a variety of different and sometimes competing voices and opinions. In the process of internalization, children learn to consider multiple perspectives on an issue by comparing and contrasting different, and often opposing, views that they are exposed to during the group discussion (Morris et al., in press).

The social processes during collaborative discussions have been found to be an important component for productive collaboration in both face-to-face and online settings (Cassell, Huffaker, Tversky, & Ferriman, 2006; Li et al., 2007; Sun et al., 2017b). To ensure smooth social processes within each group, children’s communicative dynamics and effective co-regulation of learning become essential. Research has shown that emergent leadership—a dynamic social process during which some children coordinate, enhance, or guide the behavior of others—can help groups feel more positive towards collaboration and produce better solutions (Mercier, Higgins, & Costa, 2014; Miller et al., 2013; Sun et al., 2017a; Yamauchi & Maehr, 2004). Sun and colleagues (2017a) found that after experiencing a series of collaborative discussions, children developed generalizable social skills in leadership, and effectively applied them in cooperative problem-solving activities that helped produce better problem solutions. Similarly, Ma et al. (2016) examined rotating leadership among students in an online forum and found that more than half of the participant students emerged as leaders, and deepened groups’ understanding of the scientific topics.

While there is ample qualitative and experimental evidence to suggest that peer-led collaborative discussions that feature dialogic argumentation can lead to gains in reasoning (Asterhan & Schwarz, 2017), less is known about whether the emergence of leadership can directly impact the uptake of ideas and presenting of diverse perspectives in collaborative dialogue. Little do we know about whether these social processes have downstream effects on how participants reason about a topic post-discussion.

The study therefore aims to disentangle such complicated processes and advance knowledge about how the emergence of leadership during collaborative discussions influence children’s dialogic and written argumentation about a complex policy issue. Specifically, we ask two research questions: 1) Does emergent leadership influence the quality of dialogic argumentation at the group level? 2) Does emergent leadership impact individual child’s written argumentation after the collaborative discussion?
Method

Participants
255 fifth graders from 12 fifth-grade classrooms from the Midwestern US of mainly African American (41.5%) and Latino (45.7%) children took part in this study. Depending on the school, between 79% and 99% of the participating students were registered for free or reduced-price lunch.

Research design
During the intervention, the participant classrooms studied a six-week curriculum about Wolf Reintroduction and Management in collaborative group work. The curriculum included three packets: (1) the wolves’ potential impact on the town’s surrounding ecosystem and (2) the town’s economy, and (3) basic concepts in relation to how a public policy is enacted. Each packet was comprised of readings specific to the topic, and an activity booklet that contained various activities and problems that reinforced and expanded the concepts presented in the readings. Students role played as officials in the Wolf Management Agency while learning the curriculum, and had to make an informed decision on a Big Question about whether they should give permission to hire professional hunters to kill a pack of wolves that posed a threat to a fictional town.

The study employed a jigsaw design. Teachers helped split their classes into three or four heterogeneous groups, where each group was assigned to become experts on one of the three topics (ecosystem, economy, or public policy) by learning from an information booklet and completing the activities together. After finishing their expert topic, they prepared a poster and presented the core concepts to the other groups. Children were then shuffled into new groups of experts from all three topics to hold a final collaborative discussion about the Big Question with their informed perspectives. Each student was asked to write a letter explaining the decision after the discussion.

Data sources and analyses
The data corpus includes full transcripts of 12 groups’ final collaborative discussions, one randomly-selected group from each participant class, and 75 letters written by students from these 12 groups after the discussion.

Coding for children’s leadership
Using the coding scheme created by Li and colleagues (2007), we identified four major categories of emergent leadership moves by examining speaking turn by turn throughout the transcripts: turn management, argument development, planning and organizing, and topic control. The detailed coding scheme and examples can be found in Table 1. About 20% of the leadership coding was checked separately, and the inter-rater agreement percentage was 90% (Cohen’s Kappa = .79).

Table 1: Leadership Coding Scheme Adapted from Li et al., 2017

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn Management</td>
<td>Direct turns, solicit ideas, ask those who interrupt to let someone else talk, yield a turn to someone who was unable to gain the floor.</td>
<td>What do you think? Did you want to say anything?</td>
</tr>
<tr>
<td>Argument Development</td>
<td>Prompt for reasons, evidence, and clarification from others, or ratifying other's arguments by restating them or making comments.</td>
<td>Why? Where did you find that evidence?</td>
</tr>
<tr>
<td>Planning &amp; Organizing</td>
<td>Provide structure and monitor the group’s processes.</td>
<td>Let’s take a vote!</td>
</tr>
<tr>
<td>Topic Control</td>
<td>Encourage peers to look at another side of a topic, or go back to the original topic.</td>
<td>I think we are off topic. Should we think about the no side?</td>
</tr>
</tbody>
</table>

Coding for structure of group-level reasoning
To decompose the structures of students’ reasoning during the collaborative discussions, each speaking turn was coded for elements of argumentation, based on the coding scheme created by Anderson and colleagues (2011). We identified statements of position, reasons in support of a position, considerations of counterarguments, and rebuttals. The inter-rater reliability was 94% (Cohen’s κ = .89).

Coding for structure of individual-level reasoning
To examine the structure of individual-level reasoning in the wolf decision letters, each letter was segmented into communication units (Crooks, 1990), and then coded for statements with positions, counterarguments, and rebuttals (Reznitskaya et al., 2009). The inter-rater reliability was 98% (Cohen’s κ = .92).

Findings
Overall, there were 2,789 speaking turns from the 12 transcripts, of which 221 turns contained at least one type of leadership move. A substantial number (72%) of the leadership moves were “argument development” where students solicited reasons from peers, prompted for clarifications/evidence, challenged with refutation or counterargument, or supported with ratification. Though the distribution of leadership varied across groups, three out of the four leadership moves occurred in every discussion. The fourth one, “topic control,” only appeared in four discussion groups. Though appearing less frequently, the topic control moves exerted a significantly positive impact on the comprehensiveness of collaborative and individual reasoning.

Immediate impact of leadership on collaborative reasoning
The immediate impact of emergent leadership on group-level reasoning was examined by coding the group’s responses to the attempted leading moves. For example, if a child challenged his or her peer with a disagreement, did the peer respond with a counterargument?

Children often used the topic control leadership move to call the group’s attention to look at the other side of the issue. For example, in one discussion group where students expressed opposite positions at the beginning of their discussions, a student named Shawn used this strategy to prompt the group to consider reasons for “should.” Later, after the group shared sufficient reasons about the “should” side, Shawn called the group’s attention again to consider reasons why they should not hire hunters to kill the wolves. His leadership evidently facilitated the group to consider reasons on both sides.

Shawn Let’s go to reason why they sho-should allow [1] right now. [1]
Alice [1] Yea, we should start with why they should allow.
Shawn Ok. Maybe they should because just like a possibility of the wolves, like, getting into Winona and umm getting into their cities, maybe attacking people.

Not every group used the topic control moves in the same manner. In another group where all children held the same position from the beginning, one student decided to ask the group to consider the opposite side after they spent a significant amount of time looking for reasons to validate their opinions on the one side. Without Karen’s leadership move, the group may reach a biased conclusion without examining the negative impact of wolves on the town’s economy.

Karen Ok. Look we already know that we want the wolves to stay, but now we gotta think about the things that the wolves actually hurt.
Jay Money.
Karen How do they hurt money?

Delayed impact of leadership on individual reasoning
Using counterargument and rebuttal
There was also a notable impact of the topic control leadership move on the argument structures of children’s individual essays. An average of 70% of children considered the yes and no sides of the issue if their discussion groups had used the topic control leadership moves. However, for groups that contained no topic control or very few argument development leadership moves, an average of 30% of children wrote an essay that addressed both sides. Below is an excerpt from one essay written by a student whose group discussion contained topic control leadership moves. In the essay, she addressed the town people’s fear of wolves by not only showing evidence from the Wolf Unit text, but also providing a plausible counterargument that followed by a rebuttal.

I think we should not kill the wolves. / One of the main reasons is because wolves or a healthy wolf has no record of hurting or killing a human. / I understand you are scared that a wolf might hurt your child. / But you haven't seen a wolf in the town. / All of those attacks could have been wild dogs. /

Discussion
Early results from the present study suggest the positive impact of emergent leadership on children’s collaborative and individual reasoning. It is intriguing that the topic control moves during discussions are so
highly influential on children’s reasoning, at both the group- and individual-level. Consistent with findings from Li et al. (2007), it appears that the emergent leadership during collaborative discussions encouraged much more student talk and this talk was, on average, of a high quality with students making efforts to explain themselves as well as providing challenges to one another.

Results from this current study echo Kolikant and Pollack (2015) study which found that when adolescents held opposing views, the discussion was more energized and enriched. Similarly, Hemberger et al. (2017) argued that it was through the continuing experience of arguing with peers who held contrasting positions that the structure of a good argument becomes crystalized. Our study adds to the literature by showing that even when students initially had unanimous ideas, if someone in the group employed the leadership moves to draw attention to the opposing views, they would be much more likely to produce more comprehensive reasoning and internalize the structure of a good argument.

As a whole, this study contributes to the field by examining the interplay between children’s social and cognitive development. It advances the understanding on the social interactions that contribute to productive collaborate discussions and better reasoning about complex policy issues.

References
“I’m Going to Fail”: How Youth Interpret Failure Across Contextual Boundaries

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Megan Goeke, Science Museum of Minnesota, mgoeke@smm.org

Abstract: Previous research on youth’s perceptions and reactions to failure established a view of failure as a negative, debilitating experience for youth, yet STEM and in particular making programs increasingly promote a pedagogy of failures as productive learning experiences. Looking to unpack perceptions of failure across contexts and potential differences between self-identified sexes, youth who participated in making activities were interviewed about their experiences with failure and thoughts about the term. Youth’s perceptions of failure fell into four categories: failure as enhancing, failure as debilitating, failure as mosaic, and failure as fluid. For the majority of youth (70%), their perception of failure transcended situational boundaries and was not entirely negative as previous research suggested. These results have implications on design of learning contexts and complicate prevailing understandings of youths’ failure experiences.

Problem statement
Within science, technology, engineering, and mathematics (STEM) education, failure has been viewed as the point in which an individual stops an activity (Thomas, 2014); as giving up or not trying (Lottero-Perdue & Parry, 2014); as not obtaining an expected goal or outcome (Bidjerano, 2010); and as a learning opportunity (Simpson & Maltese, 2017). Research has illustrated how youths’ reactions to failure include hopelessness, depression, embarrassment, negative self-feelings, decrease of interest in a subject area, and reduced time in extracurricular activities, to name a few (e.g., Guler, 2013; Riketta & Ziegler, 2007). Moreover, youth tend to attribute experiences with failure to external loci or factors out of their control (Weiner, 1986), such as boring presentations, unclear expectations, and task difficulty (e.g., Boruchovitch, 2004). As such, the presence of failures within and educational experience and youths’ reactions to failures typically dwell in a negative space, despite the promotion of failures to spur innovation or inventions (Martin, 2014).

However, an emerging literature on experiences of failure within the making context suggests that the added complexities of open-ended design (Litts et al., 2016), hands-on materials (Sheridan et al., 2016) and multiple resources and supports (Ryoo et al., 2015) have the potential to reframe failure in a more positive light. As such, the focus for this study was on making contexts as failure is considered an inherent and productive part of making (e.g., Martin, 2015), which may drive learning through reflection and the process of coming unstuck (Kapur, 2008). We present this work to continue building upon this making-related scholarship by posing the following research question: How does youths’ view of failure transcend beyond making contexts and activities, if at all? We define making contexts as situations or spaces that invoke the creation of a tangible (e.g., robot) or digital object (e.g., computer program) for a purpose or play (Vossoughi & Bevan, 2014). Making activities are defined as the type of task, problem, and/or investigation the maker is engaged including the available tools, materials, human resources, and support.

Theoretical grounding
This study is grounded in the notion of boundaries, specifically the concepts of boundary objects and boundary crossing (Akkerman & Bakker, 2011). Boundary objects are defined as concrete or abstract artifacts that inhabit multiple intersecting sites and can “adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites” (Star & Griesemer, 1989, p. 393). Here, we conceptualize the word failure as a boundary object that has different meanings for different people across multiple contexts, known as a boundary crossing. As such, a boundary crossing is defined as transitions or interactions across sites (Suchman, 1994). In this study, boundary crossings include making, academic, and sporting contexts, among others. This theoretical grounding also affords researchers to consider the potential of boundary objects to invoke learning opportunities for youth (Akkerman & Bakker, 2011).

Methodology
This study is part of a larger study in which we are examining how youth and educators attend, interpret, and respond to failure while engaging in making and tinkering activities. This particular study was situated within two locations that implement maker programming for youth, an informal educational setting (i.e., museum) and a formal educational setting (i.e., public middle school), both within the United States. Youth in grades 4-8 (ages 9-14) volunteered to be interviewed regarding their perception and experiences with failure after participating in making-related activities within one of three contexts (i.e., summer camp, drop-in, school), and how this compared to their perception and experiences with failure in other areas of their life. We interviewed 133 youth: 43 in an academic setting, 46 enrolled in a week-long maker focused summer camp held at a science museum, and 44 in an informal drop-in exploration setting at the same museum. Participants across the three contexts were engaged in a variety of making-related activities, which we categorized using Bevan’s (2017) three types of educative Maker activities—assembly, creative construction, and tinkering. Assembly refers to activities that are structured or procedural; creative construction to activities that were based on a pre-set design goal and included some constraints; and tinkering to activities that provided opportunities for exploration and experimentation without a goal in mind. Interviews averaged 13 minutes in length and were transcribed verbatim.

Data analysis
Each interview was analyzed by two researchers using a constant-comparative holistic coding process as the research team had an idea of what might emerge from the data based on experiences with youth in makerspaces (Fram, 2013; Saldaña, 2013). Researchers read and reread through each interview to gain an understanding of youths’ mindset around failure across various sites. Specifically, we utilized and built upon Dweck’s (2006) scholarship on fixed and growth mindsets. As argued by Dweck, individuals’ mindsets tend to change based on context (e.g., mathematics versus art class). From our analysis, four categories surfaced: failure as enhancing, failure as debilitating, failure as mosaic, and failure as fluid. Failure as Enhancing indicates a view of failure as an opportunity for growth and opens up a space for moving forward productively; a learning-oriented perspective. Failure as Debilitating indicates a view of failure as hindering one’s progress and a need for help to continue toward one’s goal or end product; a performance-oriented perspective. Failure as Mosaic indicates a view of failure as enhancing in some contexts and debilitating in other contexts. Lastly, Failure as Fluid indicates neither a positive nor negative view of failure; allowing failure to direct a course of action through a “go with the flow” mentality. Next, we conducted two Kruskal-Wallis tests (by making context and by making activity) to determine if statistically significant differences existed among the four groups or four categories. If differences were found, researchers conducted post hoc Mann-Whitney U test to evaluate pairwise differences among the four groups. To control for Type I error, the researchers used the Bonferroni correction (α = .008).

Findings
With the exception of Failure as Mosaic perspective, youths’ views of failure did not change based on context or situation; thus, their views of failure seem to transcend multiple settings. Table 1 and Table 2 displays youths’ perspective of failure based on the making context and the making-related activity, respectively. Descriptives are presented as number of participants and percentages.

Table 1: Youths’ perspective of failure by making context.

<table>
<thead>
<tr>
<th></th>
<th>School</th>
<th>Summer Camp</th>
<th>Drop-In</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure as Enhancing</td>
<td>22 (16.5%)</td>
<td>17 (13%)</td>
<td>13 (10%)</td>
<td>52 (39%)</td>
</tr>
<tr>
<td>Failure as Debilitating</td>
<td>3 (2%)</td>
<td>13 (10%)</td>
<td>15 (11%)</td>
<td>31 (23%)</td>
</tr>
<tr>
<td>Failure as Mosaic</td>
<td>17 (13%)</td>
<td>15 (11%)</td>
<td>8 (6%)</td>
<td>40 (30%)</td>
</tr>
<tr>
<td>Failure as Fluid</td>
<td>1 (0.8%)</td>
<td>1 (0.8%)</td>
<td>8 (6%)</td>
<td>10 (8%)</td>
</tr>
</tbody>
</table>

Table 2: Youths’ perspective of failure by making activity.

<table>
<thead>
<tr>
<th></th>
<th>Assembly</th>
<th>Creative Construction</th>
<th>Tinkering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure as Enhancing</td>
<td>15 (11%)</td>
<td>22 (16.5%)</td>
<td>15 (11%)</td>
</tr>
<tr>
<td>Failure as Debilitating</td>
<td>11 (8%)</td>
<td>14 (10.5%)</td>
<td>6 (4.5%)</td>
</tr>
<tr>
<td>Failure as Mosaic</td>
<td>11 (8%)</td>
<td>23 (17%)</td>
<td>6 (4.5%)</td>
</tr>
<tr>
<td>Failure as Fluid</td>
<td>0 (0%)</td>
<td>2 (1.5%)</td>
<td>8 (6%)</td>
</tr>
</tbody>
</table>
Failure as Enhancing is exemplified by youths’ view of failure as a means to make improvements either in the process of making, or in not manufacturing the same “mistake” the next time whether in school, in making, in cooking or in sporting events. In other words, failure is viewed as an opportunity to learn regardless of context. For example, a youth in the academic setting stated, “Setbacks and failure can both teach you. Whilst I was working with this I tried out several tools and several tools failed so I have more of an understanding of what they do and how to accomplish what I want.” This was discussed within a three-dimensional design of a fictional starship from a popular television show, as well as within mathematics. Fifty-two of the 133 youth (39%) in this study exhibited this perspective.

Failure as Debilitating is similar to a fixed mindset, framed here as a negative view of failure personally (e.g., low confidence) and in limiting one’s progress toward the end product or expected outcome. Youth are not concerned with learning from failure, but focused on completion and correctness. For instance, failure implies hopelessness in the following quote.

> When something breaks or something doesn’t go correctly, and you can’t do anything about it. Like if you lost something and you can’t re-find it. . . . When you get an assignment wrong and you can’t redo it or if you take a test and you miss the whole thing, you can’t redo the test.

As with Failure as Enhancing, this perspective transcends multiple contexts and was expressed by 31 of the 133 youth (23%) in this study.

Failure as Mosaic does not transcend sites as youths’ perspective of failure changes based on context. In this study, views within making context were typically Failure as Enhancing, while views in other contexts, academic contexts for example, were typically Failure as Debilitating. For example, one youth noted how the camp setting was less serious and expressed having the ability to try new things, whereas failure in a school setting was more serious and may lead to one stating, “I’m going to fail. I’m not going to make it.” Moreover, this perspective of failure varied by classroom contexts, school subjects, and/or academic tasks. The following quote captures this idea. “There’s a difference between my core classes and this class because, in this class [Creative Design], if you fail you can re-do it. And, in other classes, you can't retake tests multiple times.” In this study, 40 of the 133 youth (30%) did not view failure the same across multiple sites or boundary crossings.

Failure as Fluid was less often expressed by youth in this study (n = 10, 8%). One youth building any structure or object using small rubber bands and small wooden dowels commented, that after his structure fell apart, “I don't really know what I did, I just started putting sticks together. I just put more rubber bands on it.” Upon further probing, the youth was unable to articulate how he decided to make changes. As exemplified in this quote, failure is not positioned as a learning opportunity (i.e., Failure as Enhancing) nor as being detrimental (i.e., Failure as Debilitating), but as some thing or abstract boundary object that just occurs and tends to work itself out for better or for worse.

Lastly, in conducting Kruskal-Wallis tests, a significant difference was found for how youth viewed and experienced failure in different learning environments based on the making activity ($\chi^2(3, 133) = 14.205, p = .003$), but not the making context ($\chi^2(3, 133) = 5.438, p = .142$). The follow-up analysis revealed that youth with a Failure as Enhancing perspective ($p = .002$), Failure as Debilitating perspective ($p = .001$), and Failure as Mosaic perspective ($p = .001$) differed significantly from youth with a Failure as Fluid perspective.

**Significance and implications**

More often than not (approximately 70%), youths’ views of failure in this study transcend across boundaries or contexts, as well as making activities. These views were framed as opportunities for growth (i.e., Failure as Enhancing) more often than views framed as limiting one’s progress (i.e., Failure as Debilitating), 39% and 23%, respectively. This finding seems to both confirm and contradict research that situates failure as only a negative experience (e.g., Guler, 2013). It seems that youths’ views of failure are on par with professionals across STEM fields (Simpson & Maltese, 2017). Additionally, youth continuing to view failure as a negative experience regardless of context, particularly in a making setting where there is a focus on rapid prototyping and celebrating failure as part of the process of creative design (e.g., Martin, 2015), is of concern as it diminishes the opportunity to learn across boundaries.

Furthermore, about 30% of youths’ views of failure in this study did not transcend across boundaries, but changed based on context and making activity. Youth who expressed Failure as Mosaic most often exhibited Failure as Enhancing during making-related activities, implying the potential power of making in shifting one’s view of failure across multiple sites, which in turn may invoke learning opportunities for youth (Akkerman & Bakker, 2011). This may indicate a transition to viewing failure as a learning opportunity regardless of contexts; hence, transitioning to a view of failure that transcends boundaries. Likewise, youth here expressed Failure as...
Debilitating during school contexts, and even sporting events, as youth were typically not afforded an opportunity to re-do mistakes and/or failures. Therefore, a change in the learning context and/or task could potentially shift these youths’ views of failure within an academic setting from negative experiences to positive experiences.

References


Acknowledgments

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Science Teachers’ Communities of Practice and Policy Implementation

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Abstract: Science education is impacted by messages from multiple sources including national, state, and local policies as well as teachers’ communities of practice. National level policies like the Next Generation Science Standards and local instructional policies such as the use of Project-Based Learning require sensemaking by teachers, an inherently social process. As teachers engage with learning events and new tools they will use their network of communities of practice to make sense of these policies, creating assemblages as they play with the policy. In this data from an ethnographic study of school policy, four science teachers engage with tensions created as they make sense of school-based policies and optional national standards. Teachers with larger communities of practice engaged in more productive play with policies. We call for expanding teachers’ networks of communities of practice and bringing policy makers and administrators into the design of learning events and tools for better implementation.

Keywords: science education, communities of practice, educational policy, taxonomy of learning

Major issues addressed
Educational policies enter schools from multiple layers of the educational system. From national policies like the Every Student Succeeds Act (ESSA, 2015), to state level standards, and local instructional policies in districts and even schools, teachers have to determine how best to implement these networks of policies in their classrooms in ways that most benefit their students. However, the messages sent at these different levels of the system are not always aligned, nor are the policies necessarily aligned with the teachers’ personal stance on teaching and learning. In this paper, we ask how science teachers’ communities of practice influence their interpretation and implementation of local instructional policy and their use of the NGSS Science and Engineering Practices. To address this question, we lay out a brief summary of work in implementation research, the theoretical and conceptual framing used to look at this problem, as well as the methods of data collection. We conclude with claims regarding the effect of communities of practice on teachers’ implementation of policy.

National and local policies in practice
At the national level, science education does not have mandated standards or curricula. However, in 2013, the Next Generation Science Standards (NGSS) were published, having been built through a collective of stakeholders from states using previous publication in science education research and policy. These standards are not currently adopted in all states, but some states have used them to draft their own state standards using the three-dimensional learning model of the NGSS. This three-dimensional model provides Performance Expectations rooted in Disciplinary Core Ideas, Cross Cutting Concepts and the Science and Engineering Practices (hereafter referred to as the Practices), which states use to create their own standards and curriculum aligned with the local contexts. Though national accountability models require state standards in science, there is no obligation to conform to the NGSS or a derivative of it. Therefore, states are free to create their own interpretation of the NGSS or choose another model altogether.

The school district represented in this study is situated in a state that has not currently adopted NGSS aligned standards, and the local district has not chosen to create an NGSS aligned curriculum. Implications for practice include that teachers must make sense of messages they receive from different layers of the education system – national, state, district, and local. Local implementation of state and national policy is often in combination with the implementation of other locale-specific policies that require or promote the use of highly specific pedagogical practices which can be in conflict. Teachers, then, must decide which policies should take precedent in their instructional practice.

Policy sensemaking and communities of practice
In addition to the policies in the educational system, a teacher’s communities of practice (Wenger, 1999) also influences instructional practices relating to these policies. Sensemaking is a collective practice; teachers do not come to decisions on their own. Teachers’ communities of practice, both within and beyond their individual
school, shape policy implementation. Looking at reading teachers, Coburn (2001) found communities of practice serve as gatekeepers, determining what policies to validate or veto, and eventually come to support the development of shared thinking. For science teachers, sense needs to be made around pedagogical practices. The values and beliefs of the communities of practice teachers engage in will therefore impact the way that they bring both teaching practices and science practices into their classroom.

Teachers involvement in multiple communities of practice can then result in multiple interpretations of a policy in different classrooms within the same school. To help inform this complexity, we take up Koyama and Varenne’s (2012) idea of “policy as productive play” where policy implementation is assemblages of discourses, peoples, regulations, rewards and punishments. In this framework, policy implementation is a non-linear, non-consensus process in which there is room for “play” – negotiation, interpretation, and selective appropriation of the tenets of the policy (Koyama & Varenne, 2012, p. 157).

As teachers engage in sensemaking around a policy, local communities provide resources to support sensemaking and implementation of the policy. Cobb and Jackson (2012) developed a taxonomy of learning supports to describe the potential that different types of resources have in supporting implementation of policy in schools and classrooms. There are four parts of the taxonomy: new positions, learning events, new organizational routines, and new tools. In this paper, we focus on the learning events and new tools provided to the science teachers in one school district to support their implementation of the local policy of Problem-Based Learning (PBL) and the Practices found in the NGSS. Learning events happen within formal professional development and communications, as well as teacher’s informal talk. Formal, or intentional learning events might look like single day workshops, meetings of Professional Learning Communities, or presentations by colleagues in a department meeting. Incidental learning events might take place in hallway conversations, lunch room discussions, or as part of small group side conversations in other meetings. New tools to engage with the policies might be the texts teachers use with students, technology aids, and written policy messages. The opportunities teachers have to engage with these learning events and tools will influence their play with policy.

Theoretical and conceptual framing
Each community of practice a teacher engages with will influence their implementation of a policy in their classroom practice and may introduce different learning events or new tools. What does and does not get taken up is influenced by multiple boundary interactions teachers have in each community (Wenger, 1999). The interpretation of policy that teachers create will be unique to each of them, based on the assemblage of messages from each of their communities of practice about the policy and its peripheral factors. As part of a larger ethnographic study of middle school culture, this study takes a sociocultural approach to teacher learning, drawing on situated cognition (Lave & Wenger, 1991) and communities of practices (Wenger, 1999) as means of sensemaking (Coburn, 2001). A conceptual framework has been designed to incorporate Cobb and Jackson’s (2012) taxonomy of learning supports with policy as productive play (Koyama & Varenne, 2012) to critically examine the ways that four science teachers incorporate two different policies (PBL and the Practices) into their classrooms.

Methodological approach
Using ethnographic methods, data was collected through semi-structured interviews, participant observation, and artifact collection (Spradley, 1979, 1980). Though interviews with multiple disciplines in the school community influenced the study, we focus our findings on four science teachers within two middle schools of Brighton School District. Participating teachers’ classroom instruction was observed over the span of 2-5 days on multiple occasions throughout the school year (see Table 1.) In addition to teacher interviews, Wilson’s (3) and Aldrin’s (2) principal, Aldrin’s vice principal (1), and two teacher leaders (1) were interviewed.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>School</th>
<th>Subject and Grade</th>
<th>Number of Interviews</th>
<th>Number of Observed Class Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talia</td>
<td>Aldrin</td>
<td>7th grade science</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>Kasey</td>
<td>Wilson</td>
<td>8th grade science</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Rory</td>
<td>Wilson</td>
<td>8th grade science</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Maggie</td>
<td>Wilson</td>
<td>7th grade science</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

Analysis was conducted using a constant comparative method and open coding (Emerson, Fretz, & Shaw, 2011; Lincoln & Guba, 1985) iteratively to create more cohesive codes. Within axial coding, emergent themes (Maxwell, 2012) were used to find patterns in classroom practice and teacher thinking in terms of how
they were playing with policy in their teaching decisions. The resulting analysis led to a focus on PBL and the Practices, which was examined through further analytic iterations.

**Findings**

Analysis of this data is still preliminary, but several working claims are backed with evidence from the interviews, observations and artifacts. Brighton School District provided teachers with broad scope professional development opportunities in homogenous settings that minimized teachers productive play with policy as these fail to account for variations on the taxonomies of learning put forth by Cobb and Jackson (2012.) The homogenized approach to broad professional development, lack of administrative knowledge of science, and misaligned communities of practice each contribute to the level of productive policy play in which each teacher engages. Within their productive play with the local policy of PBL and the national level NGSS Practices, the four participating science teachers engaged in play along a continuum for each policy. Maggie, a veteran teacher chose to ignore the policies of PBL and the Practices, incorporating neither. Talia embraced both PBL and the Practices, but struggled to implement both to a level she believed successful. Rory and Kasey each put together a patchwork of instructional practices in their classroom that attempted use of PBL alongside other tools and practices of the district. Rory, midway through the study, began to implement the NGSS, but did not quite get to incorporation of the Practices during the study’s scope.

Professional development offered within the district likely contributed to the lack of time for the district’s science community of practice to collaboratively play with the policies of PBL and the Practices. Learning events within Brighton School District around PBL represented a broad, homogenized approach. All science teachers were offered formal learning opportunities around PBL by colleagues who hold leadership roles or who had been identified as successfully implementing PBL into their own classrooms; however, these were one-off workshop sessions, often only part of a larger day of activities. Informal learning opportunities happened between teachers within and across disciplines. Rory and Kasey reached out to two colleagues who had been informally identified as successful implementers of PBL, but were not science teachers. There were no observed formal or informal learning opportunities around the NGSS or other science content.

There was some variation between schools in terms of formal learning events, but, no formal learning events focused on science offered within the district professional development schedule. Administrators at Wilson and Aldrin were responsible for setting the schedule of professional development offerings. Neither principal had a science background, had taught science, or had heard of the NGSS. Both schools offered similar percentages of learning events for Writing (18% and 19%) and Technology (31 and 30%.) With their additional professional development time, Wilson provided learning events for Project Based Learning and note taking skills, whereas Aldrin used a large portion (31%) of its learning events for mathematics. Wilson’s principal believed in developing “21st Century Skills” so students were able to collaborate, whereas Aldrin’s principal was concerned with increasing scores on the state tests coming in the Spring. Without learning events, tools for science learning, administration established roles or organizational routines to discuss science formally, Brighton’s science teachers were denied space to engage in social policy play.

Though pedagogical foci of the schools constricted the in-district productive policy play by science communities of practice, involvement with multiple communities of practice appears to increase teachers’ level of productive policy play. Talia is highly involved with external communities of practice like national, state and local level science organizations, as well as a long-term project with a local university. She engaged the most fully with PBL, allowing students to drive the instruction throughout most of the year, but voiced concerned with the lack of “doing science” (Jimenez-Aleixandre, Rodriguez and Duschl, 2000). However, Maggie, a veteran science teacher in the school district, identified no external communities of practice, did not attempt implementation of PBL and claimed to use the NGSS as a check-in for her to see if she’s “on track.” She calls the NGSS “circles instead of squares,” a phrase she uses to mean the same thing with a new name. Maggie does not see the NGSS as influencing her teaching. Rory and Kasey each fall on the continuum between Maggie and Talia. They are attempting to use new policies like PBL, and in Rory’s case the NGSS, within their classroom.

**Conclusions**

Teachers’ communities of practice, and the members within those communities, influenced how teachers play with policies in this context. Within the district community of practice, teacher learning support was provided from administration as formal learning opportunities and tools, and teachers crafted informal learning opportunities through their communities of practice. However, two other elements of Jackson and Cobb’s (2012) taxonomy of learning supports, new organizational positions and routines were not provided for teachers to engage with the Practices or PBL as a science-specific tool. Administrators need to be cognizant of the elements of the taxonomy of learning that are offered to teachers around policies. Because there was no data to
collect on new organizational positions or routines within this data set, we surmise that these pieces may have further influenced the ways in which teachers play with policy.

Communities of practice can enhance teachers’ play with non-district policies. Because the NGSS was relatively unknown to the district and school level administrators, there was no professional development offered to the science teachers in the district. Subsequently, teachers and administrators who did not have external science education communities of practice were less aware of the NGSS and did not explicitly engage with the Practices in their classroom. External communities of practice, like those with which Talia engaged, can provide learning opportunities and tools not available in the district. Experiences with more heterogeneous groups of science teachers expose teachers to a broader perspective on science teaching and learning.

Significance
Findings from this study add to our understanding of how teachers make sense of conflicting policies as part of their negotiation across school and external communities of practice. It also adds to the limited amount of research on science education and policy that involves observations and thick descriptions of practice. Though there are studies using survey data (Anderson, 2012; Aydeniz & Southerland, 2012), there are few studies of teachers’ enactment over longer periods of time. Barton (2001) does examine the political nature of education through critical ethnography but focuses specifically on the students’ culture. Similarly, Kelly and Chen (1999) use ethnographic methods to examine student discourse, but do not situate the teacher in larger community of practice of the school system. Providing thick description of the practices of science teachers engaged in productive policy play adds to the research base and provides grounding for further intervention studies.

This research informs policy making at all layers of the educational system (national, state, and district), as well as how learning events and tools should be provided to teachers in order to implement policies with success. We provide administrators, professional development facilitators and teacher leaders with information on how policies get interpreted and implemented. This can help to guide teacher learning toward opportunities for teachers to more easily implement policies that are meant to increase student learning.

Relevant scholarly references
Students’ Everyday Experiences as Resources in Whole-Class Conversations

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Abstract: This paper reports on a study of whole-class conversations in science education, with a specific focus on how students’ everyday experiences can be used as resources for exploring scientific concepts. The empirical basis is a genetics project involving secondary school students and their teacher. A combination of quantitative methods, in the form of frequency counts of structural features of whole-class conversations, and detailed microanalyses of student–teacher interactions are employed. Findings are that, when the teacher orchestrates whole-class dialogues in which students are positioned as active partners in the conversations, more references to everyday experiences are made. In addition, the analysis shows that the mobilisation of everyday experiences enables the students to reason about complex issues related to genetics as well as enables the teacher to display this complexity and coexisting perspectives. The findings are discussed according to possible implications for instruction and dialogic whole-class activities.

Introduction

Even though whole-class conversations have been described by many scholars as problematic because they often are associated with the triadic initiation–response–feedback (IRF) structure (Nystrand, 1997), scholars have shown more productive aspects of such conversations (Wells & Arauz, 2006). According to Mercer (2004), teachers in whole-class settings can provide conceptual support, such as elicitation of students’ understanding, contextualisation, and rephrasing of students’ utterances through the application of more scientific terms. The importance of facilitating learning spaces in which students are enabled to participate as authoritative and accountable persons has been emphasised within the Learning Sciences community (Greeno, 2006). One way to provide opportunities for students to become authoritative and accountable participants is to include students’ everyday experiences in classroom learning. By everyday experiences we mean knowledge and experiences that are relevant in some of the practices in which students participate outside school. Everyday experiences, for example, can be knowledge about celebrities in popular culture, characteristics of family members, knowledge gained from watching documentaries on TV or the internet, and characteristics of the students’ local community. Scholars have shown that mobilising students’ everyday experiences in conceptually oriented classroom conversations can support learning (Silseth, 2018; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). For instance, Warren et al. (2001) found that, when language minority students were encouraged to use their first language and to use everyday experiences when verbalising their reasoning in a science project about metamorphosis, it resulted in a supportive learning space as well as invoked multiple perspectives on the scientific topic.

In this paper, we explore the relationship between designing talk in whole-class conversations and the mobilisation of everyday resources. The data consist of videotaped student–teacher interactions during a science project in a lower secondary school. We employ a sociocultural approach to the study of meaning-making in which learning is described and analysed as a social and contextual process involving students’ active understanding in a practice that is created by people and cultural tools (Mercer, 2004). The following research questions guide the analysis: RQ1: What structural features characterise the whole-class conversations? and RQ2: How are students’ everyday experiences used as resources in the whole-class conversations?

Research context

The data were produced during a science project about genetics, and the participants were one class of 38 lower secondary school students, aged 15–16 years, and their science teacher. The genetics project comprised several thematic subunits, such as the genetic material (chromosomes, DNA, and genes), cell division (meiosis and mitosis), environment, and heredity. In addition to the whole-class sessions, the project contained both group- and individual activities. The teacher was not given any specific instructions regarding his role as a teacher in the science project nor how to carry out the sessions, and he was fully responsible for implementing the instructional design without interference from the observing researchers.
Methods and data analysis

The science project was carried out during 11 school lessons (each of 60 minutes). Five and a half hours of the total 11-hour long project involved whole-class conversations. The main data material applied in the study constitutes the five and a half hours of transcribed video recordings of all student–teacher interactions that took place in the whole-class conversations. Ethnographic observation notes taken during classroom observations provided supplementary contextual data for the analyses of the participants’ interactions. A combination of quantitative methods in the form of a) frequency counts of structural dialogue features and b) microanalyses of student–teacher interactions were used (cf Furberg, 2016; Hmelo-Silver, 2003). The frequency count analysis involved coding and categorising the student–teacher interactions that took place in the whole-class settings.

The applied coding scheme is based on an adaptation of selected categories from a more substantive coding scheme developed by Wells & Arauz (2006). Of particular interest for the current study are conversation sequences identified as “triadic” and “true discussion”. Triadic sequences are characterised by a structural feature commonly referred to as the IRF structure. Two forms of triadic sequences were identified: 1) triadic sequences initiated by a teacher, followed by a response by a student, and then succeeded by teacher feedback (coded as (T)Triadic); and 2) triadic sequences involving the teacher and one student, where the initiations were provided by the students (coded as (S)Triadic). True discussion sequences are speech-units defined by “the free exchange of information among at least three participants, with or without the inclusion of the teacher” (Wells & Arauz, 2006 p. 391). The coding allows for a two-fold approach to the corpus of whole-class dialogues; first, it allows for an identification and quantification of dialogic patterns within the total corpus of student–teacher interactions within the whole-class settings and, subsequently, how the identified dialogic patterns link with the occurrence of references to students’ everyday experiences. In order to explore how the teacher and students invoked everyday experiences in conversations about complex scientific concepts related to genetics, as well as how everyday experiences were used as learning resources, excerpts of teacher–student interactions were selected for detailed analysis. The applied analytical procedure was interaction analysis involving a sequential analysis of the talk and interaction between interlocutors (Jordan & Henderson, 1995). A sequential analysis implies that each utterance in a selected excerpt is considered in relation to the previous utterance in the ongoing interaction. As a result, the focus is not on the meaning of single utterances but on how meaning is created within the exchange of utterances.

Findings

The identification of conversation sequences shows that the whole-class conversations were dominated by triadic conversation sequences—conversation exchanges involving the teacher and one student. More specifically, 61% of all identified conversation sequences were in the form of triadic sequences following the (T)Triadic IRF structure. Furthermore, 20% of the identified dialogue structures constituted reverted triadic conversation exchanges—student-initiated exchanges between one student and the teacher. Only 19% of all conversation sequences were identified as those involving the exchange of information among at least three participants (i.e., “true discussions”) (cf Wells & Arauz, 2006).

Table 1: Observed frequency (and total percentage) of conversation sequences

<table>
<thead>
<tr>
<th>Conversation sequences</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T)Triadic</td>
<td>166</td>
<td>61%</td>
</tr>
<tr>
<td>(S)Triadic</td>
<td>54</td>
<td>20%</td>
</tr>
<tr>
<td>True discussion</td>
<td>51</td>
<td>19%</td>
</tr>
<tr>
<td>Total</td>
<td>271</td>
<td>-</td>
</tr>
</tbody>
</table>

The frequency count analysis also enabled a quantification of accounts coded as initiations (i.e., accounts where students or the teacher introduce new but related topics, issues, or focus during a conversation). The analysis shows that, in conversation sequences identified as triadic (i.e. (T)Triadic and (S)Triadic sequences), 68% of the initiations originated from the teacher, whereas 32% originated from the students (see Table 2).

Table 2: Observed frequency of initiations made by teacher and students according to conversation sequences

<table>
<thead>
<tr>
<th>Conversation sequences</th>
<th>Initiations</th>
<th>Teacher</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triadic (T)Triadic + (S)Triadic</td>
<td>290</td>
<td>196 (68%)</td>
<td>94 (32%)</td>
</tr>
<tr>
<td>True discussion</td>
<td>240</td>
<td>88 (37%)</td>
<td>152 (63%)</td>
</tr>
</tbody>
</table>
In sequences identified as true discussion, 63% of the initiations originated from the students, whereas only 37% were put forward by the teacher. Concerning references to everyday experiences, the vast majority of such references (both made by the teacher and the students) were made within conversation exchanges identified as true discussions. More specifically, 61% of all conversation sequences identified as true discussion contained references to everyday experiences, whereas only 12% of all (T)Triadic and 22% of (S)Triadic sequences contained references to everyday experiences. These findings indicate that, in dialogues identified as true discussions, the students were more often provided with opportunities to influence the topic, content, and focus of the conversations, implying that the students’ own interests, challenges, and inquiries were put to the fore.

Based on the frequency count analysis, all dialogue sequences identified as true discussion containing references to everyday experiences were analysed. In order to illustrate some central findings from the microanalysis, we provide a detailed turn-by-turn analysis of one episode in which everyday experiences were mobilised. In the following episode, the participants engage in a discussion about whether different human characteristics, in this case, “short hair,” are a result of heredity or the environment. There are conflicting opinions among the students. Most argue in favour of the environment, but a few argue for heredity. The teacher decides to linger on the different positions. We enter when the teacher invites Frode to share with the class:

---

1 Frode: Yes, there is a soccer player who doesn’t, yes, who used—He doesn’t get longer hair than this, this long. (shows with his fingers)
2 Teacher: Yes, like this. (shows with his fingers)
3 Erik: Rooney?
4 Frode: Yes, Rooney doesn’t get longer hair than this.
5 Arne: It has something to do with age.
6 Tom: He used, like, implants.
7 Arne: Perhaps it has something to do with age.
8 Frode: Yes, he used implants. It can’t be just because. He doesn’t do that on purpose; then he would have used a lot of money on implants. Then, it has to be because of heredity.
9 Teacher: It isn’t just because he has small frizzy curls?
10 Frode: No. No, he has, like, these small stubbles on his head.
11 Teacher: Mm, yes, perhaps age is involved here?
12 Frode: He is 26, 27 or something. Don’t know; something like that. He has never had much hair on his head, never.
13 Teacher: Twenty-six, yes. He’s not older, no. It’s an interesting case. This is not as clear as we perhaps might think. Else did you have some inputs?
14 Else: Yes, I was about to say that. It depends on where you’re from. Like, for example, in India, you get really long hair because the hair is so strong, but others, like, grow, but it gets very worn, so it doesn’t get much longer.
15 Teacher: Yes?
16 Else: It has to do with heredity too.
17 Teacher: So, if we think, if we nuance a little bit how long the hair gets, then a heredity factor is present, but if we just think short hair, like Truls or Erik, right, then we agree upon that we are here (points to the word “environment” that appears on the blackboard).

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When Frode brings up Wayne Rooney as an example of someone who is not able to grow hair, several students enter the conversation. Arne adds that hair length can be related to age (lines 5 and 7), something that is nuancing the discussion. Backing up Frode’s heredity position, Tom brings in the issue of hair implants (line 6), and Frode then argues that, since Rooney is spending a considerable amount of money on implants, having short hair cannot be an act of Rooney’s decision (i.e., related to environment) but must be a result of heredity (line 8). As a response to the students’ input, the teacher points out the complexity of the topic they are discussing, and then nominates Else to contribute. By referring to people living in India supposedly having strong and long hair, Else argues that the ability to grow long hair depends on the quality of the hair, which in turn depends on where you are from (line 14). Else’s argument indicates that she takes a heredity position. However, her account in line 16, “It has to do with heredity too” (our emphasis), shows that she argues in favour of both an environmental and a heredity position. In line 17, the teacher wraps up the conversation by revoicing what they have discussed, thus appropriating the different voices and ideas and explaining that the question of environment and heredity is related to the perspective you adopt when addressing the issue and that these things are dependent on context. While doing this, he uses the students as examples to make his points more concrete.

The microanalysis displays two important aspects of true discussions involving everyday experiences. The first aspect concerns how the participants engage in this type of conversation. With the analytical focus on the teacher in these settings, he provided more open-ended questions, refrained from providing the “correct” answer, invited more students into the conversations, and prompted the students to respond to other students’ input. With the analytical focus on the students, they were more likely to provide input in the form of comments and references to their own experiences and ideas instead of providing contributions in the form of questions.
mainly addressed to the teacher. Furthermore, they also tended to follow up other students’ contributions and not only the teacher’s—as was the case with triadic conversations. The second aspect concerns how everyday experiences were used as resources for unpacking complex conceptual issues related to genetics; everyday experiences were invoked both by the teacher and the students in order to explain, contextualise, and show the relevance of general scientific principles.

Conclusions and implications
Scholars have demonstrated the potential of whole-class conversations as instructional activities that might support student reasoning about academic matters (Wells & Arauz, 2006). By combining frequency counts of structural features of whole-class conversations, and detailed microanalyses of student–teacher interactions, the current study adds to this body of research by relating structural features of conversations and the mobilisation of students’ everyday experiences. Furthermore, the microanalysis of teacher–student interactions illustrates how students’ everyday experiences can be used as resources during whole-class conversations.Echoing findings from previous studies on whole-class conversations, the frequency count analysis showed that the majority of the whole-class activities were dominated by triadic dialogue structures (Nystrand, 1997; Wells & Arauz, 2006). In line with Wells and Arauz’s (2006) study, the current study shows that most initiations were made by the teacher. Exceeding this finding however, the current study shows that, in conversations identified as true discussion, the vast majority of initiations were made by the students. In other words, in dialogues where the students have the opportunity to initiate, and by that, influence the topic, content, and focus of the conversations, more students engaged in the conversations.

Previous studies have demonstrated that students’ everyday experiences can be used as resources for supporting students’ conceptual learning and invoking multiple perspectives on scientific issues (Silseth, 2018; Warren et al., 2001). The current study confirms, as well as expands, the findings from previous studies. In addition to containing more student initiations and multiple student participations, conversations identified as true discussion involved substantially more mobilisations of students’ everyday experiences—both by the students and the teacher. The microanalysis showed how everyday experiences were used as resources for unpacking a scientific concept in ways that support students’ conceptual learning. Furthermore, the mobilisation of everyday experiences enabled the students to reason about complex issues related to genetics as well as enabled the teacher to display this complexity and these coexisting perspectives. Overall, the analyses suggest that orienting to students’ everyday experiences in whole-class conversations might enable the teacher to position students as active partners in inquiring into science topics. The current study provides knowledge that can be useful for teachers and teacher educators in designing productive whole-class conversations that support student learning. The empirical findings highlight the importance of designing whole-class dialogues that explicitly invite students to initiate and share their interests and challenges. They also highlight the importance of actively mobilising students’ everyday experiences, and provide opportunities for students to invoke their everyday experiences.

References
Silseth, K. (2018). Students’ everyday knowledge and experiences as resources in educational dialogues. Instructional Science. doi:10.1007/s11251-017-9429-x
Will Time Tell? Exploring the Relationship Between Step Duration and Student Performance

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Abstract: In this paper, we explore how the time students take to solve a problem may relate to their success. Even though prior research indicates that students’ response times can provide some indication regarding correctness, time is not consistently and broadly used when modeling students’ performance. We aim to clarify the relationship between the step duration – that is, the time a student takes to carry out a step of a learning task – and the outcome of this step with respect to correctness for STEM-related courses. Then, we discuss our early findings, how they can be used to enhance student modeling and to provide meaningful and timely feedback to students.

Introduction
The multifaceted nature of the relationship between time to complete a task and performance make using time as a predictor variable for success challenging. This, in turn, makes providing just-in-time hints and scaffold in Intelligent Tutoring Systems (ITSs) a complex and unsolved question. The focus of this ongoing work is to clarify the relation between time-on-task and student performance for various types of learning activities, domains and student characteristics. The main contribution of this work is the development of statistical tools that allow us to predict student performance based on response time. As a first step, we explore how step duration (that is, the total length of time spent on a step of a learning task) relates to correctness for STEM-related courses that were facilitated by ITSs.

Research hypothesis
This work builds on the hypothesis that a student who takes either too little time or too long to respond to a tutor’s question or carry out a step of a learning task, will most likely be unsuccessful in that step – thus, there is no linear relationship between step duration and correctness. The rationale is that, on the one hand, a student needs a minimum amount of time in order to process the problem, retrieve appropriate information, and to construct a correct response. On the other hand, taking too long to carry out a step could indicate lack of background knowledge, failure to retrieve critical information, and inability to address the step. Our research hypothesis is that there is a time frame defined by a minimum and a maximum step duration (dt_min and dt_max respectively) in which a student will likely provide the correct answer (and thus the error rate will be low in the same interval). Consequently, every step that lies outside this time frame will most likely be solved incorrectly or not solved, and the error rate will be high. From now on, we refer to this time frame [dt_min, dt_max] as the Zone of Interest (ZOI). The concept of the Zone of Interest and the research hypothesis is depicted in Figure 1. Based on the research hypothesis, the error rate for the steps answered in less time than dt_min and more than dt_max will be higher than the error rate for the steps that were answered within these time thresholds. We propose a mechanism to identify this zone from students’ response data, and to extrapolate their predicted performance based on where future response times fall in the distribution (inside the zone of interest or not).

Figure 1. The Zone of Interest (ZOI) and the research hypothesis. The horizontal axis depicts the steps of a learning task and the vertical axis depicts the step duration. The steps on the horizontal axis are ordered with respect to their duration, from shorter to longer duration.
Related work

Previous work has identified different characteristics of the relationship between response times and performance. Response time has been studied as a proxy of engagement. For example, Shih et al. (Shih, Koedinger, & Scheines, 2011) used response times as a proxy to distinguish when students use bottom-out hints to their benefit, and Beck (Beck, 2004) proposed the use of response times along with correctness to model students' engagement in a task. Beck argues that hard-setting a time threshold and advising students to go faster or slower is counterproductive since it doesn’t take into account personal characteristics. Instead, one should ask whether the student is engaging in the task rather than whether the student spends time on the task.

Response times have also been directly related to performance. For example, Miller et al. (Miller, Lasry, Lukoff, Schell, & Mazur, 2014) studied the relation between response times and performance for a classroom response system for Conceptual Physics. The authors pinpoint three main findings: a) response time for correct answers was faster than for incorrect answers b) background knowledge and self-efficacy affect response times (good background knowledge and high self-efficacy relates to fast response times and c) gender does not relate to response rates.

However, other work (Xiong & Pardos, 2011), was not successful at predicting future performance using a model that took into account past response times, even though, using response time and related features led to small improvement for student performance prediction when response time of the predicted action was known. Xiong noted that they did not identify a clear trend between response time and correctness. Similarly, Lin et.al. (Lin, Shen, & Chi, 2016) incorporated response times in BKT models and explored whether this addition would lead to better performance in terms of prediction accuracy in next-step’s performance. The results suggested that response time can potentially be a good predictor for post-test scores but does not always support predicting performance per step. Thus, it is still not clear what would be a “good” response time - that is a response time that indicates the student is knowledgeable about the task - or a “bad” response time - that is a time that indicates that the student either is not interested in the activity or does not have the required background knowledge to address it - and how to model it.

Method of the study

Methodology

In this work, we operationalized the Zone of Interest (ZOI) using the duration of steps that students had to carry out while engaging in various learning activities. In particular, each learning activity consists of multiple steps. In order to complete a learning activity, a student has to go through all the steps of the activity. Each step is characterized by a duration - the time elapsed while the student reads the task, contemplates and provides an answer - and an outcome, that is whether the student performed this step correctly or not. For each activity and for every student we collected a set of duration times per step (step duration) and outcomes. Then, we computed the standard score (z-score) of the steps duration per student per activity. Here, the ZOI is defined as the zone between one standard deviation below and one standard deviation above the mean step duration of each student. From the definition of standard score it follows that the ZOI will make up for the 50% of the area under study while the area outside the ZOI will make up for the rest 50%. Next, we analyzed the performance of students with respect to the Zone of Interest. We computed and compared the error rates per student and per activity inside and outside the Zone of Interest.

Based on our research hypothesis, students will most likely carry out a step correctly when the time spent on this step (step duration) falls within the Zone of Interest. On the contrary, students will most likely carry out a step unsuccessfully when the time spent on this step falls outside the Zone of Interest. In other words, the error rate outside the Zone of Interest should be smaller than the error rate inside the Zone of Interest. We operationalize the ZOI in this way for two reasons: a) to address potential imbalance between correct and incorrect steps that may occur in the dataset and b) to assist the choice of thresholds (dt_min, dt_max) by using ±1 SD.

Dataset

We use five different datasets to test the research hypothesis. These datasets were collected from science courses that were supported by intelligent tutoring systems. An overview of the courses and a short description of the learning activities in these courses are given in Table 1. All courses were STEM-related and they mostly aimed at problem-solving activities. All datasets are shared via the online repository Datashop (Koedinger et al., 2010). From these datasets we only used steps that were identified as correct or incorrect (excluded hints and unidentified steps).
Analysis and results

To study the research hypothesis, we have computed the error rates for student steps inside and outside the ZOI, as described in the Methodology section. The error rate in the ZOI was computed as the number of incorrect steps in the ZOI over the total number of correct and incorrect steps in the ZOI. Similarly, the error rate outside the ZOI was computed as the number of incorrect steps outside the ZOI over the total number of correct and incorrect steps outside the ZOI. Furthermore, we studied the error rates in each one of the areas that lie on the left and right side of the ZOI. To compare the error rates we used the Wilcoxon signed-rank test. For all courses, the differences in error rates were statistically significant (see Table 2).

As it can be seen in Table 3, students have more errors when taking long to respond than when taking short periods. Importantly, the error rate for short durations is non-zero, suggesting that these errors play an important role in the relationship between step duration and correctness. Moreover, when considering the error rate in the ZOI, we see that there is not a consistent linear relationship between increasing durations and error rate.

Table 4: Mean step duration (in seconds) for correct and incorrect steps inside and outside the ZOI

<table>
<thead>
<tr>
<th>Course name</th>
<th>Mean duration for correct steps in ZOI</th>
<th>Mean duration for incorrect steps in ZOI</th>
<th>Mean duration for correct steps in Non-ZOI</th>
<th>Mean duration for incorrect steps in Non-ZOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>12.6</td>
<td>12.7</td>
<td>40.6</td>
<td>39.3</td>
</tr>
<tr>
<td>Fractions</td>
<td>4.3</td>
<td>3.3</td>
<td>33.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Geometry</td>
<td>4.9</td>
<td>3.7</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Real Genetics</td>
<td>2.5</td>
<td>3.4</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>6</td>
<td>6.2</td>
<td>61.4</td>
<td>10.5</td>
</tr>
</tbody>
</table>
Error rate inside the ZOI is statistically significantly lower (roughly 10% on average) than the error rate outside the ZOI. This suggests that when the step duration is either too fast or too long then the student is more likely to fail this step. Moreover, the error rate in the Low Non-ZOI area was lower than the error rate in the High Non-ZOI area (roughly 15% on average). This indicates that students were more likely to fail a step when they were taking too long instead of being too fast. The mean step duration for correct and incorrect steps inside and outside the ZOI is presented in Table 4.

Discussion
Our results contribute to the description of the relationship between time spent completing an activity and performance in that activity. Steps with durations that fall inside what we called the Zone of Interest are more often solved correctly than steps with durations that fall outside of that zone. Determining this zone takes into account the distribution of step durations for each student and, therefore, accounts for differences in reading time and other individual characteristics. Defining the zone of interest for each student is fundamental to characterize when a step might be solved incorrectly because the relationship between correctness and step duration is not linear. When students are too fast or take too long to complete a step, they are less likely to complete it correctly (and vice-versa). These results suggest that steps that are below the average step duration for similar students and content might not have been processed successfully. For example, students might not have read the whole problem or tried to retrieve critical previous information (Heckler, Scaife, & Sayre, 2010). Similarly, step duration above the average step duration for similar students and content might indicate that students were not able to access or construct the necessary information to successfully solve the problem (Miller et al., 2014). This has clear implications to ITS development: when a student is too quick she should be encouraged to further work on the step, and when a student takes too long she should be provided with a hint or another scaffold that allows her to succeed. In future work we envision creating a model to predict student performance based on step duration using the ZOI approach (instead of modeling time as continuous predictor). It is also important to test the generalizability of the ZOI approach and the model to new areas outside STEM and ITS, for example, language and social sciences in online courses. Finally, it is fundamental to test a successful model in a novel ITS that provides students with scaffold and feedback based not only on their historical accuracy, but also their response time.

References

Acknowledgments
For this research we used the following datasets accessed via DataShop (pslcdatashop.org): the 'Geometry Area (1996-97)' dataset, the 'REAL Genetics Study Data 2015' dataset, the 'Fractions Lab Experiment 2012 - Classroom study 2013' dataset, the 'USNA Introductory Physics Spring 2010' dataset, the 'Pittsburgh Science of Learning Center Stoichiometry Study 1' dataset.
Influence of Affective Factors on Practices in Simulated Authentic Science Inquiry

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Abstract: Science literacy is critically important but some aspects, such as epistemological beliefs about science, are difficult to define and assess. New technologies, such as simulated authentic science inquiry, may allow for better assessment of epistemology. Science Classroom Inquiry (SCI) simulations offer real-time, scalable assessment of student practices in authentic science inquiry and by extension their epistemological beliefs about science. Our previous work demonstrated that undergraduate student practices exist on a continuum of sophistication, which may be explained by differences in epistemological beliefs or affective factors like self-efficacy, metacognition, or identity. Our current study examines the relationship between affective factors and inquiry practices. Preliminary analysis suggests that students with expert-like investigations are more likely to identify as a science person. This study raises provocative questions about the intersection between inquiry practices, epistemological beliefs, and affective factors and highlights the potential of simulation-based assessment to examine abstract constructs such as epistemology.

Keywords: authentic science inquiry, epistemology, simulations, science education

Introduction
Achieving science literacy is an essential part of science education, and involves not only gains in disciplinary knowledge, but also an understanding of the practices of scientists and how those practices are used to generate science knowledge. The beliefs an individual possesses about the nature of science and how science knowledge is generated are known as epistemological beliefs. Epistemological beliefs about science influence how a student perceives, understands, and engages with scientific knowledge and are therefore critical for achieving science literacy (Peffer & Ramezani, Under Review). Although epistemological beliefs about science are recognized as important for attaining science literacy, they are difficult to define and consequently assess. For example, what makes an epistemological belief sophisticated? Existing metrics of epistemology are criticized for their static examination of what an individual knows or believes only at one point in time, design flaws that falsely assume that the participant is interpreting the assessment in the same manner as the survey author, and the lack of reliability and validity (Sandoval, Greene, & Bråten, 2016; Sandoval & Redman, 2015; Sandoval, 2005).

An emerging solution is to examine epistemology via student science practices, such as in the context of argumentation (Deng, Chen, Tsai, & Chai, 2011) or inquiry (Sandoval, 2005). Our previous work (Peffer & Ramezani, Under Review) examined the practices of experts and novices (where expertise was defined as professional experience with authentic science inquiry) in the simulated authentic science inquiry environment provided by Science Classroom Inquiry (SCI) simulations (Peffer, Beckler, Schunn, Renken, & Revak, 2015). Practices served as a proxy for examining the participants’ epistemological beliefs situated in authentic science inquiry, or their Epistemology in Authentic Science Inquiry (EASI). We found that experts scored higher than novices on a pre-test assessment on their understanding of science practices, and that these scores predicted practices in authentic science inquiry. Expert-like practices included performing complex investigations aimed at uncovering an underlying mechanism of action, pursuing outside information, spending significant time in preparation before engaging in inquiry, and using tentative language when explaining research results (Peffer and Ramezani, Under Review; Peffer & Kyle, 2017). We also observed that novice practices existed on a continuum of more-or-less expert-like. Do the differences between novice participants reflect variability in their EASI, or do those differences reflect a combination of factors, such as how they identify as a science person or their self-efficacy? For example, self-efficacy has previously been shown to be related to students’ epistemic beliefs about science and their motivation to learn science (Tsai, Ho, Liang, & Lin, 2011). However, we do not know how affective factors influence science practices or EASI. Here, we present our preliminary analysis of the relationship of motivation, metacognition, self-efficacy, and science identity to expert-like practices in authentic science inquiry and potentially EASI.
Methods
17 undergraduate students pursuing degrees outside the “hard” sciences (e.g. biology, chemistry, physics) participated in this study. We decided to use non-science majors because little is known about their epistemological beliefs about science and their university science courses are, for many, their last formal science experience and consequently the final opportunity to foster sophisticated epistemological beliefs. Participants included 12 females (70%) and 5 males, of all stages of degree programs (eight freshmen, three sophomores, one junior, and five senior students). All data was collected during a single two-hour session. First, students completed a pre-test. The pre-test included two Likert-style metrics, a measure of science identity (Godwin, Potvin, Hazari, & Lock, 2016) and the motivated strategies for learning questionnaire (MSLQ) (Pintrich, Smith, Garcia, & McKeachie, 1993), with motivation and self-regulated learning being the constructs this metric most effectively captures (Credé & Phillips, 2011). Our current analysis of MSLQ items focuses on the subscales in those categories that are most relevant to our research questions: intrinsic goal orientation, self-efficacy, and metacognitive self-regulation. The twelve identity items do not give a composite score, but each measure different constructs within disciplinary identity: recognition, competency, and interest (Godwin, Potvin, Hazari, & Lock, 2016). Out of the twelve identity items on the pre-test, our discussion will focus on the Overall Identity Item, “I see myself as a science person,” which captures self-recognition with a science identity. Pre-test items were counter-balanced.

After completing the pre-test, students logged into a SCI simulation module that presents a current biological phenomenon relevant to the western United States: the avian range expansion of a nuisance bird, the Great-tailed Grackle. In the simulation, students were situated as scientists attempting to determine why the Great-tailed Grackle has moved north from its ancestral home in Mexico. Students can pursue any investigative approach that they choose, generate any number of hypotheses, examine any tests available within the simulation, and can use the in-simulation library or Internet searches to seek additional information. Actions, including the students’ rationale for each decision, were saved by the SCI simulation engine. On average, the simulation took 25.23 minutes (SD = 10.99) to complete. The simulation logs created for each user were reviewed and coded blind by two members of the research team to determine if the investigation was complex or simple in nature. Complex investigations tend to explore multiple cause and effect relationships, often pursuing several tests and seeking information outside the simulation in a logical, systematic manner that describes a putative mechanism. Since complex investigations use a variety of sources of information and various knowledge streams, these simulation activities may indicate epistemological beliefs that science knowledge is tenuous and derived through a variety of experiments. Simple investigations are limited to pursuing a single cause and effect relationship, usually with very few tests performed or information sought outside the simulation. These investigations are also characteristic of simple inquiry as described by Chinn and Malhotra (2002), and may reflect beliefs that science knowledge is certain. Overall agreement was 82%, and differences were resolved through discussion. All statistical analysis was performed using SPSS 23.

Results
We first examined the differences in pre-test scores between students who pursued complex or expert-like investigations and those with less expert-like investigations. The MSLQ subscale categories have a mean response calculated from the relevant survey questions, and the identity metric is scored independently on a scale of 0 to 4. A total of 8 students performed investigations that were coded as complex, and 9 students performed investigations that were coded as simple. We found that students with complex investigations scored on average slightly higher on several of the MSLQ and identity items (Figure 1). Using a t-test to compare the means between these classifications, the Overall Identity Item (“I see myself as a science person”) was found to be significantly different between those whose investigation style was coded as simple ($M = 1.33$, $SD = 1.22$) or complex ($M = 2.50$, $SD = 0.76$) ($t(15) = 2.32, p = .0345$). Although the MSLQ items did not yield a statistically significant result, students with complex investigations tended to have greater intrinsic goal orientation, self-efficacy, metacognition, critical thinking and help seeking.
We next examined differences in pre-test scores and expert-like simulation behaviors using Pearson’s correlation coefficient; while our sample size was too small to do multiple regression analysis, correlations demonstrate that linear relationships may exist between these variables. We first compared students who pursued information outside their investigation and those who did not. Information seeking is known as an expert practice in both SCI simulations (Peffer & Ramezani, Under Review) and in authentic engineering tasks (Atman et al., 2007). Nine participants chose to seek outside information, while eight did not explore information beyond what the simulation provided. When compared with pre-test metrics, there were no significant differences between those who sought out information versus those who did not. However, when looking at the spectrum of actions, the number of information-seeking actions are correlated with the pre-test metrics of self-efficacy ($r = .514, p = .035$). Another expert-like practice, the amount of time spent preparing for investigation, which included time spent reviewing introductory material in the simulation, exploring information outside the simulation, and devising a hypothesis and testing strategy, was found to be correlated with self-efficacy ($r = .514, p = .035$), metacognition ($r = .487, p = .047$), and overall science identity ($r = .512, p = .036$) (Figure 2).

Conclusions and discussion

While data collection is still in progress, we observed that students who view themselves as competent at science, as seen in both their MSLQ scores and their views of being a “science person,” tend to demonstrate more expert-like investigations and consequently may have a more sophisticated EASI. Although the MSLQ data is not statistically significant with our current sample size, it suggests that students with more complex investigations are scoring higher across learning behavior categories. This is consistent with our identity metric, which was statistically significant. This suggests that students who identify as science people, in spite of not pursuing degrees in the sciences, have more sophisticated or expert-like investigations and potentially more sophisticated EASI.

For this study, we only examined three specific practices that may indicate a more sophisticated EASI: pursuing a complex investigative strategy, seeking outside information, and spending time preparing a hypothesis before moving on to the investigation stage of the simulation. Ongoing work will investigate the relationship of affective factors to other measures of expertise in SCI, such as the use of tentative language (Peffer & Kyle, 2017). Future work will expand existing statistical models of EASI (Peffer & Ramezani, Under Review) to include these affective factors. One limitation of this study is that participation was voluntary and students who are already confident in their science ability or who identify as science people may have been more likely to sign up to...
participate. Repeating this study with a different method of recruitment, such as by using SCI simulations as assignments in non-majors’ science classrooms, may increase participation and reduce possible selection bias. Additionally, both identity formation and epistemological beliefs about science are dynamic processes. Since data was collected in one meeting only, we have a static view of their identity and EASI. If a student completes multiple SCI simulations, it may be that their identity, science practices, and EASI may morph over time.

This work describes our preliminary attempt to connect expert-like practices as a proxy for sophisticated EASI with affective factors such as self-efficacy and science identity. Assessing epistemological beliefs about science via practices in authentic inquiry, and the relationship of both to affective factors may provide novel insight into how students understand science, and consequently improve overall science teaching. If students view themselves as science people, or are motivated to learn science, are they more expert-like in their practices because they seek out more science opportunities and may therefore have been exposed to more science experiences? If so, perhaps encouraging a science identity may be a pedagogical focus to encourage the development of sophisticated epistemological beliefs about science. It may be that adoption of a science identity and gaining self-efficacy and motivation towards science is necessary to attain sophisticated epistemological beliefs and consequently science literacy. Since this work was done with non-science majors, perhaps these affective factors are critical for the formation of overall science literacy for all students, not just science majors who seem naturally inclined to their respective disciplines.

In conclusion, this manuscript builds on our previous work that positions SCI simulations as a method for assessing epistemological beliefs as seen via practices in authentic science inquiry. We extend our previous work to include affective measures which could influence practices in the simulation, epistemological beliefs, or both. Although additional work is needed, this work highlights a novel method for how technology can be leveraged and used in combination with existing metrics to better understand difficult to measure constructs and consequently improve educational practice.

References


From Quantified Self to Building a More Fit Community: Data Tracking and Science Infographics as Boundary Objects

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Abstract: This design case study considers one teacher's use of two socio-technologically enhanced supports to promote students' thinking across boundaries. Quantified self biometric tracking technology is used to capture data related to students' physical experience while an infographics authoring activity is utilized to afford students making sense of these data, synthesizing disciplinary knowledge, and ultimately producing public knowledge artifacts for their communities. The designed integration of these technologies allows and demands that students connect their personal experiences to disciplinary ideas and practices as well as to an audience of their local school community.

Introduction and purpose
This design case study considers how student generated infographics can be incorporated into content driven, formal learning spaces as tools to cross disciplinary boundaries, incorporate students' experiences, and authentically engage communities. During a ten-week health and fitness class, high school students used an ensemble of technologies to record and catalog their own physical fitness, engage with new content knowledge and generate a series of their own science news infographics that related their findings and claims to the larger school community. Infographics are multipart visual representations of complex data and concepts that present scientific data, ideas, and arguments to an audience. Student generated infographics became artifacts that served as boundary objects that encouraged students to reflect on and synthesize their own experiences, build disciplinary knowledge, and express their agency and capacity to affect change in their communities. In this Fitness for Life (FfL) class, students gathered biosensor and self-report information, particular kinds of quantified self (QS) data, as an entry point for understanding and reflecting on their everyday practices related to fitness and health. Simultaneously, students integrated and synthesized disciplinary content knowledge related to biology, health, and mathematics to produce a series of 'public service announcement' infographics with data visualizations geared towards various community audiences.

The FfL course is one of many classes that are part of our broader project, STEM Literacy through Infographics (SLI), that considers how to best design learning environments to foster students' STEM (science, technology, engineering, and mathematics) literacy in an era of a vast amount of data presented in a multitude of representational forms. We are concerned with how the use of technology and various representational modalities can bolster student self-reflection, discourse, and learning across disciplinary boundaries. In this paper, we examine how this teacher adapted a general model for infographics integration to include quantified self data. The course was designed to make visible students' everyday experience, consider these QS data in relation to new disciplinary content knowledge, and ultimately synthesize their multi-dimensional learning to make predictions about their own future health and recommendations for a public audience.

Theoretical framework
The SLI project is driven by a socio-culturally informed design principle of "contextualizing science in life" (Polman, Gebre, & Graville, 2014). We encourage teachers to invoke students' own experiences, make connections across disciplinary boundaries, and challenge students to communicate complex ideas to a variety of public audiences in multiple contexts. Student generated infographics serve as mediating artifacts (Wertsch, 1998) that allow for presentation, synthesis, and integration of multiple forms and sources of knowledge. In this sense, the infographic artifacts allow students to span various boundaries, disciplinary or otherwise. As there continues to be increased specialization in disciplinary knowledge, boundaries manifest as what Akkerman & Bakker (2011) call "socio-cultural differences leading to discontinuity in interaction or action" (p. 152). Such boundaries not only divide disciplinary knowledge, but also divorce students' lived experience and out of school learning from classroom content. We see student generated infographics serving as boundary objects that cut across social worlds and sites of discourse, or otherwise enable bridging (see also Polman & Hope, 2012). These sorts of boundary objects inhabit multiple worlds and become grounding artifacts where multiple fields of inquiry or practice can interact. Infographics as boundary object allow for students to dialogically hybridize and engage multiple fields of knowing in discourse (Akkerman & Bakker, 2011). As a result, boundary crossing can lead to increased student agency, new forms of community engagement, and ultimately transformation.
Transformation may occur as students identify their own positioning across several domains and coordinate diverse perspectives, experiences and ideas through communicative connection and translation.

The framing of infographics as mediating artifacts and boundary crossing objects pairs nicely with a growing interest in and access to the 'quantified self' (QS) movement in educational technology and design. QS involves 'extended tracking and analysis of personally relevant data' (Lee, 2014, p. 1032), that is innately interesting to active learners (Moher et al., 2014). While many initiatives intended to teach students data literacy primarily focus on accessing and understanding large existing data sets (Hammerman, 2009), QS interventions draw on students' authentic, lived experience as primary source material for analysis. Data collected through analog practices like journaling or technologically enhanced means such as wearable devices often reveal patterns and phenomena about one's own embodied experience that are otherwise not visible. These sorts of socio-technological systems can be used to support knowledge building and knowledge sharing in highly participatory learning environments integrating multiple dimensions of knowledge (Lee, 2014). Scientific ideas derived from instruction, QS data from students' own bodies, and knowledge from other classes each serve as individual 'inscriptions' of student experiences (Latour, 1990). By curating and organizing these various inscriptions into a cohesive visual argument, students can use infographics to represent an accumulation or cascade of inscriptions, mobilizing multiple knowledges that transcend established boundaries.

Research context and methods
Data for this analysis are primarily drawn from one teacher's reflection on the design and implementation of her course, supplemented by other artifacts. We consider three structured interviews with the instructor Abby (a pseudonym), her course planning materials, two observational field notes, and the student generated infographics that happened in four cycles. The analysis here is a case study of the designed learning environment and the teacher's perspective of how the course provided opportunities for and demands for students to develop their thinking and ideas.

The Fitness for Life course was designed by Abby in the fall of 2016 after she attended a weeklong professional development regarding integrating data literacy and infographics into the classroom. The course took place at an ethnically, socioeconomically and geographically diverse, residential high school in the intermountain West of the United States designed for students that were not finding success in traditional school settings. Five students participated in this ten-week class that met for forty sessions, each lasting 2.25 hours. Abby's initial course proposal outlined student learning objectives including "Learning about their own bodies and how to take ownership of their health...[to] connect this to the real world," and "predict how their diet and exercise habits will influence their future lives." Abby designed the course to be interactive, multi-disciplinary, and draw on variety of student funds of knowledge. Abby noted, "I don't really think you can engage in understanding about our bodies, fitness, or health without understanding at least some level biology and math."

Case study findings
Abby's curriculum and design activities were enhanced through two socio-technically supported mediating systems; infographics and technology to track biometric data. Student generated infographics were integrated into the curriculum as platforms for students to synthesize content knowledge and their own lived experiences into tangible artifacts that would be shared with community members. Abby reflected, "When I went to the infographics [professional development] institute, it was like a light bulb ... infographics are this perfect vehicle to teach them things about how to make a graph and y=mx+b and p-values, and then how to relate that to the biology we learned in class, and how does that relate to community ... and to see how they are integrating all of these things." Four cycles of infographic activities (Table 1) were built into this class.

Table 1: The four cycles of infographic assignments in the Fitness for Life class

<table>
<thead>
<tr>
<th>Content</th>
<th>5 elements of fitness (Week 1)</th>
<th>Obesity &amp; Fitness (Week 3)</th>
<th>Open Choice (Week 6)</th>
<th>Synthesis of Class &amp; QS Data (Week 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audience</td>
<td>Instructor</td>
<td>Youth</td>
<td>Adolescents</td>
<td>'future self' &amp; school</td>
</tr>
<tr>
<td>Data Source</td>
<td>Class Syllabus</td>
<td>instruction on biology &amp; health</td>
<td>instruction on biology, math &amp; public health</td>
<td>10 weeks all instruction &amp; biometric data</td>
</tr>
</tbody>
</table>

Abby also designed the class so that students would track their own biometric data throughout the semester in analog fashion and with technologically supported systems. Students kept daily written logs that tracked things...
like the amount of sleep they got, general mood, and specific logs related to exercise routines (e.g., number of sit ups, push ups, or times for cardio events). In addition, each student was issued a FitBit to track biometric data from the beginning to the end the semester. She explained that students, "don't realize we are tracking data about our life or making predictions for the future, I think we just do it automatically and I try and teach my students to do it explicitly as there is an inherent math component at being good at doing fitness."

Each of the four units culminated in the production of a student created infographic artifact geared for a particular audience. The first week students completed an introductory infographic to become familiar with the online design canvas and recognize the five elements of fitness that would be covered in the class. For the next unit covering childhood obesity, the expectation of providing a visually appealing, scientifically relevant argument by way of a public service announcement infographic was paramount. Abby explained "They are asked to create an infographic that would be appealing to the child, like real colorful... but it would also be informative for the parent who is making a decision about how to help [their] kid stay healthy." Here, students did not simply demonstrate comprehension of content knowledge, rather they used this information to form persuasive arguments towards a real audience. In the third unit, students could choose their own topic so long as it related to adolescent health. Students were to 'pick a position and convince' their peers of a fitness related topic. Examples included the dangers of steroids, importance of stretching, strategies for increasing muscle mass, etc. The final project required that the students somehow integrate the quantified self-data they had gathered over the ten weeks with the interdisciplinary content they had learned in class. Abby explained, "So the idea is for them to see this change over your body, and you have hopefully learned enough biology and math to say why these changes take place. And what was happening inside your muscles or lungs that made your heart rate decrease? And how does this relate to the information you learned? And what is your plan for the future? And how does this relate to other community health concerns?" Figure 1 shows an excerpt of a student infographic that uses the calculated slope of her fitness gains to make predictions about her future performance and various aspects of her changing health. These final infographics that synthesized students' own habits, content knowledge, and community recommendations were then displayed in the school gym and student findings were shared at their end of semester school wide oral presentations.

Abby structured the FfL class around a school learning objective of 'creating healthy life choices.' For her, this required much more than students simply understanding disciplinary knowledge related to health, biology, or mathematics. Her goal was for students to make informed decisions about their own practices, set goals for the future, and be able to offer informed opinions to their peers and community members. She explained, "The theory was to take this individual information, like I saw this happen to me and then relate it to scientific knowledge, and then relate it in a way that would somehow be beneficial to the community." The quantified self data helped reveal students' own routines while the infographics served both as a platform for personal synthesis and integration, and also as a medium to communicate interdisciplinary knowledge to a broader audience. In this sense, these technologies helped students cross several boundaries (see Figure 2).

![Figure 1](image1.png)

**Figure 1.** One excerpt from a student generated infographic tracking change in fitness and health over time.

![Figure 2](image2.png)

**Figure 2.** The infographic serves as a mediating object to assist in at least three distinct boundary crossings.

The first boundary students in the FfL class crossed (B1) concerns a distinction between individually enacted experiences and disciplinary content knowledge. From the very start of the course students completed daily health and fitness logs and were encouraged to wear FitBit devices 24/7. Through this analog and technologically supported tracking, students' individually enacted practices began to be made visible by way of 'raw' or unprocessed data (e.g., spreadsheets with quantities). Yet, despite these data being 'visible' by way of recording and display, the data lacked meaning in that they were not yet directly tied to the learning students were doing in the FfL course nor were patterns obvious. Through classroom instruction, Abby hoped that students would be enabled to draw connections between the math, health and biology content represented in
their own quantified self-data. She explained, "I really hoped [the infographic] would be a platform that the students could use to integrate and then showcase their knowledge... This is about real life, not just a class. And if you drill down to that base level, you have to be interdisciplinary." The quantified self data made visible students own daily practices and through the mediation and synthesis afforded by the infographic authoring, students were challenged to integrate this knowledge with the disciplinary content provided through instruction.

The second boundary crossing (B2) concerns the distinction between academic disciplines themselves. Often increased specialization, particular methods, or isolated literatures prevent integration of content knowledge across disciplinary boundaries (Akkerman & Bakker, 2011). By design, Abby worked to provide platforms for students to synthesize and integrate multiple forms of knowing drawing from math, health, and biology. The quantified self data provide personalized numerical fodder for analysis while infographic authoring affords a space to synthesize. She explained, "[The infographic] let me see how the person is relating to this knowledge...so it is really interesting for me as an instructor, from a formative and then summative perspective, to see how they are putting things together." Students do not simply demonstrate competence in one scholastic discipline, instead they are challenged to use the infographic to synthesize different content knowledge into a coherent argument for a specific audience or to make predictions for their future selves.

The third boundary crossing (B3) in the FfL course concerns a move from individual knowledge comprehension to public engagement in the students' communities. Abby explained that each student considered and was motivated by the fact that their final products would be printed and displayed around their school space. She explained that she did not want students to "just type up a paper, like some boring rote thing," but instead create a visual artifact that would have some immediate effect in the school community. She was surprised that after students completed their final products, they requested that they could hold a non-required school gathering to share their findings with peers and staff. In fact, the students had calculated predictions about the change in overall fitness of the campus population if new protocols were enacted regarding where the buses regularly parked. If the buses stopped further down the hill, students predicted that their peers may lose 1.5 pounds over the course of a semester. As students' awareness of their fitness crossed personal and disciplinary boundaries, the teacher saw their agency and desire to affect change in their lives and communities as increasing.

Conclusion and significance

This case study of the Fitness for Life class design demonstrates how a teacher working across disciplinary and spatial boundaries can invite student synthesis and integration of multiple forms of knowledge. The inclusion of quantified self (QS) data as primary research fodder and the use of infographics as mediating artifacts that span boundaries grounded learning in students' own experience and expanded this to public engagement. QS tracking made visible students' tacit fitness habits as raw data, the integration of design synthesizing content knowledge added meaning to these data, and the production of public facing infographic artifacts challenged students to communicate their findings as scientifically sound and persuasive claims to affect positive change across existing boundaries. This variety of socio-technically enhanced learning originating in students lived experiences and realized in public expands the use of QS educational technology beyond the individual and invokes community as a way to drive engagement and learning. Future socio-technically enhanced learning interventions may benefit from designing learning environments around the use of cascading inscriptions that draw on students' authentic experience and incrementally build towards public engagement.

References

Using Classroom Video and Technology to Blend Teachers’ Learning in Independent and Collegial Contexts

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Abstract: This paper reports on a professional learning (PL) program blending independent and collegial contexts. The program was supported by classroom video and technology to notice and respond to students’ thinking. Two cohorts of teachers used software and paper supports to plan, capture and study video of their own classrooms, and to develop and share video cases. The research explored what teachers notice about their students’ thinking during independent and collegial studies of classroom video. This paper highlights a case of one teacher’s PL. Video cases, transcripts of independent study, collegial study and of an exit interview were analyzed. Doing the independent study first, the teacher identified problematic student thinking to discuss with colleagues. Collegial discussion subsequently clarified students’ thinking and explored next steps in teaching. Affordances of independent and collegial learning contexts and the role of video, technology, and related supports in fostering teachers’ PL are discussed.

Keywords: teacher professional learning, classroom video, video analysis

Major issue addressed and significance of the work
A key purpose of classroom video in teachers’ professional learning (PL) is to help them reflect on students’ thinking. Advances in video annotation technology make it possible to support teachers’ reflection (Rich & Hannafin, 2009). For example, after using a video analysis software emphasizing noteworthy events like issues in students’ thinking and pedagogy, teachers developed skills in explaining their students’ ideas and the influence of particular teaching moves on students’ thinking (van Es & Sherin, 2002). Teachers may conceivably use such technology for independent study. Additionally, Video Clubs where teachers share and discuss video of their own classrooms with colleagues may promote teachers’ PL. Research shows that collegial discourse bolstered with video and questions about students’ conceptions helps teachers examine the meaning behind students’ ideas (Luna & Sherin, 2017), and discuss pedagogy in light of students’ thinking (Sherin & Han, 2004). But there is little understanding of how one may blend independent and collegial contexts to support teachers’ learning, and how classroom video and technology may serve this end. The issue of blended PL anchored in classroom video and technology is critical because learning involves both individual and social aspects (Salomon & Perkins, 1998). By integrating independent and collegial learning, educators may thus leverage the strengths of the two contexts in fostering teachers’ PL. This paper presents a video-supported blended model of teachers’ PL designed to foster their skills in understanding and responding to students’ thinking in science.

Theoretical approach and research questions (RQ)
The PL model and the associated research draw on a framework for teachers’ professional noticing, which comprises three inter-related processes: focusing on students’ disciplinary understandings; analyzing or making sense of these understandings; and deciding how to respond to the understandings (Jacobs, Lamb, & Philipp, 2010). Specifically, in science instruction, teachers need to attend to students’ science ideas, interpret the ideas in light of the learning goals, and use these interpretations to plan next steps (Barnhart & van Es, 2015). This research explored two questions to understand how independent and collegial studies of classroom video contribute to teachers’ PL. RQ1 was: During independent study, what do teachers notice about their students’ science thinking? RQ2 was: During collegial study, what do teachers notice about their students’ science thinking?

Methods
Research approach, participants and context
This paper reports on teacher learning in the context of a video-supported PL program. Two cohorts of four cross-grade, upper elementary school teachers participated in the program. The cohorts were from different school districts. The paper highlights a case study of PL of one teacher (identified with the pseudonym Ms. Collins) from one of the cohorts. The program aimed to help teachers develop abilities to notice students’ science ideas and reasoning, and to use these understandings to inform next steps in teaching. The teaching experience in the cohort
ranged from five years to 22 years. The case study focused on Ms. Collins because she had spent the fewest years teaching (and teaching science) compared to the rest of her cohort. The study will thus clarify how video-based blended PL can support teachers with limited professional experience to notice and respond to students’ thinking.

The study took place in a suburban school in Northeastern U.S. The cohort participated in a four-part sequence of PL activities: Plan-Enact-Study-Meet (PESM). Teachers first used hardware, software, and paper-based supports to plan, enact and videotape whole class discussions from their science curriculum on matter, and study these videos independently. A paper-based discussion planner prompted teachers to craft student learning goals and discussion questions, and anticipate students’ ideas and teacher responses. A paper-based study tool prompted teachers to note students’ actual ideas and reasoning heard on video, and generate questions and insights about students’ thinking. The software provided an organizing frame called Science Lens to help teachers study students’ thinking. The Science Lens presented a set of tags to annotate students’ ideas and reasoning: Idea related to Goal, and tags about students’ reasoning based on key scientific practices like making sense of data, and constructing explanations based on evidence and scientific principles (NRC, 2012). Teachers also used the software and paper-based guidelines to develop and share video cases in Video Club meetings with their cohort. They crafted focus questions for the meetings and selected and presented relevant video clips of students’ thinking. Each teacher implemented the PES parts four times, and a total of five Video Club meetings were conducted.

Data collection and analysis

Multiple data sources were used. First, Ms. Collins’ commentary was audiotaped and transcribed four times during the (independent) Study part of the program (for RQ 1). The first author used generic prompts (e.g., ‘what are you noticing?’) to elicit the teacher’s commentary after studying every two minutes of the videos. The teacher was not prompted to make any specific observations. Second, Ms. Collins’ video cases were examined for her focus questions (for RQ1). Third, Video Club meetings were audiotaped and transcribed (for RQ2). Ms. Collins shared video cases at three of these meetings. Finally, a post-program interview was conducted and transcribed (across RQ). This paper reports on a subset of the data from the first year of implementing the program. The independent study and Video Club transcripts were coded based on a rubric derived from literature (e.g., Sherin & Han, 2004) and data from the program. The categories and sub-codes were: topic/focus of attention (e.g., students’ science thinking); analytic stance (e.g., interpretive); and pedagogy (e.g., pedagogy connected to students’ science thinking). The exit interview transcript was examined to confirm and extend findings from the other data sources.

Major findings

The key findings were that independent study first of her own video, assisted by software and paper tools, allowed the teacher to focus on and make meaning of her students’ science thinking, and in the process, raise questions about students’ thinking and pedagogy. Collegial study subsequently yielded different perspectives, broadening the teacher’s understandings of these ideas and of next steps in teaching. Specifically, in a fourth-grade earth science lesson on comparing the weights of equal volumes of different earth materials (sand, soil, water, and mineral oil), she noticed students’ science thinking, attending to their idea that air pockets (space) between grains of soil made the soil weigh less. In interpreting this idea, she believed it distracted the students from the goal of understanding that for equal volumes of samples of different materials, some materials are heavier than others. The teacher also remarked that most students ignored how their idea about air pockets did not account for sand—another granular material—having the most weight; the students simply did not apply this idea to a new context.

So for some reason, this idea of the pockets and the chunks is just like coming back up again. I think it’s good because we had just talked about that, so they remembered it. But at the same point, I think [they’re] almost getting stuck on it. But no one brought up, in this whole discussion besides [student name] just now, that sand and soil are the heaviest and the lightest. But they both have the air pockets. So that theory doesn't really hold up, which I think [student name] is trying to say. But nobody really got there, which is interesting.

Further, with respect to pedagogy connected to students’ science thinking, Ms. Collins saw it important to probe students for explanations to help them go beyond stating basic observations.

A lot of them were talking about, it’s just heavier. So I was trying to push them into why is it heavier, which they had a harder time with.
For the video case, she focused on questions about students’ thinking and implications for pedagogy. She wondered why students believed the amount of holes a material had made it weigh less, and how she may respond to this belief. She also asked for strategies to help students explain why some things are ‘heavy for size’.

In a Video Club meeting, Ms. Collins posed these questions and shared video clips showing her students’ thinking about why different materials of equal volumes had different weights. In focusing on and interpreting students’ science thinking, the collegial discussion clarified which aspects of students’ thinking were problematic and needed to be addressed, whilst revealing other aspects that were promising yet overlooked by the teacher.

Colleague 2: So was [student] saying, because I didn't quite hear it, that he's not surprised that people got different measurements for soil? Or he is surprised that people did? [different student groups were working with different soil samples during the science lesson]
Ms. Collins: He's surprised that about similar measurements for soil.
Colleague 2: Because the amount of space in between might differ. That's a pretty sophisticated thought.
Colleague 3: Yeah, I think that is, yeah, having the chunks, so maybe it gives it some more space, but-- well, and then you would expect that there be different amounts, like holes.
Colleague 1: Yeah, it wouldn't be uniform. It's not uniform.
Colleague 3: You could take a soil, sample of soil, and have it have different amounts of holes.
Colleague 1: I don't really know if their holes idea is really a misconception. I think, in fact, it's a strength that they understand that it's that empty space that's causing it to weigh less.
Ms. Collins: I guess now talking about it, I wish they would have said something about the sand, the thing that nobody…They're all fixated on the soil.

Informed by this analysis, the teachers discussed pedagogy connected to students’ science thinking, exploring strategies for redirecting the science discussion and for engaging students with counter-examples.

Colleague 1: So how could you redirect the conversation in that way [to discuss why sand was the heaviest] if that's where you wanted it to go? I guess that's the question.
Ms. Collins: Yeah, I guess we could start the next lesson by saying, you talked a lot about the soil last time. But no one addressed this idea of sand. So why do you think that weighs the most? Because they clearly know that the soil weighs the least and because--
Colleague 3: Well, once they put them on the weight line --
Colleague 2: From heaviest to lightest, you could say, oh, look the soil. The sand is the heaviest. It's way over here. Why?
Colleague 3: I want to bring it back to the liquid when you're having that conversation - if there aren't bubbles in the oil and bubbles in the water, so there are no holes. Why would there be any difference? It seems like a counter example. If they can talk about sand is more densely packed together than soil is, and that explains some difference between the two. And then go back to water-- Does it explain the whole difference? Hmm, so do you think that there's a difference in how tightly packed the oil is in a container compared to how tightly packed the water is? Now, I guess you'd have to have two samples in front of them without bubbles.

Additionally, connecting pedagogy to students’ science thinking, Ms. Collins recognized she had developed a better understanding of her students’ ideas and the missing pieces she needed to address:

I feel like (colleagues) helped a lot figuring out what the next thing should be, making me realize that [students] do know more than I maybe gave them credit for at the beginning, which I feel is just because I know them. But they do have a better understanding than I thought about this idea of the soil having those air pockets. I want them to connect it to why. Why is [soil] the lightest compared to the other three? I think that's the connection that I was missing.
In the exit interview, the teacher pointed to affordances of independent study of classroom video, namely the repeated opportunities to listen to and examine students’ ideas in relation to the learning goals, and to use the software and paper-based supports to inform video cases and discussions with colleagues:

I was able - when we watched [the video] together - to take notes. And then I feel like when I was at home, then I looked at those notes. And I found those points and watched what I wanted to again, based on our conversation first. So I really liked the way that was laid out [the paper-based discussion planner and study tools], to think about it and then be able to look back at - what were the [learning] objectives? What did I think [the students] were supposed to say versus what they actually said? And I think that helped, having watched it and taken just notes the first time, and then going into the software and really pinning things and taking things apart [referring to annotation tools]. I think once I did that it got a lot easier making the [video] cases.

She also emphasized affordances of collegial study occurring after the independent study, namely that diverse interpretations from colleagues helped her notice students’ thinking from a different perspective:

I feel when you watch it by yourself, you pick up on things. But I think it's also really helpful to have other people-- if you notice a problem or a misconception. I really liked being able to show somebody else. Because I feel when you sit there and watch it-- I feel sometimes I focus on such a small thing. And somebody else would get it, even when I'm questioning it. So I think it's helpful to talk with colleagues about the video, once you've seen it yourself.

Conclusions and implications
This case study is a first step in exploring how a blended PL model of independent study and collegial study, anchored in teachers’ own classroom video, can support them to notice their students’ thinking. The findings lend preliminary evidence that doing independent learning first, assisted by video analysis software and paper tools, allows teachers to engage deeply with their video, and to revisit their students’ thinking related to the learning goals. Teachers gain initial insights into their students’ thinking and generate questions to pursue in their practice. These insights prepare them for subsequent collegial learning which, in turn, enhances the initial sense-making. Diverse perspectives from colleagues broaden teachers’ understandings of their students’ thinking and inform their teaching. This study speaks to the ICLS 2018 theme of exploring technology-facilitated learning in the real world. The study reveals how a blended PL model, supported by video, software and paper supports can situate teachers’ learning in their own practice, help them develop greater awareness of their students’ thinking, and shape instruction. To further explore the potential of this model, future research will examine the learning of this and other teacher cohorts and compare the learning of teachers with varying professional experience in the cohorts.

References

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Designing an Educative Curriculum Embedded Within an Interactive Web-Based Platform to Facilitate Teacher Learning

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Abstract: Educative curricula are often considered as one potential vehicle to support changes in how students learn science in classrooms, especially for instruction currently not aligned with ambitious instructional reforms. Our work presents one such effort, focused on teachers as a community of learners. Using a design-based approach, we developed a web-based tool, iPlan, which provides online access to educative curriculum materials in an interactive learning platform. The purpose of this study is to examine design features of iPlan in terms of affordances and challenges. We examine an implementation in an integrated math-science curriculum unit. Through qualitative analysis of interviews with 13 high-school biology teachers across two cycles of design and testing, we identified the ways in which teachers used and learned from the iPlan tool; which features seem to work and why. The study provides implications for developing online learning environments for teachers.

Introduction

Science education has recently been the focus of ambitious instructional reforms in the United States. The Framework for K-12 Science Education (National Research Council, 2012) together with the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) emphasize in-depth development of core explanatory ideas and engagement in scientific and engineering practices. This will mean substantial instructional changes for many teachers (National Academies of Sciences, 2015). Well-designed, reform-based curriculum materials in science can be used to anchor discussions about efforts to put these reforms into practice and as tools to guide initial attempts in the classrooms (Schneider et al., 2005). Particularly, educative curricula—curriculum materials designed to address teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005)—can be leverage for large-scale instructional improvement. Moreover, given the scale of the need for the kind of complex learning called for in these ambitious reforms, another promising area for supporting teachers’ learning is online environments (Moon et al., 2014; National Academy of Sciences, 2015).

This paper presents an effort that was conducted for instructional improvement in biology classrooms by considering teachers as key players for successful implementation of reform-based curriculum that aims to address goals for student learning as envisioned in the NGSS. As part of this effort, educative curriculum materials that integrate biology and mathematics ideas within an engineering problem context were developed. The curriculum targeted key goals for students’ learning as defined in the NGSS, and was educative for teachers. They were situated in an online platform, iPlan, that creates a web-based community of learners among teachers implementing the reform-based curriculum materials. Our goal in this study is to uncover design features of iPlan in terms of affordances and challenges during the implementation of these curriculum materials. Specifically, we are interested in identifying specific design features of iPlan that were (or were not) taken up by teachers and the reasons for why. Consistently, this study aims to answer: (1) How did teachers use educative curriculum materials embedded in the designed online learning environment? (2) How did teachers use collaborative aspects of the online environment in which curriculum materials were embedded?

Theoretical framework

Among all different instruments for conveying reforms on a large scale, curriculum has the most direct effect on what teachers do in their classrooms, making curriculum a frequently used tool for reformers and policymakers to influence practice (Brown & Edelson, 2003). Curriculum is often transformed and goes on to influence students’ learning through teachers (Stein, Remillard & Smith, 2007). Therefore, curriculum materials should be developed by placing teachers’ learning at the center of these development efforts (Ball & Cohen, 1996).

There has been growing knowledge base about the design and use of educative curriculum materials. Davis and Krajcik (2005) proposed a set of design heuristics for educative curriculum materials that facilitated discussion about how curriculum materials support teachers’ learning. Designing curriculum materials that are written to speak to the teachers about the tasks and the ideas underlying them has also been emphasized (Remillard, 2000) because it is important to engage teachers in the ideas underlying curriculum designers’ decisions and suggestions. One consideration in the design of educative curriculum materials is how and what
teachers read, and where they focus (e.g., Beyer et al., 2009). These studies suggest that more needs to be done to understand what teachers focus on in the curriculum materials.

Educative curriculum materials could be more effective if they are used in conjunction with other forms of support for teachers (Davis & Krajcik, 2005). For example, in a study of three beginning teachers Forbes and Davis (2007) suggested the formation of materials-based teacher communities especially for beginning teachers who have little or no expertise in using particular curriculum materials. Davis and colleagues (2004) discuss design principles of one such design for new elementary science teachers.

Given the potential of the online learning environments for creating rich opportunities for teachers’ learning that are scalable and accessible to large numbers of teachers (National Academies of Sciences, 2015), we brought together educative curriculum materials and online learning environments in our design to facilitate science teachers’ learning. By doing so, this study stands out contributing to the limited knowledge base given the general focus on teachers as isolated learners in prior research on educative curriculum materials. In general, little research has examined online learning environments for teachers, especially science teachers (National Academies of Sciences, 2015).

Methods

Background and context

The study was situated within a project that focused on the design of scalable STEM units aimed to teach rigorous mathematics tied to big ideas in biology in high school science classrooms. We focused on the implementation of one of these units in Fall 2013 and Spring 2014. The curriculum that we focused on was a four-week genetics unit situated within a large design challenge for students to help an imaginary local zoo to develop a plan to breed rare geckos. The tasks in the unit were developed to help students to explore how genetic information is inherited and expressed. NGSS-based emphases on greater depth, connections to mathematics, and engagement in scientific practices were incorporated into the design of this four-week unit. The unit differs from traditional curriculum in inheritance in important ways, including its impact on students’ learning gains (Schuchardt & Schunn, 2016).

The design of the iPlan tool was grounded in design-based research (The Design-Based Research Collective, 2003). In Fall 2013, 3 high-school biology teachers voluntarily participated in the study. They used the iPlan tool during their implementation of the curriculum described above. Based on the feedback that they provided, iPlan was revised and was used again in Spring 2014 by another 10 teachers during their implementation of the same curriculum. We focused on a broad range of science classrooms with students that differ in their achievement levels and socio-economic status.

iPlan: Educative and interactive learning platform for teachers

iPlan tool is both a learning environment for teachers designed to support interactions among the teachers as well as a resource that provides access to educative curriculum materials. iPlan was designed to create a web-based community of users, thereby giving implementing teachers access to peer resources but also by locating expertise and knowledge-building in the participating teachers. The web community extends across space (geographical boundaries) and time (teachers can access discussions and implementation notes from others even if they are not implementing at exactly the same time).

Educative curriculum materials embedded in iPlan were designed to support teachers’ learning as they enact our reform-oriented curriculum materials. Representative set of the curriculum materials were analyzed for educative aspects using the criteria for educative quality by Beyer, Delgado, Davis, and Krajcik (2009). These analyses revealed that curriculum materials address all three domains of knowledge in Beyer et al.’s criteria: PCK for science topics, PCK for scientific inquiry, and teacher’s subject matter knowledge (Schuchardt et al., 2017). These analyses provided justification for the claims about the educative nature of the materials.

Table 1 provides features of iPlan designed to structure and support learning interactions among teachers as well as features of educative curriculum materials and structures built in iPlan to make these features visible for the teachers (also see Figure 1). The first three features focused on facilitating teachers’ learning through their implementation of the curriculum materials and also supporting them in making adaptations that were consistent with the intended learning goals. The latter two features focused on supporting teachers more broadly in productive adaptations (i.e., considering broader pragmatic and local context issues) and also leveraging distributed expertise to support curricular innovations.
Table 1: iPlan Design Features and Rationales

<table>
<thead>
<tr>
<th>Design Rationales</th>
<th>Structures and Functionalities Embedded in iPlan</th>
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<tbody>
<tr>
<td>Conceptually connected arc of tasks</td>
<td>Each task in the curriculum has a macro and micro view. The macro view clarifies the connections between tasks through two specific sections: “Why this task now?” situates the task within the larger unit; “Moving on from here” how it conceptually relates to the next tasks.</td>
</tr>
<tr>
<td>Modeling a vision for quality science teaching as emphasized in the NGSS</td>
<td>Micro view of each task makes clear the relevant NGSS practices and concepts involved completing the task. For example, “target” boxes indicate the core ideas that students should develop in the task; “important” boxes indicate why the teacher or students are suggested to do certain things during the implementation of the task.</td>
</tr>
<tr>
<td>Transparency of the designers’ intent</td>
<td>iPlan has tools and structures to bring teachers’ attention to “why” regarding the purposes and timing of recommended task components.</td>
</tr>
<tr>
<td>Locating expertise and knowledge-building in the participating teachers with an encouragement to share</td>
<td>iPlan provides space for teachers to take notes about the lesson implementation (e.g., lesson planning notes, reflection, modifications, reminders, etc.) and to share these notes with others.</td>
</tr>
<tr>
<td>Supporting learning interactions for knowledge-building</td>
<td>iPlan allows dialogue with other teachers and developers within discussion sections.</td>
</tr>
</tbody>
</table>

Data analysis and preliminary findings

Teachers were interviewed just after their implementation of the curriculum. Questions targeted the ways in which iPlan supported teachers’ implementation of the curriculum. For example, one of the questions was: Were there particular sections of the iPlan tool that helped you to understand not only what we wanted you to do but also the reason for why we recommended you to do certain things? We analyzed the interviews to find patterns in the aspects of the educative curriculum features that were (or not) found to be helpful by the teachers, the ways in which they used collaborative aspects of the curriculum materials, and why. Therefore, in our analysis our purpose was not only to identify what works but also why.

The analysis from the first round of data collection informed the revisions in the iPlan tool, which were quickly implemented before the second round of implementation/data collection with the second set of biology teachers (a given teacher covers this topic only once a year). In the first round, teachers were satisfied with having access to the curriculum materials online because they liked having everything organized in one place and easy to access from everywhere. They did not find the interactive features as useful. Some of their challenges informed the redesign (e.g., difficult to find earlier posts; not located in a visible space on the page). However, some of the reasons for not using these features were related to their issues of their current constraints (e.g., finding the time to write implementation notes).

The second-round interviews have already revealed that most of the teachers found the detailed guidance with designer intent information to be helpful. While some teachers found it helpful to read implementation notes posted by other teachers in the online platform, some stated that they did not find other teachers’ implementation notes as useful since other teachers’ classroom context seemed to be different than their own classroom context and student composition. Some of the teachers also expressed hesitation about posting in an online platform. These (preliminary) analyses have begun to reveal that teachers did not see the benefit or necessity of collaborating with other teachers virtually. Future analysis will examine the patterns for the reasons for why teachers did not choose to use interactive features of iPlan as intended by the designers.
Discussion
Given the recent ambitious instructional reforms and the scale of the need to successfully implement these reforms, designs for teacher learning that can reach out to more teachers in meaningful ways have gained more importance. Curriculum is often seen as a tool to influence practice on a large scale. Similarly, there has been a growing attention to online learning environments. In this study, we combined these features for teachers’ learning within a new tool, iPlan. This study will reveal key and effective design features of an online platform that supports enactment of NGSS-aligned curriculum materials.

Evidence base on the online programs designed to support teacher learning is not very robust (National Academy of Sciences, 2015). Moon and colleagues stated (2014), “as a field, we know little about how these web-enabled and social media capacities interact with teacher learning ... By connecting particular design elements to the theoretical basis for the design and to a set of research questions about that design, the important work of theory building for online PD, indeed PD more generally, can proceed.” (p. 175) Addressing this call, this study has the potential to contribute the knowledge base on teachers’ learning in online environments.

References
Brown, M., & Edelson, D. (2003). Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their changes in practice. (Design Brief). Evanston, IL: Center for Learning Technologies in Urban Schools.
Socio-Emotional Regulation in Knowledge Building Mediated by CSCL Reflection

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Abstract: There are few studies focused on supporting socio-emotional regulation in knowledge building contexts, so we designed a project-based learning environment that supports socio-emotional regulation. Fifty first-year university students participated in the project, using Knowledge Forum (KF) as a digital portfolio to collaboratively reflect on face-to-face activities. Metacognitive prompts were provided through KF’s scaffold function to facilitate reflection, especially on socio-emotional aspects. Our analyses revealed that not all students fully regulated socio-emotional challenges encountered through experiencing collaboration in the environment. Moreover, in the case studies, we found that students who attempted to maintain idea diversity to rise above the ideas of individual group members tended to resolve socio-emotional challenges, while others tried to proceed with tasks through avoiding both consolidating ideas and regulating socio-emotional challenges. These findings imply that in addition to socio-emotional supports, epistemic supports are necessary to facilitate socio-emotional regulation.

Keywords: idea improvement, idea diversity, rise above, socio-emotional regulation, computer-supported collaborative learning

Introduction
Incorporating the processes of knowledge-creating enterprises into education has been considered as a promising approach toward helping learners meet the emerging needs of the 21st-century economy (Griffin, McGraw, & Care, 2012). Through long efforts, knowledge building theory has come to describe what should be seeping into a community of learners to transform them into knowledge-creating organizations (e.g., Scardamalia, 2002). Knowledge building (KB) emphasizes learner autonomy and community self-organizing processes for creating knowledge that is of value to the community. Learners are encouraged to take ownership of their learning for sustainably improving ideas. Central activities in KB are idea generation, co-elaboration, and diversification, which improves the depth and breadth of generated ideas (Hong & Sullivan, 2009). Learners collaboratively develop, improve, and consolidate ideas to innovate more complex idea structures that remain available for subsequent use. Scardamalia (2002) listed 12 principles for guiding these knowledge-creating processes in classrooms. Closely related principles to the central activities are improvable ideas, idea diversity, and rise above. In KB, all ideas are treated as improvable and are surrounded by various other ideas, including contrasting ones. Knowledge-creating activities entail formulating higher-level problems through synthesizing new ideas that supplement weaknesses of competing ideas for further knowledge advancement. Therefore, facilitating sustainable idea improvement and maintaining idea diversity are essential for improving both the depth and breadth of ideas.

These collaborative idea-developing and idea-improving activities necessitate teamwork, which is an essential skill for success in a constantly changing world (Griffin et al., 2012). Nevertheless, recent studies (e.g., Näykki, Järvelä, Kirschner, & Järvenoja, 2014) reported that learners often fall into socio-emotional conflicts during idea co-elaboration and diversification processes. Learners fail to negotiate a fit between their ideas and those of other group members, resulting in abandoning idea diversity because such processes require learners to change their initial beliefs, thoughts, and opinions. Some learners try to overrule other members’ ideas, or disagreeably elaborate on other members’ ideas because they do not want to change their own. In such situations, supports for socio-emotional regulation are vital (Näykki et al., 2014). Because socio-emotional aspects of collaboration have been neglected for so long (Dillenbourg, Järvelä, & Fischer, 2009), few studies, especially in KB contexts, have researched developing supports for socio-emotional regulation and analyzing its effectiveness.

In this study, therefore, we attempted to design a computer-supported collaborative learning environment for supporting socio-emotional regulation and examined how students solved socio-emotional challenges. Knowledge Forum (KF; Scardamalia, 2002) was used as a digital portfolio where students collaboratively reflect on face-to-face project-based learning with an ill-structured task from the perspective of
teamwork. We provided metacognitive prompts through KF’s scaffold function to facilitate student reflection, especially on socio-emotional aspects. We assessed how students’ socio-emotional challenges emerge and how they resolve those challenges.

**Method**

**Design description**
Fifty first-year university students (22 female, 28 male) took a thirteen-week course for learning how to manage teamwork through participating in project-based learning. They were randomly divided into thirteen groups of four to five, then given the task of collaboratively applying data-science techniques to make innovative propositions for improving the city where the campus is located. Four mentors supported group activities and collected classroom observational data. Each week, students engaged in ninety-minute face-to-face sessions, then wrote their reflections on the regulatory processes on KF.

The project was mainly divided into three stages. In the first stage (weeks 1–4), students were expected to understand the basics of data-science techniques through co-constructing visualizations of restaurant data from four major Japanese cities, obtained from a restaurant guide website (https://tabelog.com/). Students were required to choose appropriate visualization methods and to adequately interpret visualizations. In the next stage (weeks 5–8), students identified problems to solve in the city where the campus is located. Students were also required to gather necessary data on their own and to illustrate and support their ideas through data visualization. Students then held a poster fair in week 9 to exchange ideas on the problems and subjects they identified. In the last stage (weeks 10–12), students co-invented propositions for improving the city based on the problems they identified in stage 2. Students were required to once again co-construct data visualizations that support their propositions. In week 13, students held a final poster fair.

During this project, we asked students to collaboratively keep public group progress notes on KF and to add individual reflections as public build-on notes each week after the ninety-minute face-to-face sessions (Figure 1). To support their reflections, especially regarding socio-emotional aspects, we used KF’s scaffold function to provide metacognitive prompts, based on the Adaptive Instrument for Regulation on Emotion (AIRE; Järvenoja, Volet, & Järvelä, 2013). Example prompts are “Did each member have different priorities toward the group task?,” “Did you find it difficult to create a collaborative atmosphere?,” “Did each member fully commit to the group task?,” and “Is there any disagreement among group members on ideas about how to conduct the group work?” AIRE focuses on assessing learner experiences of socio-emotional challenges by asking them to rate how well generic scenarios of socio-emotional challenges that Järvenoja et al. identified describe their experiences. We utilized those generic scenarios to develop the metacognitive prompts.

**Data collection and analysis**
In addition to the collected data on KF (group progress and individual reflection notes, mentor observations reported in private KF notes not visible to students), we also conducted free-response questionnaire surveys.
after the poster fairs on weeks 9 and 13 to examine socio-emotional challenges and regulation strategies that students applied during the project. In both questionnaire surveys, we asked students to individually describe how they engaged in group work (“Describe what did and did not go well in your group work. Also, describe how you or others further improved your group work.”). We also collected behavioral engagements in group activities using audio recorders.

In the first analysis step, we assessed the questionnaire responses to reveal the number of socio-emotional challenges that each student encountered and how many of them were regulated. We first counted socio-emotional challenges and regulation strategies reported in each response to the questionnaire. We then evaluated each reported regulation strategy for challenges that students experienced. For example, the description “I asked her politely to be cooperative” is a regulation strategy corresponding to “One member doesn’t fully commit to the group work,” which describes a socio-emotional challenge. At the end of the first analysis step, we counted by group the socio-emotional and challenges that were regulated, and then calculated the proportion of regulated challenges. In the second analysis step, we conducted case studies to further elucidate how students resolved socio-emotional challenges, or why they could not regulate unsolved socio-emotional challenges.

**Table 1: Number of socio-emotional challenges and proportion of regulated challenges by groups**

<table>
<thead>
<tr>
<th>Group ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of socio-emotional challenges</td>
<td>17</td>
<td>10</td>
<td>2</td>
<td>13</td>
<td>1</td>
<td>12</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Proportion of regulated challenges (%)</td>
<td>94</td>
<td>50</td>
<td>0</td>
<td>77</td>
<td>100</td>
<td>58</td>
<td>100</td>
<td>67</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

**Case studies: How socio-emotional challenges were regulated**

**Successful regulation of socio-emotional challenges**

Group A resolved socio-emotional challenges as expected. One group member (“A1”) did not actively participate in discussions at first, and was absent several times (e.g., “[A1] dozed off several times today,” from a mentor’s observation notes in week 6). Other members attempted to co-regulate her to participate in discussions, because they wanted to involve all members in the discussion (e.g., “[A1] seemed to not be good at discussion, so I helped her to discuss with us,” from a group member’s responses to the questionnaire in week 9). In week 13 they were able to present a proposition that included all members’ ideas.

**Unsuccessful regulation of socio-emotional challenges**

Contrary to expectations, group B did not resolve many socio-emotional challenges. The group had a member (“B1”), who was resistant to other members’ ideas. Until the poster fair in week 9, they were very concerned about the credibility of their identified city problems (“Progress is slow, though they are carefully considering backups,” from a mentor observation note in week 5). Due to time constraints, they decided to focus on B1’s idea (e.g., one group member said, “We shouldn’t make an incomplete presentation [in week 9],” from voice recordings in week 8). After week 9, B1 barely incorporated other member ideas, and members ended up just searching for data to support B1’s idea (e.g., “[B1] is strictly sticking to her idea,” from a mentor observation note in week 10). Consequently, they created a poster based on B1’s idea.

**Discussion**
This study aimed at designing a learning environment that supports socio-emotional regulation for accelerating collaborative idea development and improvement. We examine how students solved socio-emotional challenges in the environment. In the first analysis step, we found that not all of the students in our study successfully regulated socio-emotional challenges. We thus conducted further case studies of two groups to identify underlying factors describing why students successfully or unsuccessfully regulated socio-emotional challenges for future instructional design. Qualitative analysis revealed that a group that attempted to maintain idea diversity to rise above the ideas of individual group members regulated most challenges, because improving both the depth and breadth of ideas necessitates socio-emotional regulation. On the other hand, a group that tried to improve only the depth of ideas could not resolve socio-emotional challenges. Members of group B applied avoidance-focused strategies; in other words, they engaged in tasks without removing the source of socio-emotional challenges (Näykki et al., 2014). This may because improving only the depth of ideas is to some extent possible without resolving socio-emotional challenges. These findings suggest that in addition to socio-emotional supports, epistemic supports for broadening ideas, such as maintaining idea diversity and encouraging rise above, are essential to facilitating socio-emotional regulation.

There is room for further discussion. Since we provided metacognitive prompts not for supporting solutions to socio-emotional challenges but for student awareness of challenges, we could see that group B members did not express competencies for resolving challenges, whereas members of group A did. Moreover, we can interpret that it is necessary to support students in regulating socio-emotional challenges. To prepare students for the 21st-century economy, however, we must encourage students to be engaged in the self-organizing processes of a knowledge-creating community and let them “learn by doing.” We should thus find ways to induce students’ socio-emotional regulation. In future studies, therefore, we will adopt the jigsaw method (Miyake & Kirschner, 2014) as an epistemic support to further facilitate deeper and broader ideas by promoting co-elaboration and diversification processes.

To more rigorously test our discussion, we should first conduct further case studies of other groups. Although we highlighted two groups in which members encountered socio-emotional challenges, there were groups in which members experienced few socio-emotional challenges. More investigations are needed to confirm our findings. Second, we should assess students’ regulatory processes concerning specific metacognitive prompts through analyzing weekly KF notes. We expect that such analyses would further reveal that how the supported reflection worked and theoretically contribute to establishing generalizable findings to design learning environments. Lastly, although we qualitatively examined how students improved ideas in relation to socio-emotional regulation, to further elucidate links between regulation and collaborative idea improvement, we should also quantitatively analyze idea quality and how ideas are developed.

References

Acknowledgments
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“Choose Your Own Adventure”:
Responsive Curricular Choices in Elementary Science

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Abstract: The complexity and dynamism of learning raises important considerations about the role and design of curricula, and how teachers interact with curricula. In this study, we explored elementary teachers’ participation with a curricular mini-unit in science that invited them to choose among possible next steps, selecting experiments that would responsively build on student thinking. We coded 41 written segments of teachers’ reasoning about their selected next steps to document varied resources that teachers used in making curricular choices. In the vast majority of segments, we found that teachers drew on student ideas and interests as resources for determining next steps. We also identified four clusters of resources that represent different ways of interacting with students’ contributions, with implications for responsiveness, learning, and equity.

Keywords: teacher noticing and responsiveness, curriculum, elementary science, resources

Lines of scholarship across fields, including educational philosophy (e.g., Dewey, 1915/1966), psychology (e.g., Vygotsky, 1978), and the learning sciences (e.g., Rosebery, Ogonowski, DiSchino, & Warren, 2010), depict learning as a complex, dynamic process of situated meaning-making. Meanings that emerge through localized interactions of learners and environments may be patterned in some ways but are also often idiosyncratic (Hammer & Sikorski, 2015), as they emerge from the specific experiences, understandings, motivations, and contextual details in play.

Such complexity raises important issues about curricula and how curricula are used in and across classrooms. Curricula in which the content and sequence of lessons is fully prespecified, even in research-grounded ways, may not support the meaning that unfolds in a given classroom and the authentic engagement of learners in meaning-making (Dewey, 1938/1997). However, it would be untenable for teachers to create emergent curricula that are fully responsive to students’ contributions, both pragmatically and systemically as educational systems need shared foundations from which to build.

This paper explores teachers’ use of a curricular mini-unit that defines content to be learned but is highly adaptable to students’ hypotheses. As part of an elementary teacher professional learning experience in science, we designed a mini-unit of instruction with a “choose your own adventure” component, inviting teachers to choose among possible next steps based on what they noticed in student thinking (Sherin, Jacobs, & Philipp, 2011) and what might forward students’ meaning-making in relation to a focal scientific phenomenon. This invitation represented a substantial shift for teachers from “following” a scripted, activity-oriented science curriculum to “participation with” the mini-unit (Remillard, 2005). Thus, in this study, we ask the following exploratory question: How do elementary teachers employ varied resources (personal, social, conventional) in making responsive curricular choices in science? In particular, we attend to how and to what degree teachers worked with students’ ideas and questions as resources for curricular choices, given findings from studies of teacher noticing and responsiveness, which we turn to next.

Conceptual framework

Teacher noticing and responsiveness
A growing body of research attends to the ways in which teachers notice and are responsive to student thinking, in support of meaning-making (e.g., Robertson, Scherr, & Hammer, 2016; Sherin, Jacobs, & Philipp, 2011). While studies show that teachers can notice and respond to student thinking in practice from early in their careers, they also highlight substantial variability in teachers’ practices of doing so as systems of schooling commonly draw attention elsewhere (Sherin & van Es, 2009; Thompson, Windschitl, & Braaten, 2013). Further, responding in ways that actively build on students’ contributions and advance learning can be especially challenging (Harris, Phillips, & Penuel, 2012). These findings suggest that a critical area to both understand and support is teachers’ determination of next steps that build on the work students have started within their classrooms.
Resources in and for instruction
To explore how teachers determine next steps in this study, we draw on the construct of resources and their situated use in instructional contexts (Cohen, Raudenbush, & Ball, 2002; Stroupe, 2016). Defined as “physical and intellectual commodities that teachers use” (Stroupe, p. 51) to inform and shape their practice, resources may be wide-ranging and include things like teachers’ own instructional aims and knowledge (what Cohen et al. refer to as “personal” resources), ideas and expectations from colleagues and broader institutions (“social” resources), and more “conventional” resources like materials or time. Investigating which resources teachers recruit or recognize and how they coordinate such resources enables us to develop multifaceted, situated accounts of teachers’ curricular choices, with particular attention to how teachers work with students’ contributions as influential social resources in conjunction with other resources.

Study context
Data for the study come from K-2 teachers’ participation in a blended (partly in-person, partly online) Learning Lab on scientific modeling with young students. We organized the Lab around a four-lesson mini-unit in which students create and revise scientific models of why a puddle on the grass disappears over time. For Lesson 3 in the mini-unit, we provide multiple options for experiments that teachers may choose among, with tables highlighting how particular experiments may address common questions or support specific conceptual insights; teachers may also devise their own approach to forward students’ meaning-making. We collaboratively examine students’ models from teachers’ classrooms as part of the Lab as well and consider implications for Lesson 3.

Data and methodology
We focused on online reflective posts as our primary data source, in which teachers were asked to share artifacts, insights about student thinking, and instructional considerations that arose as they taught the mini-unit. Specifically, we examined K-2 teachers’ posts about Lessons 2 and 3 in the mini-unit for explicit reasoning related to next steps and selected segments in which such reasoning was evident (e.g., “I chose to do the How Does Water Soak Into The Ground experiment because…”). This selection process garnered 41 selected segments across 28 teachers.

To characterize the resources teachers employed in making curricular choices, we engaged in multiple rounds of inductive coding and refinement (Corbin & Strauss, 2008), guided conceptually by Cohen et al.’s (2002) broad categories of personal, social, and conventional resources. This iterative process resulted in the preliminary scheme depicted in Table 1, which we used to code all selected segments. Segments were given multiple codes (e.g., “Deepening understanding” and “Adding ideas”) if evident in the teacher’s reasoning.

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal</td>
<td>Deepening understanding</td>
<td>Describes aim of extending student understanding of processes, how and why things occur</td>
</tr>
<tr>
<td></td>
<td>Clarifying concepts</td>
<td>Describes aim of clarifying student understanding of particular concepts</td>
</tr>
<tr>
<td></td>
<td>Testing ideas</td>
<td>Describes aim of testing or “proving” student ideas</td>
</tr>
<tr>
<td></td>
<td>Exploring ideas</td>
<td>Describes aim of exploring or investigating student ideas</td>
</tr>
<tr>
<td></td>
<td>Adding ideas</td>
<td>Describes aim of adding ideas that students have not considered</td>
</tr>
<tr>
<td></td>
<td>Inclusiveness</td>
<td>Describes aim of addressing multiple ideas or contributions</td>
</tr>
<tr>
<td></td>
<td>Expansive content knowledge</td>
<td>Uses content understanding beyond that built into unit</td>
</tr>
<tr>
<td>Social</td>
<td>Student ideas</td>
<td>Cites specific ideas students raise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Subcodes include common, less common, and individual)</td>
</tr>
<tr>
<td></td>
<td>Student interests</td>
<td>Cites what students are focused on or want to pursue</td>
</tr>
<tr>
<td></td>
<td>Missing components</td>
<td>Notes what is missing from students (e.g., particular ideas, deeper understandings of how or why things occur)</td>
</tr>
<tr>
<td></td>
<td>Colleagues’ contributions</td>
<td>Cites discussions with or feedback from colleagues</td>
</tr>
<tr>
<td>Conventional</td>
<td>Classroom artifacts</td>
<td>Cites artifacts like class model</td>
</tr>
<tr>
<td></td>
<td>“Zoom-in”</td>
<td>Mentions “zoom-in” (a way to show unobservables on models)</td>
</tr>
<tr>
<td></td>
<td>External materials</td>
<td>Describes use of materials or supplies beyond that built into unit</td>
</tr>
<tr>
<td></td>
<td>Logistics</td>
<td>Discusses feasibility or time</td>
</tr>
</tbody>
</table>
Findings

Overall trends in resource use across segments
In terms of our focus on working with student contributions as resources for curricular choices, a notable trend is that 27 (of 41) segments explicitly referred to student ideas in discussing next steps (e.g., “[student] posed the idea that heat causes evaporation, after disagreeing with the picture of a magnet next to the sun, saying it can’t pull the water… we developed ideas about how to investigate the claim”). Seven additional segments referred to student interests, including directions students wanted to pursue or questions they had. Taken together, this means that 83% of segments cited students’ contributions as social resources in play.

Other overall trends included infrequent citing of colleagues’ contributions (5 segments, 12%) and logistics considerations (4 segments, 10%).

Clusters represent different ways of interacting with students’ contributions
Additionally, we saw that some resources tended to cluster together. Looking across our coding, we identified four patterns that seemed to represent different ways of working with students’ contributions, with different implications for curricular choices.

Cluster 1: Exploring what students are interested in (10 segments)
Segments in this cluster described exploring or investigating student interests or ideas, including questions that students raised. Frequent codes included exploring ideas (personal), student ideas and student interests (social), and classroom artifacts (conventional). The example below shows what the reasoning in this cluster sounded like, as a teacher considered how to move forward in relation to the class’s model (which had multiple numbered ideas):

In terms of what kids would like to do, the most popular ideas are number 4, looking at how does the sun dry the puddle or what happens there. The other one is how the roots drink the water… And so I’m just going to think a little bit about which one seems to make the most sense to be able to do in class.

In this segment, the teacher cited specific ideas students would like to pursue from the model and indicated that she planned to explore one of the proposed ideas. A common consideration was which ideas were most “popular” or “interesting” among students.

Cluster 2: Deepening students’ understanding of ideas (7 segments)
A different cluster emphasized deepening students’ understanding of the processes and causes underlying the ideas they raised, combining codes for deepening understanding and expansive content knowledge (personal), student ideas and missing components (social), and several conventional resources, including zoom-ins. In such segments, teachers tended to identify both an idea students raised (e.g., “my group talked about the water could have ‘went underground’ and ‘soaked into the grass’”) and a way the idea could be pressed deeper (e.g., “they weren’t quite sure why or how”), describing their selected next step as a way to deepen understanding. Teachers exhibiting this reasoning often selected experiments that provided observable evidence of how processes occurred.

Cluster 3: Clarifying common and/or individual (mis)understandings (6 segments)
The clarifying (mis)understandings cluster focused on specific ideas from students that teachers felt required clarification or rectification. Here, the emphasis was not on missing components as above, but rather on clarifying concepts (personal) in relation to common and/or individual student ideas (social) as seen in the following example: “Many replied that the sun was most like the sponge because it ‘sucks the water up.’ We need to clarify the evaporation process, so I plan to do the kettle experiment.”

Cluster 4: Inclusively pursuing multiple ideas (5 segments)
Finally, several segments depicted teachers planning to do several experiments to address multiple ideas in play in their classrooms, including less common ideas. Codes here included inclusiveness (personal), student ideas and student interests (social), and external materials (conventional) as teachers sought to support additional ideas (e.g., “I think I’m going to try to find information about storm water management for ‘the water goes into the drain’”).
Discussion

While we know that teachers frequently make curricular choices or adaptations in practice, we know less about the varied resources they draw on in doing so and how the dynamics change when they are explicitly invited to do so in relation to student meaning-making. This study contributes to our growing understanding of how teachers may “participate with” curricula (Remillard, 2005) and make responsive choices in science teaching.

We found that teachers drew on students’ contributions as resources for curricular choices across 83% of coded segments—a high proportion, given the variability seen in teachers’ attention in prior studies when they were asked to focus on student thinking (e.g., Sherin & van Es, 2009). This finding sparks questions of why. For instance, one conjecture is that the Lab’s focus on scientific modeling, and specifically the notion of students as creators and editors of models over time, provided a cohesive context or frame within which to build on student thinking. Moving forward, we intend to explore this conjecture as well as whether particular curricular supports or Lab activities were especially useful for teachers, which can inform the design of future professional learning opportunities.

Additionally, this study identified four primary ways that teachers worked with students’ contributions in determining instructional next steps. While one of the identified clusters (Cluster 3, clarifying (mis)understandings) reflects a more traditional emphasis on correcting students’ ideas, the other three clusters represent different approaches to responsively building on students’ contributions. However, we believe that the approaches may have diverse affordances for advancing particular forms of learning (Harris, Phillips, & Penuel, 2012) and equity across perspectives and participants in the classroom community. For example, Cluster 2’s emphasis on deepening understanding may advance students’ learning of the hows and whys of specific processes, but may also limit how many and whose ideas are elevated for consideration. Future studies could explore the prevalence and fluidity of these approaches to being responsive to student thinking and their implications for learning and equity.

Endnotes

(1) We recognize that varied kinds of content knowledge are likely involved in teachers’ choices, but such resources are largely tacit or underdetermined in their posts. Here, we highlight use of “expansive” content knowledge that clearly extends beyond content discussed in the curriculum.

References


Math: It’s Not What You “Think”

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Abstract: This paper presents an emerging pedagogical approach for implementing critical mathematics. I describe a specific tactic for teaching mathematics: to avoid using the word “thinking.” This approach is informed by scholarship on race, critical mathematics, and embodied cognition. I argue that using the term “thinking” is not necessary for facilitating authentic learning experiences. Moreover, this tactic disrupts a number of pernicious historical narratives (i.e., stereotypes) about mathematics education and about who can and who cannot do mathematics. The crux of the paper is that avoiding the word “thinking”—and other terms associated with “smartness”—loosens the grip Cartesian epistemology has on mathematics education by shifting classroom discourse away from math-as-thinking to math-as-action, which may, in turn, create stronger opportunities for learning. From a learning-sciences perspective, I present other hypotheses stemming out of this pedagogical approach that warrant further research.

Keywords: Cartesian dualism, embodied cognition, equity, mathematics learning, race

“Who thinks that they could explain their thinking for question one?”
– Deborah Ball to her fifth-Grade math class

“You should have those five Gauss-Markov assumptions sort of... in your head.”
– Statistics professor to his graduate students

“There is no right or wrong answer. We’re only interested in your thinking. ... You’ve done a fantastic job of explaining your thinking!”
– Mathematics education researcher to a middle school student

“What do you think?”
– Everyone

Introduction and objectives

Thinking and related phrases, such as What do you think?, are ubiquitous in secondary math classrooms (Herbel-Eisenmann, Wagner, & Cortes, 2010). They are assumed to be pedagogically neutral or positive. This paper is part of my ongoing research that challenges and problematizes this assumption.

Focusing on “thinking” and related notions like abstraction and manipulating symbols has the potential to overlook other authentic forms of knowing in mathematics. In a previous study (Gutiérrez, 2015), I conducted a year-long participatory ethnography of a secondary math class. I focused my analysis on Mr. Matthew Lam, a teacher who believed that “math=thinking=liberation.” He repeatedly presented this metaphorical “equation” to his class, and its underlying logic appeared to guide his instructional decisions. One of Mr. Lam’s primary pedagogical objectives was to support student thinking—critical thinking in particular. He associated certain types of mathematical thinking (e.g., generalization) with the ability to “see,” “critique,” and “understanding systems,” which is something that he sought to foster in his students as part of his social justice pedagogy (Gutiérrez, 2015). That said, what Mr. Lam called mathematical “thinking” emphasized “abstractions” that involve “letters.” In his instruction, Mr. Lam occasionally conflated mathematical reasoning with using symbols. This negatively influenced his students’ agency, because it overlooked other authentic forms of knowledge and knowing that did not rely on “abstraction” or manipulating symbols as evidence of mathematical “thinking.” For instance, some students constructed generalizations using an array of semiotic resources such as verbal speech, rhythm, gesture, repetition, and non-conventional notations that were never sanctioned by the teacher (Author, 2016). If students’ emergent ways of knowing and different forms of knowledge go unrecognized, this can lead to distorted notions of what counts as mathematics.

Mr. Lam’s expressed belief that “math=thinking” is not unusual. In a linguistic analysis of 148 classroom transcripts involving eight different math teachers in a variety of school contexts, Herbel-Eisenmann, Wagner, & Cortes (2010) reported that the second most frequent group of words found in their data was What do you think. This particular phrase, which they refer to as a “lexical bundle,” had 198 instances spread across 8
classrooms. (The most frequent bundle was a directive, *I want you to*, which had 333 instances spread across those same 8 classrooms). These findings indicate that notions of math-as-thinking are quite common in classroom discourse. The objectives of this paper are: (1) to argue that this hidden aspect of mathematics education is not just a semantic issue but a substantial point that could have a tremendous impact on student learning; (2) to describe a specific tactic for teaching mathematics: avoid using the word “thinking” when working directly with youth in mathematical contexts; and (3) to present a series of hypotheses stemming out of this pedagogical approach that warrant further research.

**The Cartesian Grip on mathematics education**

The use of the term “thinking” is not necessary for facilitating authentic learning experiences and fostering conceptual understanding. On the contrary, the constant use of this term in classroom discourse reinforces a Cartesian mind-body dualism (1) that interferes with learning mathematics (cf. Cook & Brown, 1999), as in the case of Mr. Lam and his students (Gutiérrez, 2016). Functioning just under the radar, the Cartesian view of mathematics privileges knowledge “possessed” or “acquired” by the individual over group participation and social practice (cf. Sfard, 1998), which severely underestimates the importance of social interaction in conceptual learning (Radford, 2003; Sfard, 2007; Vygotsky, 1978). Cartesian dualism also promotes stereotypical notions of mathematics based primarily on analytic, decontextualized reasoning which, in turn, promote false notions of mathematics education as an acultural and ahistorical enterprise. Critical educational scholars have repeatedly argued against the idea of mathematics education as politically neutral because it ignores the structural dimensions in the organization of learning (Nasir, Hand, & Taylor, 2008; Valero & Zevenbergen, 2004).

To clarify, this paper does not argue that thinking is absent during mathematical activity or problem solving. What I am arguing, is that there are social-historical narratives that equate mathematics to thinking (i.e., “math=thinking”). Moreover, these narratives posit that pure thinking (i.e., mental activity that is disconnected from perceptual or bodily activity) is what drives mathematical discovery and therefore learning. The Cartesian view of mathematics reproduces a stereotype of mathematics as tantamount to pure thinking. Math learning is believed to be mostly an “amodal” phenomenon, a way of reflecting on the world that begins and ends “in the head.” The process of mathematical problem solving is to “think about stuff,” and the final products that result from that “pure mental activity” are other clearer/logical/cogent ways of thinking. An exclusive focus on math-as-thinking ignores the fundamental roles that the human body, action, discourse, and signs play in mathematics learning (Abrahamson & Trninic, 2015; Alibali & Nathan, 2012; Nemirovsky, 2003; Wertsch, 1998).

Furthermore, this problematic stereotype of math-as-thinking is fundamentally linked to another socially constructed narrative: math-as-intelligence. Through the prism of Cartesian epistemology, mathematical ability is often seen as an index of general intelligence, rather than simply the development of skill or competence within certain genres of semiotic activity. In their analysis of race and mathematical practices, Shah and Leonardo (2017) further unpack the notion of math-as-intelligence and point to one of its limitations:

> The practice of doing school mathematics in the U.S. context is associated with a particular set of meanings. Mathematics is typically viewed as the most difficult of all subjects; only the elite few are thought to possess the innate capacity to understand mathematics (Schoenfeld, 2002). Perhaps as a result, mathematical ability and intellectual capacity are believed to go hand in hand (Ernest, 1991). And because mathematical ability is viewed as innate, it tends not to be seen as something that can develop through concerted effort over time. (p. 60)

In sum, the deployment of the word “thinking,” explicitly in mathematical contexts, functions as an insidious vessel that laces everyday classroom discourse with Cartesian epistemology. In turn, classroom discourse that subscribes to Cartesian precepts overlaps with racial-mathematical discourse (Shah, 2017; Shah & Leonardo, 2017) that serves to create a “racial hierarchy of mathematical ability” (Martin, qtd. in Shah, 2017, p. 11). (2)

**Mathematics education research as complicit with the math-as-thinking regime**

Through the use of everyday terms such as “thinking,” Cartesian dualism is “baked into” the everyday language of mathematics education. This results in the reproduction of hierarchical category systems and phraseologies related to both mathematical ability and intelligence (e.g., “fast” versus “slow kids”; “advanced” versus “below basic” courses; and “failure” versus “success” with problem-solving) that have pernicious effects on learning and student identity (Horn, 2007; Larnell, Boston, & Bragelman, 2014; Ruthven, 1987). Furthermore, the implications of these hierarchies extend beyond the classroom. I maintain that constructs stemming from the research world—such as “grit,” “smartness,” and “resilience”—are actually derivative of Cartesian dualism.
Whereas certain research constructs are intended to be useful tools for investigating and improving mathematics education, they in fact “tighten” the grip and delimit opportunities for learning, because these, too, are relational constructs (Shah, 2017) based on “differences” that have been demarcated, historically, along racial lines. Therefore, these constructs, although believed to describe “objective” properties of individual students so as to identify leverage points to bolster “smartness,” for example (Leonardo & Broderick, 2011), instead serve to reproduce and strengthen the racial–mathematical hierarchy due to the tight, three-way link between mathematical ability, intelligence, and race.

Future research

To loosen the Cartesian grip on mathematics education, I suggest eliminating certain types of statements during classroom discourse (see Table 1). I hypothesize that students would respond differently to prompting strategies that emphasize action and perception (cf. Abrahamson, 2012). A set of specific hypotheses stem from this approach (Table 2), which future research can explore in laboratory settings or classroom contexts, or both.

Table 1: Two different prompting strategies

<table>
<thead>
<tr>
<th>Avoid these prompts:</th>
<th>Use these instead, focus on perception and action:</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>What do you think?</em></td>
<td><em>What do you see?</em> (Alt: <em>What do you notice?</em>)</td>
</tr>
<tr>
<td><em>How are you thinking about that?</em></td>
<td><em>How are you seeing that?</em></td>
</tr>
<tr>
<td><em>Can you explain your thinking?</em></td>
<td>*Can you show/ explain what you did?</td>
</tr>
<tr>
<td><em>How do you think THIS is related to THAT?</em></td>
<td>*How is THIS related to THAT?</td>
</tr>
</tbody>
</table>

Statements such as those in the left column of Table 1, above, reify Cartesian epistemology and stereotyped notions of mathematics that ignore the bodily activity. Statements from the right column (along with other discursive action such as gesturing, body movement, and voice prosody) shift the attention to perceptual and sensory-motor action that can provide the substrate for conceptual learning. Avoiding explicit mention of thinking in classroom discourse, and instead drawing on other semiotic and embodied measures, can shift the discourse away from math-as-thinking to math-as-action, which creates more robust opportunities to learn (Abrahamson & Trninic, 2015; Alibali & Nathan, 2012; Nemirovsky, 2003).

Table 2: Hypotheses to be explored

<table>
<thead>
<tr>
<th>Hypothesis:</th>
<th>Suggested study and research questions (“RQ”):</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Avoiding “thinking,” as a primary prompting or questioning strategy, will elicit different responses from learners.</td>
<td>Controlled laboratory study. Conduct basic experiments that explore and compare the types of mathematical statements and strategies elicited by math-as-thinking versus math-as-action prompts in a structured setting. Example RQ: Do “thinking” and/or non-“thinking” prompts support the construction of mathematical generalizations?</td>
</tr>
<tr>
<td>2. For teachers or instructors of mathematics, avoiding “thinking” will lower the threshold to gesture (cf. Kelly, Byrne, &amp; Holler, 2011), possibly improving communication with learners.</td>
<td>Classroom-based study: conduct case studies of teachers’ initial attempts to use this tactic. Example RQ’s: Do teachers gesture more? Do they gesture differently? What is the nature of the referents indicated by their gesturing actions? Is the conceptual space (in terms of these referents) expanded as a result of this tactic?</td>
</tr>
</tbody>
</table>
| 3. “Loosening the Cartesian grip” is a useful theme for pre-service teacher training programs as well as continuing professional development programs. Teachers can engage in discussion of, as well as explore in their own practice, a variety of discourse strategies whose affordances for teaching/learning are well-documented. | Teaching and teacher education study. Example RQ: How can we support teacher learning of different instructional models, orientations, and tactics? A few examples include:  
  • “Professional perception” of mathematical objects and processes (Goodwin, 1994; Stevens & Hall, 1998)  
  • “Revoicing to position” (see Enyedy et al., 2008)  
  • Designing instructional gestures (see, e.g., Alibali et al., 2013)  
  • “Action before concept” (Trninic & Abrahamson, 2013) |

Concluding remarks
In general, teachers and instructors of mathematics interested in implementing this approach might find it challenging to make this shift in discourse. That said, avoiding “thinking” can bring about not only a superficial linguistic shift, but can actually spur a shift at the level of deep semiotic-cognitive structure, and thus expand a teacher’s communicative means of instruction, including bodily activity. This constraint on what a teacher does (or does not say) can induce critical reflection on what exactly is being communicated and how it’s being communicated, in situ, regarding constituent elements in a given problem space. This approach has the potential to introduce precision not only in terms of general language-use, but also in the moment-to-moment multimodal micro-practices that engender shared meaning-making and conceptual learning. Over time, a classroom culture based on this approach could enhance both the teacher’s and students’ semiotic means of objectification of mathematical objects, structures, and generalizations (Gutiérrez, 2013, 2016; Radford, 2003).

Endnotes

(1) Cartesian epistemology is a branch of philosophy attributed to René Descartes and his study of knowledge. Cartesian dualism refers to his concept of the mind and the body as two completely different types of substances (immaterial vs. material) that interact.

(2) Danny Martin proposes that this hierarchy is one in which “students who are identified as Asian and White are placed at the top, and students identified as African American, Native American, and Latino are assigned to the bottom” (qtd. in Shah, 2017, pg. 11).

References


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Acceptance and Refusal:
Examining Conflicting Goals Within Co-Design

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Abstract: This case study examines a small co-design team within a larger multi-year design-based implementation research (DBIR) project. During the 2015-2016 school year, a group of teachers and researchers collaboratively designed and piloted four English language arts (ELA) project-based learning (PBL) curricular units. Teachers and researchers split into four teams, one of which was tasked with designing a project that examined relationships between humans and technology. Throughout this team’s design process, co-designers encountered moments of tension that led to increased productivity; however, these tensions also pointed to the ways that participants struggled to navigate multiple roles and goals in agentic ways. This study uses Wertsch’s (1991) notion of mediated action to examine the ways that designed curricular objects mediate co-designers’ multiple roles (Penuel et al., 2015) and connected goals.

Keywords: Co-design, Curriculum Design, English Language Arts, Project-Based Learning

Introduction
Collaborative design (co-design) has roots in participatory design, a process through which researchers and designers team with users to develop products that solve specific problems, giving attention to details with an intention of promoting change (Latour, 2008; Voogt et al., 2015). Education researchers have adopted participatory design tenets to promote the inclusion of practitioners in the development of research and curriculum (Penuel et al., 2007). While educational research often points to the ways that co-design can empower teachers by shifting practice and offering space for acknowledged agency (Leary et al., 2016; Severance et al., 2016), more research is needed to establish understandings of the roles co-designers perform, the multiple goals attached to each of those roles, and the ways that acceptance and refusal of designed objects can demonstrate agency.

During the 2015-2016 school year, nearly 25 teachers and researchers began a project to collaboratively design a 9th grade English language arts (ELA) project-based learning (PBL) curriculum. In this paper, I examine the ways that curricular objects mediated co-designers’ multiple roles (Penuel et al., 2015) and goals, sometimes leading to tensions around the acceptance or refusal of prototypes during the iterative design process. Analyzing data from a small team of co-designers, I explore the ways that these tensions may hold implications for the development of co-designed projects. I ask the following research questions:

- How do individual designers illustrate and articulate their roles within a small co-design team?
- In what ways do designers’ acceptance or refusal of designed objects reflect agency in navigating their roles and connected goals within co-design?

Related works
This paper draws upon sociocultural approaches to learning and goal setting as mediated action (Wertsch, 1991), as well as conceptions of co-design that center collaborators as agentic actors within communities of practice (Lave & Wenger, 1991). In co-design teams, members play multiple roles in order to navigate the complexities of iterative design (Design-Based Research Collective, 2003).

In this study, co-designers described playing a number of simultaneous roles (e.g., teacher, parent, designer, researcher, coach), each of which intersected with multiple goals that were determined by different stakeholders (e.g., individual co-designers, districts and administrators, researcher agendas, and project funders). Designed curricular objects served as artifacts that mediated action (Wertsch, 1991) around participants’ roles and goals. Co-designers’ creation, adoption, adaptation, and refusal of artifacts, both within design meetings and during classroom-based implementation, uncovered some of the ways that individual designers navigated between their many roles to pursue oft-contradictory project, district, and individual goals. Tensions appeared to arise when these multiple goals intersected with co-design practices that thrust participants into boundary practices (Penuel et al., 2015) and led them to accept or refuse the co-designed objects and activities.

Research context and methods
In the summer of 2015, primary investigators met with funders to develop goals for creating a 9th grade ELA curriculum that would incorporate social-emotional learning (SEL) and universal design for learning (UDL) principles into a project-based learning (PBL) context. In August of that year, a team of 14 teachers and 11 researchers held a design institute to create shared understandings of PBL, SEL, and UDL and to develop initial ideas around four curricular themes. These themes were situated under the umbrella concept “Composing Our World,” and included heroism, change, place-based literacy, and technology. From this initial meeting, small design teams formed around each of the four project themes, though the larger project team continued to meet every other month to offer professional development and refine shared goals.

Teachers chose the theme they were most interested in pursuing. Four 9th grade teachers from three schools in two districts collaborated with three university-based researchers (two graduate research assistants and one primary investigator) to co-design the Singularity project. We began with Kurzweil’s (2005) technological Singularity—when technology outpaces human intelligence—and designed toward goals of humanizing students within classroom spaces, while incorporating design criteria and ELA objectives developed by other stakeholders.

The researchers on this team each had experience teaching 9th grade ELA and had worked in teacher education. The teachers had varying degrees of experience in the classroom. Lisa (all participant names are pseudonyms), beginning her second year of teaching at a new Core Knowledge charter school, identified as a novice teacher, “entering the project to learn from others.” Maria, who taught at West High School, had been teaching for six years and frequently referred to her own expertise in the classroom, as did James, who was a third-year teacher at Ridgeview High School. Though Elizabeth had ten years of ELA classroom experience at West High School and was the most experienced teacher on our team, she never claimed expertise, instead referring to herself as practicing.

The Singularity team met monthly during the fall 2015 semester to plan the project that teachers would pilot in the spring of 2016. As designers collaborated and began to define roles, individual, district, and project goals emerged, causing tensions common within the co-design process (Potvin et al., in press; Penuel et al., 2015).

Data sources
This study draws from design-based research (Cobb et al., 2003) to examine the ways that participants understood their role within co-design during the first year of a long-term co-design project. The data used for this analysis was primarily from the Singularity team meetings, classroom observations, and interviews; however, interviews with PIs and field notes from whole-project meetings were also included as data sources. For nine months, researchers conducted eight individual interviews with teachers, and collected field notes and audio recordings during more than 20 classroom visits and 16 design meetings. Additionally, the author conducted interviews with teachers and four researcher co-designers from the larger team to better understand participants’ views of their individual roles and connected goals within the co-design process.

As a member of the co-design team, my role was that of participant observer (Spradley, 1980). I analyzed data sources using first-cycle and deductive coding to identify data that revealed the ways that participants approached co-design, and inductive coding to remain open to emerging analysis of participants ideas of roles and goals (Miles, Huberman, & Saldana, 2014). During second and third-cycle coding, I sought out patterns, writing analytic memos to make sense of critical moments and grouping representative examples into themes.

Findings
In this study, co-designers entered the design process with multiple goals that were determined by their roles within districts, outside of school in personal contexts, and as designers for the Compose Our World project. For example, teacher co-designers were at once expected to play the role of designer with the goal of piloting tenets of PBL in their classrooms, while also adhering to district expectations for teaching ELA skills in traditional ways. Drawing upon research that acknowledges the inherent tensions in co-design when designers attempt to navigate multiple roles (Potvin et al., in press; Penuel et al., 2015), this study sought to understand how individuals navigate various roles and goals through the refusal or acceptance of curriculum.

Understanding intersecting roles and goals in a small co-design team
Co-designers worked to acknowledge that establishing community can be tenuous because participants enter with varying backgrounds (Penuel et al., 2015). Researchers made efforts to position teachers as agentic experts by providing opportunities for choice in small design teams and by collaboratively developing design norms. Within the Singularity team, participants initially discussed co-design as a democratic process.

Despite the expectations of researchers that teachers would take the lead as designers in developing flexible projects that could be supported in a variety of contexts and with a variety of content and standards, the four teachers on the Singularity team each established different goals for themselves as co-designers. Lisa and
Maria consistently returned to district mandates during the design process, often expressing frustration that the project was “not focused on standards.” At different points, they each refused the co-designed curriculum rather than adapting it to meet their classroom needs. In contrast, Elizabeth stated that she was comfortable piloting new ideas in her classroom. She self-identified as a “social justice educator” and wrote that she joined the co-design project because she was interested in providing students with “opportunities to build relationships.” Elizabeth consistently adapted and changed the co-designed curriculum to use ELA content that she felt would best “reflect students.” James explained that his goal was to “dive into something new” with his students. In an interview, he described seeing himself as a “leader within the [co-design] group,” as well as the person “most comfortable with chaos” in implementing something “not quite finished.” While James taught very little traditional content in our observations, he implemented the Singularity project with the most fidelity.

Team meetings illustrated the ways that both project and individual goals were expected to be met when teachers shared the role of designer. While the researchers attempted to recruit teachers to lead portions of these meetings, teachers frequently expressed hesitation. Analysis of audio recordings showed that though teachers were willing to guide meetings toward classroom problems of practice, most expressed reticence to take on roles that would require time spent designing or collaborating outside of monthly meetings. In an interview, Lisa explained that though her initial goal in joining the project had been to participate in “develop[ing] stronger curriculum,” she hesitated to lead design because she was concerned about “burnout.” Lisa also reflected that while she appreciated the activities presented in meetings, she needed “to reinstate more self-care” rather than taking on additional responsibilities. The goals Lisa had as a teacher, a co-designer, and a person outside of school conflicted and caused her to feel tension in choosing between herself and her work.

Although researchers were initially perplexed by the perceived hesitancy of teachers to prototype curricular activities—one email correspondence between researchers questioned how to “transfer ownership” of the project—researchers ultimately adopted the role of lead designers, bringing prototypes to the group for feedback. While we expected teachers to embrace leadership roles if explicit attention was given to democratizing the co-design process (Voogt et al., 2015), teachers on this team struggled to navigate between various goals when their multiple roles were at odds with one another. As Lisa’s correspondence illustrates, her goals for protecting personal time and space, creating new curricula, and upholding school requirements conflicted.

**Acceptance and refusal in co-design**

Of the four teachers on the Singularity team, Elizabeth and James actively piloted the project in their classrooms. Maria took up some of the activities, but refused others, and Lisa left the co-design team, explaining that she was feeling “overwhelmed” and could not see how to “make the project work.” If curriculum objects are seen as mediating action (Wertsch, 1991), then the acceptance and/or refusal of these objects can help us understand the ways that the co-designers on this team navigated between (and asserted agency within) their multiple roles.

Elizabeth was the only teacher to adapt the curriculum, supplementing activities and content with other resources that better mirrored her students’ experiences. In an interview, Elizabeth explained that she actively piloted the curriculum because it allowed her to address “a crisis point in [her] career.” She stated, “I don’t feel like I’m very effective anymore and I find myself going to these places of ‘what’s wrong with kids these days?’ And then I’m like, did I just say that? Like, what’s wrong with you these days?” Elizabeth wanted to change her classroom in ways that honored “students’ social and emotional well-being” and “better reflected social justice.” The curriculum design goals matched her goals as a teacher, and so Elizabeth was able to navigate her roles across these spaces in ways that she and the research team deemed successful.

While James and Elizabeth had very different reasons for co-designing, each was able to create goals for co-designing that fit with the other roles they played. For James, the co-design process felt chaotic, but he repeatedly described the ways that he was “comfortable with chaos in the classroom” and wanted to “embrace chaos because it’s how we learn.” James said he saw himself as a leader with a lot of district flexibility. He never expressed a tension between project and district goals, and he made few adjustments to the co-designed project during his implementation because he was more concerned with “big concepts than specific standards.”

For Maria, implementation of the project was more complicated. While Maria’s administration encouraged implementation, she articulated her goals for students as more closely aligned to standards. Maria often argued vehemently in co-design meetings when her proposed activities were changed, and during implementation, researchers observed her refusal of most of the co-designed project materials in favor of the original activities that she had proposed to the rest of the team. While Maria’s implementation of the project was initially analyzed by researchers as furthest from the research team’s intentions for PBL, Maria’s refusal of the co-designed curriculum points to the achievement of a secondary project goal, that of positioning teachers as agentic and capable professionals. While neither Maria nor Lisa were able to reconcile their multiple roles and goals within this project, each of them used refusal as a means of asserting their agency as co-designers.
Significance
For each of the teachers, data analysis showed that the more participants see goals from their multiple roles reflected in the co-design process, the more likely they are to adopt the goals of co-design projects. Wertsch (1991) explained, “human action typically employs ‘mediational means’ such as tools and language, and that these mediational means shape the action in essential ways” (p. 12). Actions reflect the roles and connected goals with which individuals identify. In this study, co-designers were expected to navigate their multiple roles in ways that would allow them to meet the goals attached to each of those roles by different stakeholders. As tensions arose, the co-designers on this team exhibited agency through the acceptance or refusal of mediating curricular objects, pointing to the ways that these roles and goals intersect. While researchers initially analyzed teacher’s refusal of the Singularity project as evidence of some teachers’ failure to engage in the co-design process, Wertsch’s theory offers a lens through which to see all of these co-designers as agentic actors reaching for disparate goals. By encouraging participants to voice their multiple roles and connected goals, the researchers may have found more success in encouraging teachers to lead the design process and/or pilot curriculum. As researchers continue to pursue co-design as a means of educational transformation and empowerment for teachers, we must also take into account not only the multiple roles that co-designers play (Penuel et al., 2015), but also the ways that goals attached to those roles intersect.

References

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The Quality of Open Online Education and Learning: Towards a Quality Reference Framework for MOOCs

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Abstract: This paper aims to address the quality issues of open online education and learning with a focus on MOOCs. Specifically, our research goal is to develop a Quality Reference Framework (QRF) with quality indicators and tools in close collaboration with all interested stakeholders worldwide. Based on a rigorous literature review and analysis of existing quality approaches and quality indicators for MOOCs, the Global MOOC Quality Survey was designed targeting at three core interest groups: MOOC learners, MOOC designers and MOOC facilitators. A total of n=267 took part in the survey. The survey results were complemented with 45 semi-structured interviews with MOOC designers, facilitators and providers. This mixed method research was selected to provide a more coherent picture and analysis of the quality issues of MOOCs by investigating them from diverse and different perspectives. This paper presents first results from the survey and semi-structured interviews, the first QRF draft and the feedback gained from workshops at international conferences.

Introduction and theoretical discussion

Global challenges and changes in the educational and economic front have not only greatly shaped our working and living conditions, but also affected the way we teach and learn (OECD, 2016). Notwithstanding the individual process of learning has not completely changed, the contexts and channels of teaching and learning are becoming more diverse (Stracke, 2017a). In particular, educational systems are challenged by changing objectives and developmental goals to innovate and to open up education (Stracke, 2017b).

Within the Open Online Education, Massive Open Online Courses (MOOCs) has undeniably gained a strong foothold in the education arena, in particular, in higher education and lifelong learning (Conole, 2015; Stracke 2017b). The first MOOC came into being in the year 2008 and, since then, the number of MOOCs has been constantly rising (Gaskell & Mills, 2014). A first peak could be discovered in the year 2012 which was commonly coined, the "Year of the MOOCs" (Daniel, 2012). It gave rise to a growing discourse on the quality of MOOCs and their value as learning experience and educational tool. This also explains the multitude of research on the quality of MOOCs in the last five years. Reiterating the words of Macleod et al. (2015), “when one designs any course, one has to have some learner cohort in mind” (p. 9). Researchers on quality of MOOCs caution against discussing quality issues using a specific MOOC type, rather, the quality features of a good MOOC should take into account the general design principles and good pedagogical practices (Bali, 2014; Daradoumis, Bassi, Xhafa, & Caballe, 2013). Others advocate that research on quality of the learning experience with MOOCs should consider the given learning situation as well as the core stakeholders involved (Hayes, 2015; Macleod et al., 2015). Hence, this paper seeks to address this longstanding issue on the quality of MOOCs by investigating the quality indicators of a good MOOC from the perspectives of four core MOOC stakeholders: MOOC learners, MOOC designers, MOOC facilitators and MOOC providers. In this paper, the research activities with the interim results are presented to provide a first insight into the varying perspectives on the quality of MOOCs from the four core stakeholders.

Motivation and research background

The quality of MOOCs, and of online education and learning in general, is often questioned. The dropout rate is the typical measure in traditional distance education courses and in all formal education settings. The same mode of measurement is often applied to MOOCs to determine their quality. The MOOC completion rate is reportedly very low and often under 10 %. Therefore, it saw the first demands for re-booting the design of MOOCs and the related research for their quality improvement (Margaryan, Bianco, & Littlejohn, 2015; Reich, 2015). But this discussion is mainly based on an improper adoption and interpretation of dropout rates. Dropout rate is a formal evaluation concept from face-to-face education which is not the most appropriate evaluation method for MOOCs which engender mostly non-formal learning experiences (Onah, Sinclair, & Boyatt, 2014). Thus, alternative evaluation measures have been proposed and discussed to measure the quality of MOOCs by investigating learners’ intentions and goals (Henderikx, Kreijns, & Kalz, 2017; Stracke, 2017b). On the same note, to address these quality issues, the development of a Quality Reference Framework (QRF) for MOOCs
was envisaged: An international alliance was established to connect and bring together the key experts and organizations to collaboratively address the quality of open online learning and education with a focus on MOOCs. Our expectation is that this alliance will demonstrate the potential significance and achieve its overarching goal to improve the quality of MOOCs and online education and learning in general.

Methodological framework

A Quality Reference Framework (QRF) for MOOCs is the main long-term objective of this empirical work. This will be achieved by means of both quantitative and qualitative research. To address the quality issues and to facilitate the QRF development, several research surveys and instruments with different methodological approaches were developed and combined. They serve to analyse the current status and to explore the needs from different perspectives. First, an in-depth literature review and analysis of existing quality approaches, evaluation instruments and quality indicators for MOOCs were conducted and the findings are currently under publication. Based on findings from the literature review and analysis of existing quality approaches, the Global MOOC Quality Survey was designed and developed in two phases: in phase one, a small pre-survey focusing on learners’ intentions and personal goals was implemented. There was a total of 45 participants. Findings showed that most MOOC learners and MOOC designers do not share similar intentions and goals. In phase two, the Global MOOC Quality Survey was developed for three target groups: learners, designers and facilitators of MOOCs. It was conducted with the support of leading international associations and institutions over a period of four months. Table 1 below introduces the constructs that were developed for and used in the Global MOOC Quality Survey and Table 2 presents an overview of all participants from the three target groups and of the subsets of the participants that responded to the open questions.

Table 1: Overview of the constructs developed for and used in the Global MOOC Quality Survey

<table>
<thead>
<tr>
<th>Constructs</th>
<th>MOOC learners</th>
<th>MOOC designers</th>
<th>MOOC facilitators</th>
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<tbody>
<tr>
<td>Pedagogical Decisions</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Objectives</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Duration and Structure</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Duration and Interaction</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Learning Resources</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Learning Support</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Flexibility and Inclusion</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Progress</td>
<td></td>
<td></td>
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<tr>
<td>Learning Environment</td>
<td></td>
<td>X</td>
<td>X</td>
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<td>Learning Assessment</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Learning Certification</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Design Process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online Facilitation</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Table 2: Overview of all participants of the Global MOOC Quality Survey and of the subsets for open questions

<table>
<thead>
<tr>
<th></th>
<th>MOOC learners</th>
<th>MOOC designers</th>
<th>MOOC facilitators</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants</td>
<td>166</td>
<td>68</td>
<td>33</td>
<td>267</td>
</tr>
<tr>
<td>Open questions</td>
<td>117</td>
<td>41</td>
<td>27</td>
<td>185</td>
</tr>
</tbody>
</table>

Semi-structured interviews with MOOC designers, facilitators and providers were also conducted to obtain more in-depth details and insights. Each interview contains different key questions for the three target groups and the interview questions are in line with the constructs of the Global MOOC Quality Survey (see Table 3).

Table 3: Overview of the interviews with MOOC designers, facilitators and providers

<table>
<thead>
<tr>
<th></th>
<th>MOOC designers</th>
<th>MOOC facilitators</th>
<th>MOOC providers</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key questions</td>
<td>15</td>
<td>10</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td>No. of Interviews</td>
<td>15 x 1 hour</td>
<td>15 x 1 hour</td>
<td>15 x 1 hour</td>
<td>45 x 1 hour</td>
</tr>
<tr>
<td>Summaries</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>45</td>
</tr>
</tbody>
</table>
In parallel, several interactive workshops were also organized to obtain more feedback and to initiate in-depth discussions at international conferences (see Table 4 below) with the aim to facilitate close collaboration with all interested stakeholders worldwide for the development of the QRF with quality indicators and tools. Table 4 provides the overview of the workshop with selected key quality indicators for the MOOC design phase that gained most attention and discussions in average by the workshop participants.

Table 4: Overview of the workshop on the needs and phases for a QRF and related quality indicators

<table>
<thead>
<tr>
<th></th>
<th>OE Global 2017</th>
<th>EDUCON 2017</th>
<th>EARLI 2017</th>
<th>EC-TEL 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>All questions</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Key questions</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>QRF phases</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Key QRF indicators</td>
<td>Learning design &amp; theory, Definition of success factors, Re-usage of former courses</td>
<td>Pedagogy, Templates &amp; story boards, Language, User experiences, Interactivity</td>
<td>Usability and accessibility, Learning paths, Defined goals, tasks, content &amp; added value</td>
<td>- (not addressed)</td>
</tr>
</tbody>
</table>

Interim results
The first interim results from the Global MOOC Quality Survey, the interviews and the workshops are presented below.

Interim results from the Global MOOC Quality Survey
More than 250 participants shared their experiences and expertise (n=267) and most of them reported positive experiences with MOOCs. However, the experiences with MOOCs vary across the three target groups MOOC learners (n=166), MOOC designers (n=68) and MOOC facilitators (n=33) as shown in the following figures:

Learners ($\mu=4.22, \sigma=0.876$) rates their MOOC experiences higher than designers ($\mu=3.99, \sigma=0.855$) but a little bit lower than the facilitators ($\mu=4.30, \sigma=0.529$). Our first interpretation is that the designers underestimate their instructional design and the MOOC quality whereas the facilitators seem to slightly overestimate the effectiveness of their facilitation in the MOOC as they may feel responsible for the MOOC facilitation and therefore tend to indicate a more positive rating. Our in-depth analysis on the other data and correlations (still in progress) explore all relationships in greater detail.

Interim results from semi-structured interviews
Two main areas addressed by all interviewed target groups (MOOC designers, facilitators and providers) were: The pedagogical design and the learning activities. For the pedagogical design, three critical determinants of the didactical approaches were highlighted and commonly repeated: Content, learning objectives and learners' profile. For the learning activities within the MOOC, three conditions to support the learning process were highlighted and commonly repeated: Interaction, feedback and assessment. That is in line with our expectations; however we need more in-depth data analysis. Currently the qualitative and qualitative analysis of the interviews has just begun started and further results will be available soon.
Interim results from the four workshops
Almost all workshop participants (61 out of 62) were positive on the selected five processes for the QRF (Analysis, Design, Implementation, Learning process and Evaluation; as presented in figure 4) and agreed or fully agreed with them. The feedback on the QRF target groups and proposed instruments and tools to support the introduction and usage of the QRF were diverse and the analysis of the data is underway. Also, the workshop results will be analysed and evaluated to allow a better understanding of the feedback from different learning communities attending the international educational conferences and participating in our workshops.

It can be summarized that the mixed method research combining different data sets and perspectives has led to a multi-dimensional needs and preferences for the QRF development.

Conclusions and implications
This paper presents the major findings and interim results from the first activities towards the development and design of a Quality Reference Framework (QRF) for the improvement of MOOCs and online learning and education. The data analysis has just started but the first insights are promising. In particular, the combination of different methodologies seems to provide a multi-dimensional overview of the needs and preferences of the different target groups.

Our vision is to improve and to foster quality in Open Online Education and Learning with a focus on MOOCs which will lead us to a new era of learning experiences. We are developing a QRF for the adoption, design, delivery and evaluation of MOOCs in order to empower MOOC designers and providers for the benefit of MOOC learners. The main goal is the development and the integration of quality approaches, new pedagogical designs and organisational mechanisms into MOOCs with a strong focus on the learning processes, methodologies and assessments. This paper is a first small step towards this ambitious objective to facilitate and support better design and delivery of MOOCs in close collaboration with all interested stakeholders worldwide.

References
Taking on the Challenges of Learning in the Digital Age: 
Grade 5 Students’ Mindsets and Strategies 
in Knowledge Building Communities

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Abstract: The goal of this study is to advance the understanding on the mindsets and strategies that students employ as they deal with the challenges, obstacles, and setbacks inherent in knowledge building communities. In the first iteration of a three-year design based research study, students in four grade 5 classroom knowledge building communities studied human body systems. We collected data on 93 students from peer-interviews dealing with the challenges and approaches that they employed during their inquiry process. Using an inductive approach that examined students’ reactions, we identified 247 relevant utterances which we organized and coded. Our first key finding indicates the inter-relation between students’ attitudes, beliefs, understandings, and feelings related to their mindsets. Our second key finding shows that students rely on different strategies of an inquiry cycle when they face challenges and setbacks. These results set the stage for further inquiry and design modifications.

Reorganizing education in the digital age
Education in the digital age needs to be reorganized to enculturate creative knowledge practices, which are the new norm in most social sectors (Adams Becker, Freeman, Giesinger, Cummins, & Yuhnke, 2016). As a key challenge, the new model of education needs to provide a way into the knowledge-creating culture for every child, not only the highly engaged learners. Collaborative, inquiry-based programs have been developed to bring authentic knowledge-generating processes and practices, like questioning, into the classroom (Hod & Sagy, 2017). Research has identified productive patterns of inquiry and discourse, with a strong correlation showing that the more students engage in such processes, the deeper understanding they achieve (Zhang, Hong, Scardamalia, Teo, & Morley, 2011). However, the learning sciences still faces a serious gap of knowledge about how to support students who are not actively engaged in such processes. Addressing this challenge requires us to understand the whole child in inquiry-based learning. In addition to investigating the sociocognitive processes of idea development, we need to understand students’ socioemotional experiences that may support or hinder their productive engagement. This research attempts to expand the idea-centered foci of knowledge building by examining the different mindsets and strategies that students take when they participate in knowledge building practices. The goal is to understand students’ approaches as they face the challenges, obstacles, and setbacks inherent in the knowledge building process and test designs to better motivate and engage all learners.

Challenges and approaches of knowledge building in the digital age
A set of core principles has been identified to characterize the complex dynamic practices that students in Knowledge Building Communities (KBCs) must develop to be productive (Zhang et al., 2011). Students need to take high levels of epistemic agency to choose what they want to learn, at what time, and with whom they want to engage in a sustained learning trajectory (Scardamalia & Bereiter, 2014). They must actively improve ideas, treating ideas as objects of never-ending refinement in their quality and coherence. Likewise, students must contribute to a culture where collective responsibility is a norm, requiring them to stay aware of the contributions of others and contribute in ways that complement those contributions even though they may be working on different inquiry questions (Zhang, Scardamalia, Reeve, & Messina, 2009). Enculturating these types of practices can be a challenging undertaking for any learner.

A great deal of research on KBCs has aimed to elucidate and foster these types of practices among the KBC participants. For example, in their study investigating the epistemic agency of students in four KBCs, Cacciamani (2010) reported on the strategic actions that students took when they engaged in self-organized learning. As part of their examination of the way students continually improved their ideas, van Aalst and Chan (2007) found that portfolios as part of the knowledge building process was effective in fostering inquiry and deeper levels of domain understanding. To foster collective cognitive responsibility, Zhang et al. (2009)
progresively adapted the social structures from fixed, to interacting, to opportunistic groups. While a significant body of knowledge has developed about how to develop the complex practices students need to foster their participation in knowledge building cultures, research has emphasized sociocognitive dimensions of learning. Investigations of learning in KBCs that also take into consideration the motivational and socioemotional aspects of the way students deal with the challenges of knowledge building are needed (Miyake & Kirschner, 2014).

**New approaches to fostering students’ growth**

In recent years, new research directions have emerged which are relevant to the challenge of promoting knowledge building in the digital age, but which have not yet been applied to this line of research. In particular, the notion of fixed and growth mindsets has gained widespread popularity across a number of areas, including organizational psychology, athletics, parenting, and interpersonal relationships (Dweck, 2006). People’s views of intelligence as being fixed or incremental and their ability to persist in the face of obstacles and challenges are associated with different learning engagements. People with fixed mindsets are likely to shy away from these challenges, as they threaten to disconfirm their positive views of their own intelligences and/or capabilities. Whereas, those with growth mindsets see challenges as opportunities to learn and grow and therefore are more likely to embrace challenges and persist despite setbacks. This line of research on mindsets is consistent with several other contemporary concepts, such as productive failure (Kapur, 2008), desirable difficulties (Schmidt & Bjork, 1992), impasse-driven learning (Van Lehn, Siler, Murray, Yamauchi, & Baggett, 2003) and research on grit (Duckworth, Peterson, Matthews, & Kelly, 2007), which suggest that persisting in the face of challenges and obstacles is a disposition of highly successful and creative people.

As a pedagogy well-suited for contemporary times that entails having students confront the complex challenges of learning and knowledge creation in the digital age, we contend that KBCs may favor students with growth mindsets, but those with fixed mindsets may face a more significant challenge, particularly in comparison with traditional modes of instruction. To begin our exploration of this contention, and with the aim of better understanding how students deal with the challenges, obstacles, and setbacks inherent in the knowledge building process, this study examines students’ mindset-related experiences in four Grade 5 knowledge building communities. Our research questions include: (a) What types of core attitudes, beliefs, understandings, and feelings do 5th grade knowledge builders demonstrate in line with a growth mindset? And (b) what are the different strategies that 5th grade knowledge builders take to deal with the challenges of knowledge building?

**Methodology**

The study was conducted in the midst of an ongoing design-based research (DBR) study with the dual aim of advancing theories of learning while contributing to practice-based principles (Anderson & Shattuck, 2012). The general structure of our research program is to implement three progressively refined iterations of a KBC in the context of 5th grade science classes taking place in one elementary school in upstate New York. We are currently analyzing data from four classrooms after the first iteration of the study and here report on our findings thus far. Based on the findings related to our research questions, we will be implementing a refined iteration in four classes during the 2017-2018 academic year, followed by a third iteration in 2018-2019.

We audio recorded, transcribed, and analyzed data from 53 student pair-interviews who signed consent forms for interview analysis (for a total of 93 students), where they were asked to reflect upon their knowledge building processes throughout the year and discuss their answers with each other. During these interviews, students interviewed each other about their ‘journey of thinking,’ where they faced challenges and obstacles and how they dealt with them, and what advice they would give future students engaged in knowledge building. Based on students’ responses to these interview questions, we were interested in examining how the students described the way they dealt with the challenges of knowledge building.

Our data corpus included 247 utterances—defined as meaningful units information about an idea—that related to their experiences and mindsets as knowledge builders. We used an inductive data analysis approach (Hatch, 2002; Strauss & Corbin, 1998), which involved reviewing the data repeatedly in stages of progressive refinement, until their meanings became clear to us and we could organize these utterances into categories. Three researchers coded the data, with an acceptable inter-rater reliability (Cohen’s kappa = .87).

**Preliminary findings**

Our preliminary findings capture a set of core attitudes, beliefs, and feelings associate with students’ knowledge building experiences as well as the range of strategic responses that the students took to deal with the various challenges and barriers of knowledge building (see Table 1).

**Table 1. Students’ reported core and secondary mindsets when faced with the challenges of knowledge building**
### Growth Mindsets Categories

<table>
<thead>
<tr>
<th>Core growth mindset (attitude, belief, understanding, feeling)</th>
<th>Examples of Sub Categories</th>
<th>Student Utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have a positive outlook and be serious about the learning</td>
<td>Work hard</td>
<td>“Try your hardest, and if it gets hard…”</td>
</tr>
<tr>
<td></td>
<td>Try your best</td>
<td></td>
</tr>
<tr>
<td>Understand their will be setbacks in the process</td>
<td>Don’t give up</td>
<td>“Never stop working hard”</td>
</tr>
<tr>
<td></td>
<td>Work it out</td>
<td></td>
</tr>
<tr>
<td>Trust or believe that your persistence will pay off</td>
<td>Believe that you will find the answer</td>
<td>“But you just got to keep going and eventually you’ll find it”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enjoy the process despite setbacks</td>
<td>Follow what interests you</td>
<td>“I find it is interesting to me. Do something that you are into.”</td>
</tr>
<tr>
<td></td>
<td>Find it interesting</td>
<td></td>
</tr>
</tbody>
</table>

### Strategies to deal with challenges

| Come up with good questions                                   | Pick generative research topics | “Pick an umbrella question - that main question and branch off of that” |
|                                                               | Ask an expert                  | “I asked the person studying the same topic as me and they gave me the answer for it” |
|                                                               | Check expert                   |                              |
|                                                               | Check resources                |                              |
| Gather relevant information                                   | Build up information           | “Start out with stuff that you understand and then excel from that point” |
|                                                               | Make connections               |                              |
| Examine or analyze the knowledge that you find               | Do experiments                 | “Bring in experiments”       |
|                                                               | Make a model                   |                              |
| Collaborate with others                                       | Share with others              | “We all worked together to solve it” |
|                                                               | Work together                  |                              |

We refer to the growth-oriented attitudes, beliefs, understandings, and feelings that the students had in regards to the challenges of knowledge building as ‘core’ growth mindset issues. Each one of these four mindset issues were further broken down in sub-categories (n=17), which were further sub-divided into a number of related utterances (n=96). The actions that students described or suggested to others as part of their mindset strategies were indicative, but secondary expressions of students’ mindsets. Like with the core mindset, each strategy was broken down in sub-categories (n=24), further sub-divided into related utterances (n=152).

**Discussion**

Our goal in this ongoing research is to understand students’ approaches as they face the challenges, obstacles, and setbacks inherent in knowledge building communities and test designs to better motivate and engage all learners. Our preliminary results are promising. Overall, we have identified four categories of core knowledge building mindsets and five related strategies after a careful examination of 93 5th grade students.

The core knowledge building mindsets span the attitudes, beliefs, understandings, and feelings that we discovered using an inductive approach to analyze the data. At this point, we cannot correlate students’ performance as knowledge builders with the type of mindsets that we have found. However, the existing data indicate that students’ reactions to the challenges and obstacles must be examined through a holistic perspective to get a full account of their experience. Students expressed feelings together with their attitudes, understandings, and beliefs, suggesting that these are interrelated. Such findings that are indicative of holistic perspectives are consistent with a wide range of contemporary sociocultural research (e.g., Heyd-Metzuyanim & Stård, 2012; Herrenkohl & Mertl, 2010).

The strategies, unlike the prior category, appeared to indicate different aspects of research that the students were collectively engaged in. Specifically, their responses corresponded to a model of inquiry along the lines of (1) question; (2) check authoritative sources; (3) gather information; (4) analyze; and (5) collaborate.
Next steps and conclusion
This first stage of research will be followed up with additional analysis steps that will build on our knowledge about the relation between mindsets and KBCs. Specifically, we plan to: (1) Conduct a content analysis to examine the quality of students’ knowledge building and how this relates to their core beliefs and strategies that we found during the peer interviews; (2) Take a careful look at students’ experiences together with their with fixed or growth mindsets to better understand their knowledge building practices at a fine level of detail; and (3) Repeat this study in iteration two and three, each time with refinements. In iteration two, during metacognitive meetings the teachers will facilitate student-led discussions about the different beliefs and strategies related to facing obstacles that the students employed, as we have discovered thus far at this stage of the research.

To sum, KBCs have reconceptualized classroom practice for over two decades, yet further research is needed to better understand how to continue to support students in the complex transition to participate in knowledge building cultures. Developing growth mindsets and strategies with regards to the challenges, obstacles, and setbacks entailed in authentic knowledge building are one of the most important goals of education in the digital age, particularly as they address the whole student. This study contributes to the endeavor to advance this vital area of research and practice on learning in the digital age.

References
Evidence-based Reasoning of Pre-Service Teachers: A Script Perspective

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Augsburg University

Abstract: Instead of using psychological knowledge, pre- and in-service teachers often refer to everyday theories when faced with problematic pedagogical situations. This paper investigated to what extent such problems are caused by inadequate evidence-based reasoning scripts that guide pre-service teachers in the way they tackle pedagogical problems. We investigated the scripts of \( N = 103 \) beginning and \( N = 236 \) advanced students by asking them to analyze fictitious, but realistic problem cases in an open-answer format. Afterwards, they were asked to describe the cognitive activities they engaged in during problem analysis. Results showed that advanced students more often than beginners reported identifying problems, while beginners more often reported setting goals. Students’ attitudes towards research on learning and instruction positively predicted their engagement in these cognitive activities. Thus, it appears that the evidence-based reasoning scripts of both beginning and advanced pre-service teachers might benefit from scaffolding, as well as supportive motivational-affective factors.

Background and aims

Teachers are increasingly asked to ground their pedagogical decisions in scientific psychological and educational theories rather than on gut feeling (Slavin, 2008). Grounding one’s own pedagogical decisions in scientific theories on learning and instruction has been termed ‘evidence-based reasoning’ (Timperley, Wilson, Barrar, & Fung, 2008). Yet, a number of studies have indicated that in many instances teachers have problems solving pedagogical problems in agreement with scientific knowledge. For example, Franke and Wecker (2017) showed that when faced with authentic classroom problems (e.g. students who seem to be unmotivated to follow the lesson) in-service teachers tend to rely on everyday theories and episodic evidence, rather than on scientific theories and evidence. Similar results have been reported for pre-service teachers (Wagner, Klein, Klopp, & Stark, 2014). The reasons for pre- and in-service teachers’ deficits in evidence-based reasoning are manifold. For example, a study by Star and Strickland (2008) showed that deficits in teachers’ evidence-based reasoning were caused by little knowledge about scientific theories on learning and instruction (see also Csanadi, Kollar, & Fischer, 2016). Furinghetti and Pehkonen (2002) demonstrated that even when teachers possess relevant scientific knowledge, they often have difficulties applying it. Further, Parr and Timperley (2008) demonstrated that teachers often hold negative attitudes towards the usefulness of scientific knowledge on learning and instruction, which might be a further barrier for evidence-based reasoning.

In this paper, we investigated whether a further reason for teachers’ problems regarding evidence-based reasoning is that they might not (yet) have developed well-established schema about how to deal with problematic pedagogical situations. In line with Fischer, Kollar, Stegmann and Wecker (2013), we refer to such knowledge as scripts, i.e. dynamic knowledge structures which guide a person’s behavior in specific situations (Schank, 1999). Based on prior research, we assumed that proficient solvers of pedagogical problem situations engage in the following cognitive activities (scriptlets) as part of their evidence-based reasoning script: (1) identifying problems, (2) reconstructing problems, (3) developing an explanatory model, (4) defining goals, and (5) considering possible actions (cf. Sherin & van Es, 2009). It can be assumed that such scripts will gradually develop towards higher degrees of sophistication over the course of university-level teacher education. Yet, research on this issue is scarce. Therefore, our first aim was to investigate the differences between beginning and advanced pre-service teachers’ scripts for evidence-based reasoning when dealing with problematic pedagogical situations.

A second aim of our study was to investigate the role that pre-service teachers’ attitudes towards research on learning and instruction play for the development of evidence-based reasoning scripts. While prior research has shown that negative attitudes are related to the extent to which teachers refer to scientific knowledge while solving pedagogical problems (Parr & Timperley, 2008), not much is known on the question whether this is also true for the relationship between these kinds of attitudes and teachers’ scripts for evidence-based reasoning.

In sum, we investigated to what extent participants engaged in the five aforementioned cognitive activities when assessing a problematic pedagogical situation (RQ 1). Also, we investigated the role of pre-service
Methodology

Sample

The full sample consisted of $N = 339$ university students enrolled in a teacher training program at a German university. 77.3% of the participants were female. The mean age of the sample was $M_{age} = 22.0$ years ($SD = 2.73$). It fell into two subgroups based on the level of their studies; $n = 103$ ($M_{age} = 20.67$, $SD = 2.60$, 79.6% female) were at the beginning of their studies ($M_{semester} = 1.66$, $SD = 1.24$), while $n = 236$ were more advanced ($M_{age} = 22.59$, $SD = 2.58$, 76.3% female, $M_{semester} = 5.58$, $SD = 1.67$).

The subgroups differed significantly regarding their prior pedagogical-psychological knowledge, number of educational courses and practical experience in teaching, supporting their perception as separate groups with regard to their status as beginning and advanced students of education.

Design

The study followed a 2-group cross-sectional design. Both groups took part in a 90-min. computer-based learning environment as part of their course work. The test environment consisted of the presentation of two written case descriptions (vignettes) of a classroom situation. The presentation order was balanced across the sample. The vignettes described the practice of one particular teacher in a classroom. This teacher attempted to solve common pedagogical problems (e.g. motivating students, designing high-quality assessments), yet did not always fully succeed (problem-based learning, Hmelo-Silver, 2004.

Participants were instructed to read the vignettes and provide their fictitious colleague with an analysis of the situation and feedback on their practice. Following the written analysis, participants were asked to reconstruct the cognitive activities they had just engaged in by selecting the relevant activities from a prepared list which was open to additions. Also, participants answered a questionnaire on their attitudes towards research on learning and instruction as part of the learning environment.

Variables, instruments, and statistical procedures

Number of cognitive activities. These were measured by counting the number of cognitive activities that conformed to the five-step theoretical model described above when participants reconstructed their problem-solving process. To test RQ 1, we ran an analysis of variance (ANOVA) to assess differences between beginning and advanced students in the number of reported cognitive activities in line with the process model. Additionally, we used a multivariate ANOVA to investigate differences in the frequencies of the specific cognitive activities.

Attitudes towards research on learning and instruction. We developed a Likert-type rating scale that measured participants’ attitudes towards research on learning and instruction that consisted of 13 items. The items were answered on a five-point Likert-scale (1 = ‘fully disagree’; 5 = ‘fully agree’; sample item: ‘The findings of pedagogical-psychological research are helpful for the competent engagement in the teaching profession.’). The scale reached good internal consistency (Cronbach’s $\alpha = .88$). We investigated the predictive power of attitudes towards research on learning and instruction for the number of cognitive activities by way of linear regression analysis.

Results

Out of the five cognitive activities in the process model, on average participants’ mentioned $M = 3.24$ ($SD = 1.08$) in the reconstruction of their problem-solving process. Beginning students mentioned $M = 3.39$ ($SD = 1.15$), while advanced students mentioned $M = 3.18$ ($SD = 1.05$) cognitive activities. Regarding RQ 1, results showed that overall, both groups engaged in activities congruent with our theoretical perspective to comparable amounts ($F(1;334) = 2.77$, $p = .10$). Nevertheless, significant differences emerged regarding specific cognitive activities ($F(3;33) = 3.54$, $p < .01$, $\eta^2 = .05$): advanced students reported to engage significantly more often in problem-identification ($F(1;334) = 4.02$, $p = .05$, $\eta^2 = .01$), while beginning students reported more goal-setting ($F(1;334) = 7.39$, $p = .01$, $\eta^2 = .02$). These effects were small however. All other differences did not reach statistical significance ($F(1;334) = 2.87$, $p = .09$ for reconstructing problems; $F(1;334) = 1.80$, $p = .18$ for developing an explanatory model; $F(1;334) = 0.02$, $p = .96$ for considering possible actions). Table 1 provides the means and standard deviations for each cognitive activity.
Table 1: Descriptive statistics for all cognitive activities.

<table>
<thead>
<tr>
<th></th>
<th>Identifying problems</th>
<th>Reconstructing problems</th>
<th>Developing an explanatory model</th>
<th>Defining goals</th>
<th>Considering possible actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Beginning students</td>
<td>0.83</td>
<td>0.37</td>
<td>0.82</td>
<td>0.39</td>
<td>0.50</td>
</tr>
<tr>
<td>Advanced students</td>
<td>0.91</td>
<td>0.29</td>
<td>0.73</td>
<td>0.45</td>
<td>0.42</td>
</tr>
</tbody>
</table>

With regard to RQ 2, participants reported rather positive attitudes towards research on learning and instruction, with beginning students averaging on $M = 3.33$ ($SD = .62$) and advanced students on $M = 3.34$ ($SD = .59$). Consequently, no significant differences were found between groups ($F(1;334) = .05, p = .83$). The number of reconstructed cognitive activities correlated significantly positively, but only to a small extent with students’ attitudes towards research on learning and instruction ($r = .12, p = .01$). Students’ attitudes towards research on learning and instruction predicted the number of cognitive activities reported by the participants significantly positive ($\beta = .12, t(334) = 2.27, p < .01$). The amount of explained variance was small ($R^2 = .02$).

**Discussion**

This study showed that evidence-based reasoning in pre-service teachers cannot only be assessed from a content perspective that looks at the knowledge (pre-service) teachers use when addressing and explaining pedagogical problems (e.g. Cook & Gorard, 2007; Franke & Wecker, 2017), but also from a process perspective that analyzes their cognitive activities during problem-solving. For this perspective, the script perspective as outlined by Fischer and colleagues (2013) proved fruitful and promising.

More specifically, our results indicated that pre-service teachers engaged in a number of cognitive activities which from a theoretical perspective make for good problem-solving in problematic pedagogical situations. Results indicated that while more advanced students focus on getting an understanding of the situation and possible critical incidents, beginning students jump more readily to conclusions and set goals for future actions. Possibly, increased proficiency in identifying problems due to experience is the reason for this. Herein a higher level of expertise in more advanced students can be assumed, as well as an increased understanding that pedagogical situations are complex and need careful scrutiny and analysis. Both in expertise research (Berliner, 2001) and in research on procedural knowledge and skills (Anderson, 1996), U-shaped developments in proficiency have been reported. Similar developments could be taking place in teachers’ evidence-based reasoning. To further investigate this possibility more career levels (e.g. beginning teachers and veterans) need to be analyzed and longitudinal research designs enacted. Furthermore, by coding participants’ written analyses for different aspects of evidence-based reasoning we seek to validate their self-report data and receive a more fully fledged picture of their cognitive script for the analysis of pedagogical problem situations.

In contrast to prior research (e.g. Parr & Timperley, 2008), our sample reported rather positive attitudes towards research on learning and instruction. Yet, in line with these investigations, we demonstrated that more positive attitudes predicted the quality of students’ evidence-based reasoning significantly positive in the form of more cognitive activities from the model reported as part of their evidence-based reasoning script. Yet, this effect was rather small. Nevertheless, this finding provides support for the importance that attitudes towards research on learning and instruction play not only for how often and how much pre-service teachers refer to scientific evidence during problem-solving, but also to the development of cognitive schemata on how to approach such problems in general.

**Limitations and conclusions**

This study is certainly not free of flaws. The cross-sectional design is limiting as the differences between beginning and advanced students might also be due to cohort effects. Also, the cross-sectional design does not allow deriving causal effects of their attitudes towards research on learning and instruction. Looking at different groups of (pre-service) teachers is a helpful proxy, yet additional career levels are needed to gather further insights into how evidence-based reasoning is enacted outside a university context. Field studies, looking at teachers’ actual classroom practice, would also increase the ecological validity of the findings. Lastly, it needs to be noted that the reported data is based on self-reports and warrants validation, e.g. by analyzing participants’ writ-
ten case analyses. This is currently done. However, we are confident in the usefulness of the script perspective and the scientific relevance of our results regarding (pre-service) teachers’ evidence-based reasoning.

Overall, our investigation adds to previous findings that evidence-based reasoning is difficult for pre-service teachers. In addition to previous studies that mainly attributed deficits in (pre-service) teachers’ evidence-based reasoning to structural problems such as a lack of knowledge or difficulties in its application, our analyses revealed that such deficits may also be due to insufficient cognitive processes. Our analysis further showed that non-cognitive factors such as attitudes need to be considered in addition to cognitive ones in research on evidence-based reasoning processes as they significantly predict their quality. Currently on-going analyses of the data indicate stronger application of scientific theories for students with more developed scripts. Herein, we see further support for the assumption that evidence-based reasoning scripts are important for (pre-service) teachers’ evidence-based practice. Our results underscore the need to support pre-service teachers in their development of high quality cognitive schema for tackling classroom problems (Klein, Wagner, Klopp & Stark, 2015). Research that systematically investigates evidence-based reasoning of pre-service teachers is desperately needed to enhance the professionalization of future teachers.

References
Social Positioning Newcomer Roles on a High School Robotics Team: A Chronotopic Micro-Analysis

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Abstract: This paper uses a chronotopic analysis to map newcomer positioning and its effect on roles for an urban high school robotics team. Comparing three distinct episodes shows that with imminent competition, the case’s newcomer positioning changes, deprivileging her learning through a rejection of any chronotopic contributions. In practice, the newcomer’s role is crafted by posing choices she can make in the imagined future of competition through chronotopic co-construction.

Purpose
Robotics teams are typically viewed as places where youth engage in science and engineering practices in authentic ways (Puvirajah, et al., 2012). As Basu, Barton, Clairmont, and Locke (2009) argue social positioning is an important way to view STEM learning opportunities. A robotics team is one such opportunity where students opt to participate much like the informal contexts studied by others (Nasir & Cooks, 2008; Ma & Munter, 2014). The purpose of this paper is to explore the produced social spaces within one robotics team in an urban high school to better understand how one newcomer is positioned in three situations over two competition seasons. The question for this study is: In the semi-formal learning environment of this robotics team, how is one newcomer afforded participation in learning opportunities as she takes on an important role on the team over her first two competition seasons?

Theoretical framework: A chronotopic approach
Chronotopes are a dialogic unit, which theoretically acknowledges the “inseparability of time and space,” according to Bakhtin (1981). This, framed in a sociocultural view of human development (Vygotsky, 1980), means that participants in the social world bring to interactions interpretations of past-space, present-space, and imagined future-space, to contribute. This study uses the chronotope as a unit of analysis to build an understanding of how social actors collaboratively position each other in interactions as part of a community like Engineering Robotics. Such an analysis provides a view on how power structures are produced.

Positioning is an “interactional, social practice” (Leander, 2004, p. 210) that builds a converging community understanding of power by crafting different roles and the members of the community that belong in them. A learner’s position, or place in relation to power and possible action within a social space, effects what and how they learn. Exploring the chronotopes participants bring to an interaction is an underused way to analyze learner positioning. Leander (2002; 2004) argues that social interactions can be viewed as the co-creation of chronotopes, building on Bakhtin’s concept; participants in an interaction bring together different chronotopes to collectively construct social life. Chronotopes, in this view, are interpretations of space-time shared and constructed together in an unfolding interaction. Foucault (1995) argues that power is enacted in a distributed way, through interactional discourse by participants who collectively discipline each other. Therefore, chronotopic analysis allows us to analyze power roles crafted in a learning community and make sense of how power is enacted in a distributed way in social practice.

Modes of inquiry
Engineering Robotics is housed at Engineering High School, a Title 1 school that serves a majority black and Latinx students from a midsized Northeastern city. All team members and mentors featured in this research are black, Latinx or southeast Asian. The participating coach is a white man, as am I. All participants are referred to by pseudonyms in Table 1 and throughout this paper. Episodes for this study span two competition years.

Table 1: EHS Robotics Club participant list

<table>
<thead>
<tr>
<th>Name</th>
<th>Major Position/Duties</th>
<th>Grades During the study</th>
<th>Year #s on Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denisse</td>
<td>Robot Driver</td>
<td>9th and 10th</td>
<td>1st and 2nd</td>
</tr>
<tr>
<td>Ave</td>
<td>Coding and Robot wiring</td>
<td>12th (mentor next year)</td>
<td>1st</td>
</tr>
<tr>
<td>Jav</td>
<td>Robot Designer, Builder and Machine Shop</td>
<td>10th and 11th</td>
<td>2nd and 3rd</td>
</tr>
</tbody>
</table>
Influenced by Interaction Analysis (Jordon & Henderson, 1995) I focused on taping the Engineering Robotics team in action, while they designed the robot, practiced driving the robot, and participated in competition. My goal was to capture a viewpoint of the participants’ experience together. I chose what to record in an emergent way deciding where learning was happening in the moment, influenced by Goldman-Segall’s (1998) digital video ethnography.

Denisse, a female Black and Latina 9th grader (during the first year of the study) and newcomer to EHS’ robotics team is the focus of this paper. She becomes the driver of the robot at competitions in her first year on the team. For this paper, I analyzed three episodes of team interactions to analyze the social patterns that result in her positioning in the role of the driver. These particular episodes occurred during instances of practice and competition over two seasons. Influenced by Sewell’s (2004) definition of culture as continually contested, I selected the episodes for this study in relation to a cursory understanding of interactional patterns. I choose two episodes that somewhat match the typical patterns and one that is a contradiction. Video data was analyzed in the tradition of Interaction Analysis (Jordan and Henderson, 1995; Hall & Stevens, 2015).

In the first video clip selected, Denisse wears the GoPro on her head as she drives a practice robot around the workshop. She eventually practices picking up and shooting a large ball at the practice goal. After Ave troubleshoots a connection issue with the robot, he gives her the controller and comments on her driving. In the second video clip, the drive team is standing with their robot discussing the competition just behind the field minutes before their first match of the season. Ave, Jav, and John are all standing near the robot, trying to re-teach Denisse the controls; Ave changed them that morning with the consent of the coach but without telling or consulting Denisse. In the third clip, Denisse and Eliza practice driving the robot in the shop during the second year of the study. In a different driving configuration than the year before, Denisse controls the motion of the robot with a large joystick and Eliza controls the mechanical motion of the robot. This video clip focuses on their interaction with John, and me (the researcher) as they practice and discuss strategy for moving around the game map. The clip takes place before the team’s second competition and exemplifies different positioning practices.

Analysis

A focus on chronotopic contributions to an interaction shines the analytic light on how participants bring different interpretations of past space-time and perspectives on the future space-time to collaboratively create present interaction. According to Leander (2004) a “lamination” occurs when these contributions become part of the interaction and are collaboratively positioned. In the case of this study, chronotope laminations locally construct the development of Denisse’s role as the driver on the team and the power that comes with it.

Episode 1: Becoming the driver

In the shop during practice, Ave and JF, the coach, laminate non-present chronotopes to collectively define Denisse’s role and construct their view of the choices she could make as a driver. Once Denisse gets to use the controller, she beings by shooting the ball the robot holds at a high goal. Ave then challenges a choice she makes:

1. The Robot: ((shooter motor starts))
2. Ave: You didn't do the sequence
3. Denisse: I don’t care.
4. Ave: Its' too late now.

In line 2, Ave refers directly to the current choice that Denisse makes, not to use the programmed shooting sequence with the push of a button but to manually turn on the shooting motor and drop the ball into the shooter. Denisse counters with “I don’t care” (line 3), laminating the chronotope with Ave’s contribution that positions her as the driver with decision making power in the future. Later in the practice session JF, the coach, asks her to justify why she was shooting from a certain distance, “why so far back,” a reference to a past-chronotope. After some discussion, he uses her input to adjust the shooter. Both of these interactions show the influence of past and future chronotope laminations. They position Denisse with power as a decision-maker in the role of the driver; they incubate her development of agency in that role.

Episode 2: A controlled driver
Minutes before their first match at their first competition of the year, Ave reviews the new driving controls for
Denisse on the Xbox controller while Jav and John look on. Two important moments in this interaction chain
highlight the way Jav, Ave, Denisse, and John position Denisse’s role as the
driver. After showing Denisse the new controls, Ave places the controller in
the middle of their interaction formation towards Jav and her. Jav grabs the
controller as both he and Denisse reach for it (see Figure 1) and says, “Alright
so run it through me” handing it to her. Paired with Jav’s words the grabbing
gesture physically embodies the denial of Denisse’s chronotopic contribution
to the interaction and her positioning as driver. It shifts the interaction to one
between Denisse and Jav. Just after, Denisse challenges the button change
she is just hearing about. John, the driving mentor, joins the interaction:

1. Denisse: I thought it was Y ((looks at Ave))
2. Jav: No we changed ((looks to John))

Denisse brings a chronotope contribution citing the past-space of the robot and her practice (line 1) where
the control was Y. Her attempted lamination is disregarded with “we changed.” Further, John’s utterance rejects any
past or future space-time contribution, bringing to bear a narrative where only the present matters.

Episode 3: Learning role of being a driver
In this clip, John is visiting the shop about a year after the clip from episode 1 and 2 took place. He discusses
strategy with me (the researcher), Denisse and Eliza, as the two of them practice driving and operating that year’s
robot. Particularly, he tries to share with Denisse that she should drive backwards when bringing a gear back from
the other side of the competition field to complete one of the objectives of the game for points.

1. Researcher: Most people want to do it that way. Right? [Drive forward all the time]
2. John: Yeah that’s a normal condition thing. Most people wanna do it that way anyway
3. John: You shouldn’t have to.
4. Researcher: [to Denisse] He’s saying try backing up. So trying grabbing it ((the gear))
   and then just backing up and dropping the gear.
5. Denisse: Oh I can do that.
7. Denisse: I don’t?
8. John: You haven’t been.

John refers to two distinct space-times to position Denisse as a driver with decision making power, while
still trying to persuade her that driving backwards can help her accomplish the task faster with the robot. First, he
refers to an imagined future-space of the competition with “you shouldn’t have to [drive forward]” (line 3). This
laminates a chronotope that positions Denisse with a decision of how to drive in competition. Then, he juxtaposes
the future chronotope with an interpretation of past space-times, “you don’t” (line 6) and “you haven’t been” (line
8). Therefore, in trying to get her to practice a specific technique, he argues for its possibility in an imagined
future, and then argues that she has not used it at all in his interpretation of past space-time of the earlier
competition. Both become laminations which collaboratively position Denisse as a decision-making driver
showing a choice she makes in the role of the driver.

Discussion
In episode 1 and episode 3 which are a year apart, different members of the interaction bring past and future
chronotopes to bear on the interaction which are them laminated, co-constructing the role of Denisse as a decision-
making driver. Both collaboratives episodes shine the light on decisions she has the agency to make as the driver:
using the sequence (episode 1) and driving backwards (episode 3). These moments show the dialogic nature of
the robotics club where members “live in the chronotope” (Bakhtin, 1981) actively participating in the
construction of Denisse’s driver role together embracing different viewpoints. Denisse’s development in this role
is privileged. In the competition episode, all chronotopic contributions are rejected by the participants except
Denisse. This constructs a social narrative consistent with what Bakhtin (1981) calls “adventure time” whereby
time and space are separated, and all historical and possible futures are disregarded for a focus on the emerging
present. Leander (2002) argues that this typically occurs in institutional spaces such as classrooms, or “classroom
adventure time.” Here, the social interactions framed in adventure time privileges the imminent competition and deprivileges Denisse’s learning, positioning her as a controlled driver who operates the robot as she is told where to go and what to do. Denisse’s disciplining deprivileges her expertise and disrupts her ability to develop a deeper sense of how the robot drives. This severely limits her ability to develop as a driver during competition.

This comparison, taken in a lens of Foucault’s micropower (1995), portrays a view of the social mechanics of how Denisse’s role is collectively disciplined. The differing access to power may be driven by perceptions of her race, as an identifying Black and Latina youth, and/or her gender, as a young woman in a male gendered space. Further analysis is necessary from a feminist and anti-racist lens to consider the reasoning. Yet, the difference between the two types of episodes, practicing episodes (1 & 3) and a competition episode (2), over two seasons of the Engineering Robotics’ paints a picture of how imminent competition may influence newcomers positioning and how roles are disciplined as acts of power. It also begs the question, does competition typically influence learning communities like this to reject the dialogic nature of chronotope co-construction and craft a narrative in adventure time?

Significance
This work points to a specific instance where a STEM learning opportunity with competition as a leading activity limited a newcomer’s development, disciplining her out of an active role in competition time. From a sociocultural perspective of participation’s relationship to learning (Rogoff, et al. 2003), we must embrace learning possibilities that focus on competitions dialogically positioning learning as a leading goal and focusing on the roles it creates.

References

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Developing a Library of Typical Problems During Collaborative Learning in Online Courses

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Abstract: Feelings of isolation and a lack of interactivity are among the reasons cited for student dropout in online learning settings like MOOCs. A possible solution is to offer MOOC participants the opportunity to engage in collaborative activities. However, small-group collaboration in MOOCs poses several challenges which may reduce the beneficial effects of collaboration and reduce participants’ satisfaction with both the collaboration process and the course. In this work-in-progress paper, we describe the development of a library of typical problems that may occur during online collaboration in asynchronous, text-based online settings. The library covers the following aspects of collaboration: communication, joint information processing, coordination, and reciprocal interaction. The library was generated in a process by combining a top-down literature search and a bottom-up identification of typical problems in existing collaboration data. The library will be used as a basis for developing intelligent support for student collaboration in online courses.

Introduction

Less than 10% of participants in massive open online courses (MOOCs) finish the course and earn a certificate (Khalil & Ebner, 2014). One reason for student attrition in these courses are feelings of social isolation which result from low participation and a lack of interaction between students (Khalil & Ebner, 2014). Research on the role of interactivity in online courses underlines the importance of student interaction for satisfaction with the course and for remaining in the course. Interaction between learners in an online course promotes a sense of community (Liu, Magjuka, Bonk, & Lee, 2007), increases students’ satisfaction with the course (Bernard et al., 2009) and reduces feelings of isolation (Khalil & Ebner, 2014), thus lowering the risk of dropout from the course. Hence, providing students with opportunities for interaction by implementing instructional designs such as collaborative learning is a promising approach (Bernard et al., 2009). Indeed, the implementation of small-group collaboration is a prominent development in the design of e-learning courses (Rosé, Goldman, Zoltners Sherer, & Resnick, 2015). By interacting, learners can benefit from each other’s resources, be it cognitively by exchanging knowledge and thereby promoting learning, or socially by connecting with each other to build relationships or to give and receive help with problems concerning the course. Further, establishing meaningful interaction between students through collaborative learning aims at reducing feelings of isolation. However, simply providing students with tools for collaboration (e.g., discussion forums or shared text editors) does not automatically lead to interaction between the learners (Kreijns, Kirschner, & Jochems, 2003). And even if students interact, effective collaboration usually does not occur spontaneously (Rummel & Spada, 2005). However, collaborative learning settings not only face challenges resulting from the absence of productive collaboration behavior, but also challenges that arise from unfavorable interaction processes. This potentially hinders the success of the collaboration and may lead to frustration. Hence, collaborative learning requires support that targets participation and effective interaction between learners, but also aims at reducing unfavorable interactions during collaboration. This work-in-progress paper describes the development of a library of typical problems that may occur during collaborative learning in online settings. Supporting students’ collaboration regarding these problems allows collaborative learning arrangements to unfold their potential, thus reducing the risk of student frustration with the online course and ultimately reducing dropout from the course.

Method

Following the procedure used by Meier, Spada, and Rummel (2007) for developing a rating scheme for the assessment of quality of collaborative problem solving, our library of typical problems was generated following three steps. In the first step, a top-down literature search was conducted to identify suboptimal interactions between learners that may lead to process-losses and dissatisfaction with the collaboration process, thereby lowering participation and increasing the risk of dropout. The process-dimensions presented by Meier et al. (2007) provided the starting point for the literature search using the databases Academic Search Premier, Google Scholar and Ovid. Next, additional literature was searched for the dimensions covered in Meier et al.
Typical problems of collaborative learning were found in overview studies describing ineffective processes during collaborative learning (e.g., Aggarwal & O’Brien, 2008), in studies reviewing several criteria for beneficial interactions during (net-based) collaborative learning (e.g., Meier et al., 2007) and in studies describing specific essential processes during collaborative learning (e.g., Baker, Hansen, Joiner, & Traum, 1999). If a publication discussed typical problems, these problems were extracted and added to the library. If a publication provided a description of interactions that are beneficial for collaboration, then the absence of the described behavior was added to the library (as the absence of beneficial interactions also constitutes a problem). For each problem, a brief description of the ineffective behavior was added to the library.

In the second step, a bottom-up approach was used to collect exemplary interactions for the problems identified during the previous step and to identify further problems that were not yet included. For this purpose, a small sample of logfiles from collaborative assignments was analyzed. This data was collected in a large university level online course (reported as Course 2 in Erdmann et al., 2017) In Moodle, each collaborative group was provided with a forum for communication and a shared text-editor (Etherpad) for working on the collaborative assignments. Out of the 55 groups across all collaborative assignments, ten groups were randomly selected for the analyses reported in this paper. Examples for the typical problems obtained in the first step were identified by manually surveying the logfiles for events matching the descriptions of the problems. Both quantitative (e.g., amount of characters in forum or shared text) and qualitative (content of forum contributions) indicators were included in the examples. Additional problems were identified by analyzing the content of the discussion forums. Problems were added to the library when learners expressed frustration with the collaboration process (e.g., by stating that they found it unfair, if not all group members would contribute to the task) or confusion about the current state of the collaboration process (e.g., by stating that it was difficult for them to assess whether a step had already been completed). In total, two additional problems were added (see next section).

The third step was an iteration of the first step and included a literature search to theoretically ground the observations from the second step. After finishing these three steps, three filters were applied to the library which excluded problems as follows. (1) Because the library will be used for developing support for an online course which utilizes asynchronous, text-based communication, problems which target synchronous collaboration were excluded. (2) As satisfaction with the collaboration process is a prerequisite for engagement and thus for interactive processes associated with learning, we focused on processes that we expect to have an impact on affective variables such as satisfaction with the course or satisfaction with the collaboration process. (3) Finally, because the library focuses on observable behavior, problems concerning attitudes were excluded. Examples for excluded problems are provided in Table 1.

Result: Library of typical problems during online collaborative learning
Following the procedure described above, eight typical problems were identified (see Table 1).

Table 1: Library of typical problems during online collaboration.

<table>
<thead>
<tr>
<th>Process-dimension</th>
<th>Typical problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Mutual understanding</td>
<td>(1) Lack of feedback on forum posts (e.g., questions, suggestions)</td>
</tr>
<tr>
<td>Flow of conversation (*)</td>
<td>No explicit turn-taking during conversation</td>
</tr>
<tr>
<td>Information pooling</td>
<td>(2) New/unshared information is introduced without reference to already shared information</td>
</tr>
<tr>
<td>Decision making (**)</td>
<td>The group decides on an option before having evaluated all shared information that was contributed by the group members</td>
</tr>
<tr>
<td>Task division</td>
<td>(3) Groups do not plan their problem solving process (collaboratively)</td>
</tr>
<tr>
<td>Structuring the problem solving process</td>
<td>(4) Groups are stuck in planning and neglect working on the task itself</td>
</tr>
<tr>
<td>Time management</td>
<td>(5) Group members do not indicate their progress on the task(s)</td>
</tr>
<tr>
<td>Equal engagement of group members</td>
<td>(6) Group members do not signal individual time constraints</td>
</tr>
<tr>
<td>Individual task orientation</td>
<td>(7) Individual group members contribute nothing or very little to the group task</td>
</tr>
<tr>
<td>Team task orientation</td>
<td>(8) Individual group members ‘nag’ their peers to contribute their share of the work</td>
</tr>
</tbody>
</table>

(*) example for a process-dimension excluded by filter (1), (**) example for a process-dimension excluded by filter (2), (***) example for a process-dimension excluded by filter (3).
Regarding communication, (1) the bottom-up analysis revealed situations where group members signaled frustration when they contributed to the forum (e.g., asking a question), but did not receive an answer from their peers, or only after a long delay. However, timely responses foster a sense of community (Sung & Mayer, 2012). Regarding joint information processing, (2) neglecting or failing to connect newly introduced information to information already shared in the group (elaboration, Webb, 1989) reduces the quality of the problem solving process, which can in turn lead to the impression that the collaboration is ineffective or to the impression that efforts previously made by other group members are not valued. Regarding coordination, suboptimal planning of the collaboration (Wittenbaum, Vaughan, & Stasser, 2002), in particular the (3) absence of task division can decrease the group’s efficiency and make the problem solving process tedious. (4) If a group invests a large amount of time into planning the collaboration less time is available for information exchange and problem solving which often are the main objectives of the collaboration. This increases the pressure on the group and potentially harms the quality of the joint product. Therefore, a group should simultaneously plan the collaboration and work on the task (Walther & Bunz, 2005). (5) The bottom-up analysis further revealed situations where individual group members contributed to the shared text but did not communicate their progress on the task to the other group members, hence creating obscurity and ambiguity, which violates Grice’s maxim of manner (Grice, 1975). The resulting lack of group awareness (Buder, 2011) appeared to make it difficult for the other group members to assess the state of the task and left them confused whether it was their turn to work on the task. (6) If students are not aware of their group members’ time constraints (e.g., when they plan to start working on the task and how much time they can allocate to it), they may mistake a group member’s intended absence (e.g., due to a competing deadline) as lack of engagement (social loafing, Aggarwal & O’Brien, 2008). Regarding reciprocal interaction, that is, all group members are equally involved in the collaboration, a common problem during collaboration is that (7) some group members invest little effort in the joint product, while receiving the credit gained through the work of the remaining group members (social loafing, Aggarwal & O’Brien, 2008). This may result in frustration or even decrease the motivation of the active group members to contribute any further (sucker-effect, Kerr, 1983). (8) If students ‘nag’ their peers to make them contribute to the task, the group climate suffers and processes of collaborative decision-making are impaired (Walther, 1996).

**Discussion and outlook**

In this work-in-progress paper, we described the development of a library of typical problems which may occur during asynchronous, computer-mediated, text-based collaboration settings in higher education. The library was developed using a top-down literature-search and a bottom-up analysis of existing collaboration data. While the top-down approach ensures that the library encompasses a broad range of typical problems with a theoretical foundation, the bottom-up approach provides exemplary events for these problems and adds relevant phenomena. This library can be used to analyze interactions and detect suboptimal collaboration behaviors which can potentially impair the collaboration process, leading to low quality of the joint product and dissatisfaction with the collaboration process. Currently, the application of the library requires human coding of collaboration data. Supporting learners in large-scale online courses would require an automated analysis of interactions. This could be realized through the application of learning analytics. For example, the analysis of action sequences (e.g., categorizing forum contributions; Doberstein, Hecking, & Hoppe, 2017) can be used to detect extended coordination phases or a lack of group members signaling their progress. Furthermore, the analysis of concepts and their interrelations within a text corpus (e.g., a forum discussion; Daems, Erkens, Malzahn, & Hoppe, 2014) can help to identify a lack of elaboration of newly introduced concepts. A limitation of the current library is the small sample size that was used for the bottom-up identification of typical problems. In order to provide further typical problems, more collaboration data need to be examined. Hence, our aim is to update and expand the library by repeating the three steps described above using collaboration data yet to be collected. A library grounded in both, theory and empirical data, would be a valuable basis for instance to develop automated analysis of collaborative behavior in large online courses and to inform the detection of unfavorable events. These automatic analyses may ultimately feed into adaptive support (e.g., in the form of intelligent adaptive tutoring; Diziol, Walker, Rummel, & Koedinger, 2010).

**References**


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Critique Processes in Digital Journalism

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Abstract: Youth who participate in online communities such as DeviantArt and Scratch benefit from a lively, voluntary critique practice, which is often absent from classroom practices. However, face-to-face participatory cultures can mirror the kind of practices found in these online spaces. My research suggests that youth who participate in digital journalism engage in peer critique on a regular, ongoing basis; that youth use peer feedback from both novice and mentors to transform their understanding of digital journalism; and that recognition of an authentic, engaged audience can create organic critique opportunities.

Keywords: digital journalism, critique, feedback, digital media production

Major issues addressed
Any brief visit to sites such as DeviantArt demonstrates that critique is a lively voluntary process in online participatory cultures (Jenkins et al., 2007). In online participatory cultures, youth members of communities such as Scratch (Fields et al., 2013) and fan-fiction sites (Black, 2005; Magnifico, Curwood, & Lamar, 2015), regularly participate in organic critique and collaborative problem solving with like-minded peers as they feel that their contributions matter (Jenkins et al., 2007). However, when critique processes are moved to the classroom, critique is often teacher driven through carefully crafted peer review questions that encourage youth to respond as they believe their teachers would want to hear (DePardo & Freedman, 1988; Ball, 2013). This reduces critique to a list of narrow topics, or feedback, and minimizes the amount of time youth spend conducting careful analysis.

Critique is not an easy task to teach, nor is it an easy task to learn. Critique requires moments of interaction where an author freely shares his or her draft with peers and discusses its ability to match the author’s vision. While feedback occurs constantly during production, critique requires a level of analysis only possible with an understanding of the author’s intent. This process becomes more complex when reviewers are asked to analyze digital texts that combine image, audio, and textual features into a single product. Perhaps for this reason, little has been written about critique practices of digital texts inside and outside of the classroom. Ball (2012) argues that critique processes are highly contextual and that criteria for assessing digital texts should be organically created with youth for each unique project. With this in mind, my case study explores the possibilities of critique in an unique interest driven face-to-face participatory culture where youth engage in video journalism production. The unique nature of digital journalism requires composing skills (coming up with a good story, characters); journalism skills (interviewing, ethics); video production skills (lighting, camera angles); and video editing skills. This complex process opens up numerous opportunities for collaboration and critique.

My work explores two research questions:
- Why do youth participate in critique while producing digital journalism?
- How do youth use feedback from the critique practice to revise their work?

Significance of the work
My study adds to current research on digital production providing a clearer understanding of youth digital critique processes. My study challenges traditional notions of peer review found in composition courses which suggests that critique is something that happens on a single peer review day and proposes that critique occurs regularly throughout the production process. Moreover, while previous research suggests that most composers recognize the complexity of audience throughout the composition process (Halverson & Magnifico, 2013), my work demonstrates how this recognition can drive critique. This conclusion has important implications for digital media educators who wish to create authentic opportunities for critique.

Theoretical approach
My work is grounded in the understanding that composition is a socially constructed activity (Brandt, 1990; Dyson, 1995; Nystrand, 1986). Just as Bakhtin (1981) argues that writing is an interaction between an individual and the social world, I recognize that youths’ knowledge about writing is shaped by the socio-political landscape of the classroom; conversations with their peers; and interactions with educators. Moreover, as youth
compose texts, they integrate their own perceptions and perspectives on a given topic as language is never neutral, but about “giving and getting different perspectives on experience” (Gee, 2001, p. 716). Critique, therefore, is a process whereby peers read a text with their own perspective and offer their own way of viewing the world. As active members of a participatory culture (Jenkins et al., 2007), I seek to understand the catalysts that inspire feedback and critique to occur, the extent to which youth seek out critique from their peers, the extent to which youth listen to their peers’ perspectives throughout the composition process, how these perspectives mesh with their own perspectives, and then how this dialogic nature plays out as youth revise their work.

**Methodological approach**

I worked as a participant observer in a digital media course serving youth ages 15-18 for the length of one production cycle. Observations and field notes were key to understanding the ongoing critique practice that occurred regularly. I coded my field notes noting the impetus for critique (teacher initiated, author initiated, audience initiated); the moments of critique (pre-production, filming, editing, and post production); and the topics discussed during critique (cohesion of ideas, creating a clear message, and recognition of audience).

I collected storyboards, rough cuts, and final cuts of videos to determine the extent to which youth incorporated their peers’ feedback. I conducted bidirectional artifact analysis, which combines narrative analysis, discourse analysis, and artifact analysis and allows researchers to move bidirectionally, “from final product backward and from initial idea forward” (Halverson & Magnifico, 2013, p. 406). I explored the relationship between students’ final artifacts and their drafts to determine how and when students incorporated elements of critique into their final products.

**Major findings**

The digital media course resembled participatory cultures found outside of school in that students were offered low barriers to artistic expression and civic engagement. In addition, students were intrinsically motivated through a common interest in creating digital journalism about student culture. Each week, youth worked in small groups to create video segments which were then combined to form their Friday video announcements, a comic and often satiric look at high school culture. This set up quickly created a community built on support, collaboration, and investment in one another’s creative work. As youth recognized that the success of the video announcements rested not only in their unique segment but also on the collective episode they came to adapt their production practices. The collaborative goal of creating a successful and engaging program made feedback a regular occurrence.

**Feedback catalysts**

Throughout the production process, youth engaged in teacher initiated, author initiated, and audience initiated feedback processes from both experts and peers.

**Table 1: Catalysts for Peer Feedback in Digital Journalism Production**

<table>
<thead>
<tr>
<th>Catalyst For Peer Feedback</th>
<th>Moments of feedback</th>
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| Teacher initiated          | 1. Pitching stories to classmates during pre-production  
|                            | 2. Viewing rough cuts of videos with classmates prior to final editing  
|                            | 3. Using self assessment rubrics post production  |
| Author initiated           | 1. Requesting group feedback throughout the planning process  
|                            | 2. Soliciting input from group members and experts throughout the filming process  
|                            | 3. Inviting feedback from all group members and experts with iMovie or Final Cut Pro knowledge during editing process  |
| Audience initiated         | 1. Offering feedback during chance encounters throughout the filming and editing process  |
The teacher initiated feedback process occurred pre-production through story pitches; during production while viewing rough cuts; and postproduction with self-assessments. Author initiated and audience initiated peer feedback took place more regularly yet most often informally through group conversations. While authors regularly sought feedback from their group, they also sought out expert classmates based on their knowledge of software and their reputation for using tools in innovative and creative ways. As youth became more comfortable with the discourse of digital journalism, their roles wove back and forth between learning and mentoring. For example, one group was made up of five students, two of whom had extensive prior experience with Final Cut Pro. In the first two weeks, the two experts started off driving the revision choices while positioning themselves in front of the computer. After a week of watching and learning from the experts, novice students’ feedback increased and they started taking control of the mouse when they wanted to demonstrate their vision to the rest of the group.

**Critique practices**

While students regularly provided feedback to their group members regarding topics such as visual, audio, and editing choices, in depth critique most often occurred when tied to audience considerations. Students showed keen attention to helping one another create segments with clear messages and visions that would hold their peers’ attention. This often came into play as many groups sought to create parodies of popular series or recreate popular YouTube sensations. In particular, one group of three young producers sought to mimic a popular YouTube vlogger, but feared that their peers wouldn’t recognize the connection with the original. They regularly presented drafts of their videos to the peers in the classroom to better understand whether their larger peer audience would understand their larger vision.

Youth also regularly worked together to revise their segments so that their teacher, who served as the executive producer and represented the larger voice of the faculty, would allow their segments to be shown during the Friday video announcements. Through this analysis, youth recognized two audiences: their peers and the faculty at their school. They navigated the complexities of composing for two audiences through organic peer critique practices.

**Using peer feedback for revision**

Early bidirectional artifact analysis suggests that youth revised their work constantly throughout the composing process using expert and peer feedback, picking and choosing when to use feedback in its entirety, when to use suggestions as a guide to ask for peer assistance and additional critique, and when to ignore the feedback. One group questioning the best method to provide viewers with supplemental information solicited teacher feedback, feedback from other groups, and talked through the options as a group coming up with a new solution that incorporated elements of feedback from several sources. Interestingly, their choices were not made by whether or not the feedback was from an expert, novice, or mentor, but whether the suggestions fit with the larger message they wanted to convey in their final product.

**References**


Words Mean Things: How Museum Workers’ Discursive Practices Position the Diverse Communities They Seek to Engage

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Michael Horn, Northwestern University, michael-horn@northwestern.edu

Abstract: How do museum workers, particularly those in science and technology centers and museums, conceptualize racial, ethnic, and cultural diversity? What might the language they use (e.g. “low-income,” “non-English speaking families”) to describe racially, ethnically, and culturally diverse communities reveal about how museum workers position persons and groups from these communities? In this paper, we present our preliminary findings from an interview study with science museum workers regarding their beliefs about diversity. In doing so, we offer insights about the racialized narratives embedded in discourses about diversity and diverse communities and discuss the potential implications of their use for learning.

Keywords: Positioning, Discourse, Diversity, Equity, Museums

Introduction and background

Calls for reform in museum education emphasize the need for museums to diversify their audiences (Smithsonian Institution, 2001; Fred & Farrell, 2008). Typically, these appeals for audience diversification are focused on the cultural, ethnic, and racial identities of museum visitors, directly addressing the underrepresentation of African Americans/Blacks, Latinos/Hispanics, Asians, and Native Americans who comprise only 9% of core museum visitors in the United States (Farrell & Medvedeva, 2010). In order to attract visitors from underrepresented groups, museums have employed a wide variety of marketing, exhibition, and educational programming strategies. Despite these efforts, participation from communities of color remains low.

Common questions asked by museum researchers and practitioners include: How can museums foster museum-going habits among underrepresented groups (Falk, 1995)? How can museums connect diverse communities with social networks that value museums over other forms of leisure (Ostrower, 2005)? How can museums provide these communities with the specialized knowledge necessary to understand and appreciate their resources (Schwarzer, 2006)? While these questions may seem innocuous, the site of change museums seek tends to be external to their institutions and located within communities of color.

Scholarly criticism of museums suggests that the change that needs to take place is within museums themselves (Sandell, 2003; Janes, 2009). Increasing attention is being given to re-examining the fundamentals of museum practice, particularly the pedagogical frameworks that underpin the design of their exhibitions and education programs (Hooper-Greenhill, 1999; Dawson, 2014). Recommendations for re(de)fining museum practice across the domains of anthropology, sociology, and education have largely converged around the need for museums to design experiences that take into account cross-cultural differences in meaning-making. These recommendations often call for designing experiences in collaboration with the communities museums seek to engage (Wali, 2006). Yet, despite the growing evidence that indicates communities of color feel unwelcome and alienated in museums (Melber, 2006; Dawson, 2014), museums struggle to meaningfully acknowledge, validate and advance the multiple epistemologies that exist across communities of color.

There exists a dearth of research on why it has proven so difficult for museums to design inclusive, culturally relevant experiences that attract and meaningfully engage racially, ethnically, and culturally diverse communities. Some posit that the historical origins of museums make it difficult for them to design for inclusion because they have been complicit in the construction of physical and cultural hierarchies that promote inequities and negative conceptions of underrepresented groups (Lynch & Alberti, 2010). Others have cited the bureaucratic nature of museums and their tendency to operate by consensus as another obstacle to developing experiences for diverse publics (Conaty & Carter, 2005). Several have speculated that museums perceive themselves as already engaged in diversity work by preserving and interpreting materials that provide the mainstream public access to the cultural lives of diverse communities (Karp & Lavine, 1991). While this prior work contributes to our understanding of some of the institutional barriers that are present in museum settings, we seek to shift the normative framing of museums from the organizational level to thinking about museums as having intentional actors—curators, exhibition developers, museum educators—whose suite of work is focused on designing and facilitating educational experiences for existing and potential publics. This shift is consequential because design decisions are not made in isolation and are deeply influenced by 1) the beliefs of museum workers; 2) their interpretations of the cultural and intellectual values and practices of their potential...
audience(s); and 3) their understanding of the beliefs and values of their institution, which may be counter to their own. It is here where we wish to locate our work as we seek to interrogate museum workers’ beliefs about racial, ethnic, and cultural diversity as well as their beliefs about persons and groups who come from communities museums have labeled “diverse.” We do this by examining how museum workers position themselves discursively in relation to the communities of color they seek to engage.

Conceptual framework
We use positioning theory, a framework developed within discursive social psychology, as an analytic lens for our work. While positioning theory is typically associated with examinations of interpersonal encounters, it has also been applied to textual analyses as well as interview data (Harré & Slocum, 2003; Konaev & Moghaddam, 2010). Our paper is a case of applying positioning theory to interviews with museum workers. Positioning requires that we engage in a close analysis of the sociolinguistic cues that museum workers use to position themselves and others. In this paper, sociolinguistic analyses based on positioning theory reveal how museum workers’ discourses position and instantiate self (and institution) in relation to the communities they wish to engage as well as to the larger, and often ambiguous, concepts of racial, ethnic, and cultural diversity. These analyses also explicitly attend to the narratives people use to ascribe themselves and others rights and duties—in other words, what do they owe and what do others owe them. By studying the way “rights and duties are taken up and laid down, ascribed and appropriated, refused and defended,” positioning theory adds a novel dimension to examinations of cognitive processes—beliefs and practices related to individuals’ moral commitments or conceptions of their moral qualities (Harré & Moghaddam, 2011, p. 132). While rights and duties are not the focus of our preliminary findings below, we foreshadow future work detailing the ways that museum workers appear to position themselves as having the right to teach and communities of color as having a duty to learn.

We place emphasis on understanding museum workers’ discourse(s) because “language not only transmits, it creates or constitutes knowledge or ‘reality’” (Bruner, 1986, p. 132). We also follow the Vygostskian notion that the meaning and structure of all discourse (public or private) is shaped by and stems from particular cultural contexts and needs to be examined in relation to the larger normative system(s) in which people live (Vygotsky, 1980). Given that one of the ultimate goals of the learning sciences is to shape, direct, or improve practice in some way, perhaps if we can understand the reality museum workers construct with their language, we can intervene in ways that help them consciously re-construct (and sustain) norms and narratives that advance the ends they (and more importantly their desired publics) seek.

Methods
We used snowball sampling to recruit 26 science museum workers from 14 institutions across 12 states to participate in our study. For this paper, we focus on 10 museum workers, all of whom work in their museum’s education department in a variety of roles including vice president, director, manager, and coordinator. We focus on museum education workers due to the perception that they perform the majority of their institution’s diversity work (a theme that emerged from our broader interview data). Of our 10 participants, two identify as African American/Black, one as mixed race, one as Latino/Hispanic, and six as Caucasian/White. Three identify as male, seven as female. Note that “science museum” includes a range of settings including natural history museums, museums of science and industry, nature and science museums, and science and technology centers. Last, the museum workers we interviewed work in museums located in major urban areas in the United States.

We conducted semi-structured phone interviews, all of which were audio recorded and transcribed. Interviews were between 60 to 90 minutes. Examples of questions we asked included: How does your museum consider the racial, ethnic and cultural backgrounds of visitors when developing exhibitions and/or education programs? How does racial, ethnic, and cultural diversity influence learning in your museum? What role do people’s racial, ethnic, and cultural backgrounds play in how they make sense of your museum’s exhibitions and/or education programs? For this paper, we focus on responses given to the following question: Are there any groups of people or communities that your museum is trying to reach that do not typically visit?

We analyzed what museum workers said by open coding interview transcripts, honing in on the phrases, terms, and labels they use to describe the communities they seek to engage to better understand how they characterize these communities. We generated codes using a modification of Strauss and Corbin’s (1998) open coding strategy, analyzing turns of talk (rather than a line-by-line analysis), which allowed us to develop themes and identify data that aligned with those themes (Charmaz, 2001). Using Strauss and Corbin’s process of conceptualizing and labeling events, we brought focus to the data that made itself known as meaningful—more explicitly, labeling both micro- and macro-events within the data allowed us to see emerging patterns. Last, we viewed our museum workers as “deep” or “key” informants (Weiss, 1994), whose knowledge was used to refute or confirm our findings as well as broaden any themes or categories that made themselves known in the data.
Preliminary findings

When asked “Are there any groups of people or communities that your museum is trying to reach that do not typically visit?,” we find that museum workers rarely or never explicitly name the communities they seek to engage. Instead, they foreground economic labels and terms such as “low-income,” “lower-socioeconomic,” “families in public housing,” “families who rely on food stamps,” “families at or below the poverty line,” “families below a living income,” and “families who live in [XYZ] neighborhoods or zipcodes” with XYZ meaning a neighborhood or zipcode known for having communities of color as their primary residents and/or for struggling with the realities of economic disparity. Our analysis also uncovered museum workers’ secondary tendency to describe communities by their citizenship status or by the language(s) they speak rather than by the racial or ethnic group to which they belong. Terms and phrases used by museum workers include “bilingual,” “first-generation,” “immigrant communities,” “non-English speaking families,” and “Spanish-speaking families.” When further pressed to name the groups or communities their museums are trying to reach, all 10 museum workers identified African Americans/Blacks and Hispanics/Latinos as the communities that are underrepresented in their visitorship and that they (or their institutions) wish to reach. Only 1 museum worker in our sample mentioned Asian communities and that same museum worker also identified indigenous native communities as a group that they would like to see visit with more frequency. We note that neither the economic labels we detailed above nor any descriptors that speak to these communities’ citizenship status or spoken language(s) accompanied the single mention of both Asian and indigenous native communities.

Discussion

There are multiple layers to the responses we received from museum workers, some of which we are still unpacking. That said, we first put forward that museum workers’ discursive practices position themselves, or their museums, as having a role to play in the educational lives of those experiencing some forms of social, economic, and/or political precarity. The labels and terms they use to describe the communities they are hoping to reach make clear a desire to engage families who may be facing food or housing insecurity, families for whom the United States may not be their country of birth, and/or families for whom English is not spoken as the primary, or sole, language. The details of the role museum workers feel their institutions can play in the lives of families experiencing such pressures will be uncovered in future analyses.

We also bring focus to museum workers’ hesitation to explicitly name communities by their race or ethnicity, instead heavily relying on the economic labels and terms we detailed above. While phrases like “low-income” or “lower-socioeconomic” might seem like benign references, museum workers’ confirmation that they are indexing African Americans/Blacks and Latinos/Hispanics with these terms signals the need to interpret these phrases as racially coded (and pejoratively classist) language. Furthermore, museum workers’ use of these racially coded descriptors positions African American/Black and Latino/Hispanic communities as economically monolithic groups, completely comprised of families living in poverty. This positioning seems to leave little room for recognizing that there is a diversity of diverse experiences among communities of color as well as a need to historically situate (or cite the social, political, and economic reasons) why and how “low-income” neighborhoods with minority residents came to be. We also ask, what does it mean that museum workers also rarely mention Asian or indigenous native communities?

We see important potential implications from these findings. We speculate that museum workers’ use of coded, economic, and racialized descriptors are constraining their ability 1) to see these communities through the lens of racial, ethnic, and cultural heterogeneity; and 2) to assess the cultural and intellectual values and practices of the communities they seek to engage. These constraints may be limiting museum workers in their efforts to develop culturally relevant exhibitions and programs that meaningfully engage communities of color. We also suspect that positioning communities of color through a primarily economic lens is influencing the ways museum workers are positioning solutions to the “problem” of audience diversity, which tend to be economic in nature. Solutions museum workers cite to engage African Americans/Blacks and Hispanics/Latinos include discounted or free museum admission, scholarships for education programs, and busing, the latter of which is troublingly similar to desegregation busing practices, wherein students of color are transported to predominantly white schools to remedy racial segregation. Foregrounding issues of citizenship and language also seem to lead to certain solutions including one-day cultural festivals, foreign language translations of exhibitions, and the development of programs or resources that communicate the value of the museum. We note that the interventions museum workers employ reveal that they seek participation from underrepresented groups in insubstantial ways and often only when it is culturally congruent. This positions communities of color as a niche audience rather than as valued stakeholders whose histories, narratives, and patronage are honored and
seen as critical components of the system of values museums hold. We must acknowledge that the choices museum workers make are often constrained by their institutional context. However, it is clear that museums need to take into full account the multiple epistemologies that exist across communities of color in order to better position themselves to design the culturally relevant experiences these (our) communities require to see museums as meaningful spaces for engagement.

References


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Agent-Based Models to Support Bioscience Learning in Nursing Education

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Abstract: This paper reports on a project to support bioscience learning of pharmacology in the undergraduate nursing curriculum. We designed an agent-based learning environment that represents the pharmacokinetic and pharmacodynamic processes in pharmacology. To evaluate nursing students learning with the proposed agent-based environment, we conducted a quasi-experimental study. The results revealed that nursing students who learned with the agent-based environment gained significantly higher conceptual knowledge within the key concepts of pharmacology comparing to students who learned via lecture-based curriculum. These findings suggest an advantage with implementing explanatory agent-based models that point out the essential mechanisms underlying pharmacological phenomena in nursing education.

Introduction
Bioscience understanding has been widely recognized in the literature as fundamental to competent nursing care (Fell et al., 2016). However, in the 1980s, bioscience education was deemphasized in the nursing curriculum leading to the current ‘bioscience problem’ where nurses are not adequately learning key concepts needed for their work (McVicar, et al., 2015). To promote increased bioscience education in nursing, we demonstrate the learnability of pharmacology, a cornerstone of nursing biosciences education, through the use of an agent-based model learning environment.

Pharmacology knowledge is essential for effective nursing practice because nurses administer and oversee prescribed drug therapies. Nurses spend as much as 40% of their work time on drug-related administration and oversight activities, often serving as the final intermediary between a patient and their drug therapy once it has been prescribed (Westbrook, Duffield, Li & Creswick, 2011). Considering the important and continuing role nurses play in the implementation of drug therapies, this project proposes a new strategy in undergraduate nursing education to enhance nurses’ knowledge of fundamental bioscience ideas. More specifically, our approach has been to develop activities and agent-based modeling simulation tools that could be used with nursing students to produce more desirable learning outcomes in the area of pharmacology.

Pharmacology education
Pharmacology is typically taught in nursing education through lectures that emphasize a set of core content including: 1) knowledge of specific drugs and their classes, 2) specific indications of use, dosages and side effects, and 3) some pharmacokinetic and pharmacodynamic processes. Pharmacokinetics describe how chemicals are processed in the body, including absorption into the circulatory system, distribution to various tissues, and two routes of drug elimination – metabolization and excretion. For instance, pharmacokinetics would address how different means of drug administration (e.g., oral, intravenous, subcutaneous) would lead to different rates of drug distribution throughout the body. Pharmacodynamics describe how the drug affects the body, including within specific macromolecular components in tissues. For instance, pharmacodynamics would address types of drug-receptor interactions.

There are thousands of drugs available for use, and it is unrealistic for a nursing student to memorize all of the individual differences among drug classes. Understanding key concepts of pharmacokinetics and pharmacodynamics can help nurses apply their knowledge across most drugs types and predict with greater accuracy the therapeutic or toxic effects, which is vital for safe medication management. Although nursing students generally find pharmacology to be interesting, it is difficult and they report that their pharmacology skills are low, especially in pharmacokinetics and pharmacodynamics. This is in part because they find the information “appear[s] as list of unconnected facts and labels” (Logan, 2011, pp. 408). These findings highlight the need for new teaching approaches, such as agent-based modeling, to promote comprehension of basic pharmacological concepts.

Agent-based modeling environment
Agent-based modeling (ABM) is a computational modeling paradigm that encodes the behavior of individual agents in simple rules so that a learner can observe the results of these agents’ interactions. NetLogo is one such modeling environment (Wilensky, 1999) and was used to construct the Pharmacokinetic and Pharmacodynamics
(PkJd) learning environment (Dubovi et al., 2018). Exploration of agent-based models encourages causal thinking in connecting individual behaviors with systemic patterns (Jacobson & Wilensky, 2006). Learning through ABM focuses on entities and their actions (also called micro-level of the system) and global flows (also called macro-level of the system), which allows students to comprehend parallel processes by which emergent phenomena form (Wilensky & Resnick, 1999). Since pharmacological processes are about nonlinear simultaneous interaction of different molecules with one another, with drug molecules (pharmacodynamics processes), and with normal body processes (pharmacokinetic processes), the current study aimed to promote learnability of these concepts through an agent-based modeling paradigm, the PkJd learning environment.

The PkJd learning environment includes several computerized models. One of these models represents the body as comprised of several compartments and was designed especially for the current study. This “compartment model” is a well-established representation in pharmacological textbooks and pharmacokinetics science (Hull, 1979). Within the ABM instantiation of the compartment model, each compartment and their interconnections represent possible pathways for drug molecules: absorption from the digestive system; the bloodstream; distribution and drug molecules distribution to different tissues (e.g., adipose tissue), and drug elimination. While learning with the PkJd model, students can choose the route of drug administration (enteral/topical/parenteral), change the dosage concentration, and manipulate parameters of distribution and elimination processes (amount of muscle and adipose tissue mass). In addition to the representation of compartments, the PkJd environment includes time plots and monitors which show the amounts of drug global actual count (macro-level) that can be easily related by students to what is viewed as happening in the different compartments (micro-level; Figure 1).

![Figure 1](image1.png)

**Figure 1.** The screenshot of PkJd learning environment. **a.** The compartment model, which schematically represents different spaces in the human body, enables exploration of molecules possible pathways for comprehension of pharmacokinetic processes. **b.** Five screen snapshots showing the spotlight effect, which allows students to pay attention to one molecule’s path and relate it to global patterns of absorption, distribution and elimination.

Learning with the PkJd environment models was guided by worksheets that provided learning activities. The activities were anchored into different parameters of the system—the micro-level, the macro-level, and the link between them. For example, to enhance understanding of the micro-level, students were asked to choose one molecule in the agent-based model and then follow it while it goes through the absorption, distribution and elimination processes (Figure 1b). Then, we asked students to follow three other molecules and compare their pathways. Since the molecules pathways in the model are random and parallel, we expected that this activity would support causal understanding of the system and link between the different pharmacokinetics concepts (e.g. distribution and elimination), which are interdependent and occur simultaneously.

**Methods**

**Research design, participants and procedure**

This study employed a quasi-experimental, controlled pretest–intervention–posttest design with quantitative analysis. Participants included sophomore nursing students who were attending the traditional, lecture-based pharmacological course during the fall semester in the Nursing Department at a university in Israel. The study was comprised of two groups of students: (1) an experimental group (n=89), who learned via the PkJd computer models for approximately 3 to 4 hours; and (2) a comparison group (n=51), who learned via the lecture-based curriculum. The live lectures were presented by two pharmacology experts for a total of 4 hours. The main topics were similar to topics that were emphasized at PkJd environment (i.e., pharmacokinetics parameters such as absorption, distribution and elimination; pharmacodynamics parameters such as drug-receptor interactions). The lecturers used PowerPoint presentations for demonstrations of written material, pictures related to the phenomena, and were based on mathematical formulas. This was typical of lecture-based instruction in undergraduate nursing education at the institution.

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Data collection instrument and data analysis

Pharmacokinetics and Pharmacodynamics (PkdPd) questionnaire
To assess students’ understanding of pharmacokinetics and pharmacodynamics principles, we developed a PkdPd questionnaire consisting of 10 questions (8 multiple-choice, 2 open-ended). The items were reviewed by experienced pharmacology lecturers in a university nursing department to ensure appropriate alignment of context and content and that responses could reflect a suitable level of expertise. The questionnaire evaluates the conceptual pharmacology knowledge which is divided into two subscales of pharmacology key concepts: (1) Pharmacokinetics concepts such as absorption, distribution; and elimination; (2) Pharmacodynamics concepts such as drug-receptor interactions affinity and maximum effect. Analysis of the PkdPd questionnaire using Cronbach’s alpha yielded an internal consistency score of 0.75.

Responses to the PkdPd questionnaire were coded as correct or incorrect, and the total score was calculated as the percentage of correct answers. The pre- and post-test results were analyzed with descriptive statistics (Mean, SD). Learning gains were calculated for each student as post-test score minus pre-test score. Then, descriptive statistics for learning gains (Mean, SD) were calculated for the experimental and the comparison groups. Learning gain scores were compared using a Mann–Whitney U test for non-parametric data with an effect size as $r$ (Fritz et al., 2012).

Results
The students’ pharmacokinetics and pharmacodynamics understanding was assessed with the PkdPd questionnaire. Descriptive and inferential statistics for the PkdPd pre- and posttest questionnaires are presented in Table 1. Overall, the learning gains for the experimental (PkdPd) group were significantly higher than those of the comparison group with a medium-to-large effect size. When broken down by subscale, results show that the highest learning gain was found for the two pharmacokinetics subscales—absorption and elimination.

Table 1: Comparisons of pre-test and post-test Questionnaire results: Scores and learning gains for the two student nursing groups (N = 140).

<table>
<thead>
<tr>
<th></th>
<th>Pre-test scores</th>
<th>Post-test scores</th>
<th>Learning gain†</th>
<th>Statistical tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exp. (n = 89)</td>
<td>Comp. (n = 51)</td>
<td>Exp. (n = 89)</td>
<td>Comp. (n = 51)</td>
</tr>
<tr>
<td>Pharmacokinetics</td>
<td>39 ± 19</td>
<td>42 ± 15</td>
<td>75 ± 12</td>
<td>48 ± 24</td>
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<tr>
<td>Pharmacokinetics Subscales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorption</td>
<td>30 ± 30</td>
<td>34 ± 33</td>
<td>73 ± 26</td>
<td>43 ± 41</td>
</tr>
<tr>
<td>Distribution</td>
<td>39 ± 27</td>
<td>43 ± 25</td>
<td>65 ± 24</td>
<td>48 ± 29</td>
</tr>
<tr>
<td>Elimination</td>
<td>47 ± 40</td>
<td>48 ± 36</td>
<td>92 ± 18</td>
<td>51 ± 41</td>
</tr>
<tr>
<td>Pharmacodynamics</td>
<td>46 ± 29</td>
<td>55 ± 33</td>
<td>85 ± 25</td>
<td>55 ± 27</td>
</tr>
</tbody>
</table>

Exp., experimental group; Comp., comparison group.
ª Data are presented in percentage mean ± SD, Median=Mdn, Range 0–100.
† Learning gain was computed to compensate for differences in prior knowledge of PDM questionnaire (postscore – prescore).
*** $p < .001$

Discussion
Robust understanding of the basic concepts of pharmacology—pharmacodynamics and pharmacokinetics—may support nurses’ clinical decisions related to medication management. Our findings show that students who learned
with PkPd environment gained significantly higher scores for all scales of the PkPd questionnaire than the comparison group who learned with a traditional, lecture-based curriculum. This study adds to a growing body of research showing that agent-based modeling supports learning of many different topics for middle-and high school students (e.g., in physics: Sengupta & Wilensky, 2009). This study suggests that undergraduate students can also strongly benefit from learning with agent-based models. The main difference in students’ learning outcomes with the PkPd versus the lecture-based curriculum involved understanding the two pharmacokinetic subscales—absorption and elimination. Drug absorption and elimination are tightly linked to the daily nursing practice of drug administration. Better understanding of these concepts could help nurses more effectively manage the ongoing process of assessment, identify possible complications, and adjust the treatment to patient’s individual pathophysiology characteristics.

This study’s findings point to the particular advantage of learning with explanatory ABM simulations, which is that they can make visible the essential micro-level mechanisms underlying a phenomenon. Agent-based models enable examination of the different attributes and mechanisms of a system and experimentation with modifications of particular parameters and how they affect the overall macro-behavior of the system. Varying the different attributes and observing their effect on the behavior of the system, can function as a proof of the system mechanism and, hence, build deeper understandings of fundamental content (Wilensky & Rand, 2015).

Future work will expand on the current findings to better articulate the features and affordances of the PkPd that facilitates knowledge integration (Linn, 2005) using qualitative data analysis. Beyond that, we suggest that future work should be comparing learning processes and gains with agent-based models not just with lecture-based education but with other simulated approaches and tools and different manners of deploying agent-based modeling.

References

Acknowledgement
We are especially grateful to the nursing students who voluntarily participated in our research and whose insights helped to improve the environment. We thank Mr. Joel Drake for his careful language editing.
Authentic Learning and Teaching in an Out-of-School Lab - First Steps Towards Empirical Investigation of a Theoretical Model

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Abstract: Out-of-school labs (OSLs) aim at fostering students’ interest in natural or social sciences by engaging them in authentic learning. However, definitions of authentic learning and explanations of its effectiveness are diverse. Therefore, Betz, Flake, Mierwald, and Vanderbeke (2016) developed a theoretical model that captures various aspects of this heterogeneous construct. Our goal in this paper is to undertake first steps towards an empirical investigation of this model based on data from two pilot studies that were conducted in an OSL. In both studies, we investigated whether the intended authenticity level of the method that students used to solve a given task had an impact on students’ perceived authenticity and situational interest. Our studies show mixed findings that are contrary to the assumptions underlying the model of Betz et al. (2016). Hence, suggestions for an advancement of that model as well as implications for future research on authentic learning are discussed.

Introduction
The goal of science education is not only to foster students’ knowledge of science (i.e., content knowledge of scientific concepts), but also their knowledge about science (i.e., knowledge of scientific practices) (OECD, 2007). Out-of-school labs (OSLs), also known as reach-out labs or non-formal student labs, seem to have potential to offer deeper insights into the practices of scientists and to promote students’ knowledge of and interest in scientific ways of thinking and working (Haupt & Hempelmann, 2015). To foster students’ literacy and interest in natural or social sciences, OSLs try to engage students in authentic experiential learning activities (e.g., Pauly, 2012). However, authentic learning approaches subsumed under OSLs are very diverse, and the same holds for definitions of the term authentic learning as well as for explanations of its effectiveness. A recent model of authenticity (see Figure 1) was developed by Betz, Flake, Mierwald, and Vanderbeke (2016).

Figure 1. Model of authenticity in teaching and learning contexts (grey box: adaption, see discussion).

The theoretical model is divided into three successive parts. Part 1 can be characterized as the input-component of the model, as it highlights the characteristics of the learners and the features of the learning setting that may affect the authenticity of the learning context. Part 2 outlines the interaction of these two components in the process of authentication, which results in the individual perception of authenticity. Part 3 of the model includes outcomes that may be influenced by the perceived authenticity, such as the situational interest of students. Hence, this framework contains the assumption that the characteristics of learners and the features of the learning setting affect outcomes such as the situational interest of students, but that this impact is mediated by students’ perceived authenticity. Previous research on authentic learning in OSLs demonstrated a
positive association between students’ perceived authenticity and their situational interest (e.g., Pawek, 2009). Furthermore, findings from Betz (2017) showed that the location of the learning setting had an impact on those outcomes, as her results illustrated that students who studied in an OSL perceived higher authenticity and situational interest than students who studied in school. However, the question arises whether the variation of the authenticity level of characteristics of the learning setting other than the location, affects students’ perceived authenticity and interests as well. In this paper we present data from two pilot studies focusing on whether a variation of the intended authenticity level of the scientific method that learners use to solve a given task or problem in two OSL-projects impacts students’ perceived authenticity and students’ situational interest. To investigate this question, we conducted two quasi-experimental pilot studies. Both investigations took place in an OSL at a large German university. Pilot study A was conducted in a lab for educational sciences and pilot study B in a lab for linguistics. Both pilot studies comprised two experimental conditions: an authentic method (A+) where students had to solve a problem by applying a scientific procedure, and a less authentic method (A-) where students had to solve the same task by using a practice that does not simulate the typical habits of scientists. Within the lab for educational sciences of study A, students in the A+ condition had to solve a complex problem without guidance prior to instruction. This approach is called Productive Failure (PF: Kapur, 2008) and is characterized as a highly authentic problem-solving method, as it simulates the professional practice of scientists (Cho, Caleon, & Kapur, 2015). Students in the A- condition received Direct Instruction (DI) before they applied the previously explained method to solve a problem. By receiving direct instruction, students were not asked to independently solve a complex and novel problem as scientists do. Therefore, the problem-solving phase of DI can be described scientifically less authentic. Within the lab for linguistics of study B, students in the A+ condition had to judge the grammaticality of a linguistic phenomenon by using the thermometer method (Featherston, 2008) which is an objective and authentic linguistic method. Students in the A- condition had to judge the same data by using a less authentic linguistic method of introspective judgements that builds upon highly subjective feelings for language.

In light of the assumptions within the authenticity model described above and previous research on the effectiveness of OSLs, we hypothesized that students’ perceived authenticity would correlate positively with their situational interest (H1). Moreover, we assumed that students of the A+ conditions would report higher perceived authenticity (H2) and higher situational interest (H3) than students from the A- conditions.

Method

Participants and design
In study A, 38 10th-graders ($M_{age} = 16.38$, $SD = 0.55$; 57.9% girls) from two classes of two secondary schools in Germany participated. The two classes were randomly assigned to the A+ condition ($n = 19$) and the A- condition ($n = 19$) as a whole. In both conditions, students experienced two successive 45 min. learning phases: a problem-solving phase and an instruction phase. To simulate the practice of scientists, A+ students started with the problem-solving phase that asked them to independently generate solution attempts for a complex and novel problem. Students from the A- condition started with the instruction phase before they had to apply the instructed method to solve the same problem. In study B, 49 8th-graders ($M_{age} = 14.40$, $SD = 0.57$; 63.3% girls) from two classes of two secondary schools in Germany participated. The two classes were randomly assigned to the A+ condition ($n = 26$) and the A- condition ($n = 23$) as a whole. At the day of the experiment, students in both conditions took part in the same introduction about the learning topic in the beginning as well as the same reflective discussion at the end of their lab visit. Only the main learning phase differed between both groups, in which students solved the same task while using different grammaticality-judgement methods.

Measures
In both studies, the same instruments were used to assess students’ individual interest in the subject, their perceived authenticity, and their situational interest. The individual interest was measured with seven items at the beginning of the students’ OSL visit (study A) or prior to their OSL visit (study B). An example item is “The subject of (in study A: educational sciences) is one of my favorite subjects”. As in previous OSL-studies, the perceived authenticity (10 items) and the situational interest (12 items) were assessed at the end of the students’ OSL-visit. An example item for perceived authenticity is “I think that the tasks in this project fit well with the work of real scientists”, and for situational interest “The engagement with the contents of this project was exciting for me”. Students replied on a scale of 1 (strongly disagree) to 5 (strongly agree) to each item of the three instruments. The internal consistencies of all three measures were satisfactory ($Cronbach’s \alpha = .78$ - .93). Moreover, in both studies, students’ grades in three different subject areas (German language, mathematics and in study A also educational sciences and in study B additionally English language) were assessed.
Results
For both pilot studies, MANOVAs revealed no significant differences between the A+ and the A- conditions in age, the reported grades in three subjects, nor the individual subject interest. To test our first hypothesis (H1), correlational analyses were conducted. For study A, the results showed a positive and significant correlation between students’ perceived authenticity and their situational interest \( r = .45, p < .01 \). For study B, the results confirmed this positive and significant association \( r = .42, p < .01 \). Therefore, our H1 is supported. To assess differences in the effect of the experimental condition on participants’ perceived authenticity (H2) and reported situational interest (H3), we calculated a MANOVA for pilot study A and a MANCOVA for pilot study B. In study B, students’ individual subject interest significantly correlated with their situational interest \( r = .33, p = .02 \) and was therefore included as a covariate. For study A, the MANOVA demonstrated a significant large-sized effect of the experimental condition on perceived authenticity \( F[1,36] = 11.15, p = .002, \eta^2 = .24 \). In line with our H2, students of the A+ condition who worked with the authentic method reported higher perceived authenticity \( M = 3.58, SD = 0.43 \) than students of the A- condition \( M = 3.02, SD = 0.59 \). However, against our H3, the MANOVA revealed a non-significant small-sized effect on students’ situational interest \( F[1,36] = 0.77, p = .39, \eta^2 = .02 \). Hence, the results of study A support H2, but not H3. For study B, the MANCOVA revealed no effect of the condition on perceived authenticity \( F[1,46] = 0.06, p = .81, \eta^2 = .00 \) which is against H2, but a significant large-sized effect on students’ situational interest \( F[1,46] = 14.43, p < .01, \eta^2 = .24 \). However, against H3, students of the A- condition who worked with the less authentic method reported higher situational interest \( M = 3.35, SD = 0.79 \) than their counterparts of the A+ condition who worked with the more authentic method \( M = 2.55, SD = 0.66 \). Therefore, the results of study B do not support H2, nor H3.

Discussion and conclusion
Our results suggest that contrary to our expectations, the intended authenticity of the method that students used to solve a task within two OSLs had different effects on students’ perceived authenticity (H2) and their situational interest (H3) in an OSL for educational sciences (study A) compared to an OSL for linguistics (study B). While in study A students of the A+ condition reported significantly higher perceived authenticity than A-students, in study B, students’ perceived authenticity did not differ between both conditions. With regard to students’ situational interest, the intended authenticity of the method did not have a significant effect in study A, but a significant effect in study B (as although the direction of the effect was not as assumed). Although the recent pilot studies do not offer conclusive evidence, especially due to the small sample sizes, our findings do have interesting implications for future research, and several explanations can be offered for the findings.

One possible explanation regarding the mixed effects of the intended authenticity of the method on students’ perceived authenticity (large effect in study A and no effect in study B) might be related to students’ prior knowledge about scientific methods that are used in a certain domain. As Vanderbeke’s (2017) qualitative analyses of student conversations during an OSL for molecular biology demonstrated, students’ knowledge about scientific procedures is often non-existent or incorrect. The same could be assumed for students’ knowledge of linguistic methods. Without this knowledge, it was probably not possible for participants of study B to evaluate the authenticity of the different methods, which in turn resulted in almost equal perceptions in both conditions. It must be noted that the assessment of students’ perceived authenticity in our studies did not aim at investigating whether students’ perceptions of the intended authenticity of the method were correct or not. Building upon the authenticity model of Betz and colleagues (2016), our goal was to investigate whether a variation of the authenticity level of the scientific method that learners use to solve a given task in two OSL-projects had an impact on their individual feeling of authenticity and in turn on their situational interest. However, one could assume that without any prior knowledge about scientific practices, students lack sensitivity to identify given problem-solving processes as scientific methods and afterwards to evaluate their authenticity. As study A revealed a different finding (large effect of authenticity of the method on perceived authenticity), it could be assumed that students’ prior knowledge about science depends on the domain. Therefore, it seems necessary to adapt the model of Betz and colleagues (2016) to include the assumption that the preconditions of the learners such as their prior knowledge about science, which affect their individual feeling of authenticity, are domain-specific (see grey area in Figure 1).

Another explanation could be related to the authentic learning environment as a whole. Betz (2017) showed that the OSL as authentic learning location had a major effect on students’ perceived authenticity. It is likely that the characteristics of the learning setting each have a different impact on the (perceived) authenticity of the environment. The OSL as authentic learning location might have had a higher impact on students’ perceived authenticity in study B than the method they used. As the location was the same in both conditions, their perceptions probably did not differ. Hence, future research should focus on investigations that modify the authenticity level of characteristics of the learning setting other than the method. For instance, a current study
from Brauch, Mierwald, and Lehmann (2017) focuses on the material that is used in an OSL for history education and examines whether the variation of the intended authenticity level of the given material affects students’ perceived authenticity. Building upon the argument developed before that students’ prior knowledge about science differs depending on the domain, it is again likely that depending on the domain, some features of an authentic learning setting play a more important role for students’ perceived authenticity than others. Hence, it seems appropriate to mark the characteristics of the learning setting within the authenticity model of Figure 1 as domain-specific. These assumptions should be investigated by future research with a larger sample size.

Our results regarding the association between students’ perceived authenticity and their situational interest are interesting, as our analyses revealed mixed findings with respect to their relation. The correlational analyses confirmed a positive relation between students’ perceived authenticity and their situational interest, but, in contrast to our H2 and H3, the variance analyses revealed that students’ reported perceived authenticity differed from their reported situational interest (e.g., in study A, students’ perceived authenticity significantly differed between both conditions, but students’ situational interest did not). Therefore, future research should focus on examination of this association that is assumed based on theory.

In sum, our findings contribute to previous research on authentic learning in OSLs and to the further development of a theoretical model of authentic learning and teaching.

References


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Beyond Analogy: Qualitative Dimensions of Comparing in Math Class

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Abstract: Comparisons have been shown to be effective for improving students’ understanding of mathematical concepts and procedures. The evidence for the effectiveness of comparisons has primarily come from laboratory experiments on analogy and analogy-based interventions in math classrooms rather than investigations of naturalistic math classrooms. As a result, the qualitative aspects of comparisons that may be important for the effectiveness of comparisons have been understudied. This paper describes preliminary research on qualitative dimensions of comparisons. Analysis of video-recordings of a math classroom resulted in identification of 244 naturally occurring comparisons that were coded along five dimensions. Two dimensions related to the ambiguity of comparisons and a system for representing such ambiguity are extensively discussed herein. Potential effects of ambiguity of comparisons on learning are outlined.

Keywords: comparison, analogy, mathematics, qualitative methods, representation

Introduction

Comparing – the act of identifying similarities and differences – underlies many of the things we do every day. Research in cognitive psychology, such as analogical reasoning (e.g., Gentner & Markman, 1997), has been primarily focused on comparisons in laboratory settings with limited applications to classroom contexts. Some research on comparisons in classroom contexts has been situated in math because of its highly pattern-dependent nature. Overall, the consensus across theoretical and applied studies is that making comparisons leads to improvements in procedural and conceptual knowledge in mathematics (e.g., Alfieri, Nokes-Malach & Schunn, 2013), but more work needs to be done to document why and how such improvements might arise.

Many interventions in math classrooms have demonstrated the effectiveness of comparison-focused activities versus “business-as-usual” math teaching (e.g., Rittle-Johnson & Star, 2011; Schwartz & Martin, 2004) but they have not qualitatively examined the mechanisms by which such activities led to learning gains relative to control groups. Providing only quantitative differences between treatment and control groups’ changes in test scores and limited description of both the interventions and of the control group conditions makes it more difficult to replicate the findings in additional studies that evaluate comparison as a mechanism. One study has suggested that the frequency with which students alternate discussing examples in a comparison-focused activity might be important for the development of students’ conceptual understanding of mathematical content (Schwartz, Chase, Oppezzo, & Chin, 2011). More qualitative data on how students’ thoughts or behaviors during the learning experience varied across conditions would provide insight as to what kinds of student behaviors teachers should encourage and inform how student-to-student interactions might productively interact with teacher-to-student interactions before, during, and after a comparison-focused activity (Kapur, 2015).

One study has helped make comparison research more readily applicable by describing qualitative dimensions of comparisons made in naturalistic, non-experimental math classrooms (Richland, Holyoak & Stigler, 2004). These researchers used a very strict definition of analogy, a specific subtype of comparison, to analyze only utterances in which a relationship between two entities was explicitly identified. Although these explicit analogies may be more straightforward to analyze because all of the elements of the mapping are clearly specified, the authors themselves acknowledged that other “hints at mapping” occurred that were not captured by their analysis. Gaining a better understanding of the prevalence and additional qualities of less-clearly defined comparisons as they occur in non-experimental classrooms would further inform teachers as to what teaching with comparisons might look like and help elucidate how students might learn from comparisons other than analogies.

Method

The data analyzed for this study were primarily video recordings of a sixth-grade honors math class during the 2017 spring semester. This class was situated in a well-resourced middle school in a suburb of a large Midwestern city. This class was selected because the teacher’s emphasis on inquiry-based learning and
Common Core State Standards mathematical practices – such as finding patterns, considering multiple solution strategies, and reasoning like a mathematician, all of which involve comparisons – made the class a good candidate for observing comparisons.

To identify comparisons systematically, comparisons were defined as any utterance that communicated a relationship between two or more entities. This definition extended the criteria used by Richland et al. (2004) which only included analogies (typically a relationship of similarity) between two specified entities and allowed for the examination of previously undocumented “hints at mapping.” This definition included relationships other than similarity, such as difference (e.g., two different strategies) and relative quality (e.g., a more efficient strategy). Comparisons of more than two entities were also included. Using the operational definition of comparison described above, two researchers collaboratively identified any utterances that included comparison in a subset of the video data selected from two days of class during a statistics unit focused on variability and mean absolute deviation. Any disagreements about which utterances included comparisons were resolved through discussion.

Qualitative dimensions of comparison

After identifying instances of comparison, all instances were iteratively coded along five dimensions to capture the variety of the comparisons. The five dimensions were: 1) type of entities compared, 2) type of relationship, 3) how explicit or implicit the entities were, 4) how explicit or implicit the relations were, and 5) in what context the comparison was made. Two dimensions – the types of entities that were compared and the context in which the comparisons were produced – were also analyzed by Richland et al. (2004) in their analysis of analogies. The other three dimensions emerged from the data as important variables that captured a variety that has not previously been examined in literature on comparisons. For this paper, two of the latter dimensions – how explicit or implicit the entities and relations of the comparisons were – will be presented because these dimensions have not previously been analyzed in the literature and have some potential implications for teaching and learning through comparison.

Representational system

To analyze the comparisons, a representational system was created that is similar to diagrams used in models of structure mapping theory of analogy (Gentner & Markman, 1997). In this representational system, squares represent entities (objects or relationships as entities). If the entity was explicitly mentioned (including by usage of a pronoun), the square was black. If an entity was only implied, it was represented as a white square. Lines represented relationships. If a relationship among entities was explicit, it was shown as a solid line connecting two or more squares. If a relationship among entities was only implied, this relationship was represented with a dotted line connecting two or more squares. Representations that exhibit a range of comparisons, as well as how they were coded on the two dimensions of comparison ambiguity (discussed below) are included in Table 1.

Comparison ambiguity: Explicitness of entities and relations

These representations allowed for categorizing of comparisons according to two dimensions: entity explicitness and relation explicitness. Entity explicitness refers to how many entities, explicit and implicit, were compared in a comparison. If additional entities were mentioned besides the ones that were the main focus of the comparison, the comparison was labeled as including entities at “multiple levels.” Relation explicitness refers to how implicit or explicit the relation was in a comparison. The difference between the two categories of relation explicitness - Alignment and Relation specified - is that comparisons categorized as alignments did not have any obvious relational language such as “similar” or “different”. Instead, these alignment comparisons usually had parallel structure that implied an interpretable relation among entities but did not have connecting words that communicated the relation explicitly. Combining entity explicitness and relation explicitness gave an overall dimension of a comparison’s lack of explicitness, or ambiguity. See Table 2 for counts of comparisons of each type of ambiguity.

<table>
<thead>
<tr>
<th>Representation and Utterance</th>
<th>Entity explicitness</th>
<th>Relation explicitness</th>
</tr>
</thead>
<tbody>
<tr>
<td>“This almost looks like a number line here”</td>
<td>Two named</td>
<td>Relation specified</td>
</tr>
</tbody>
</table>
Table 2: Counts of Comparisons by Category of Ambiguity

<table>
<thead>
<tr>
<th>Relation explicitness</th>
<th>Entity explicitness</th>
<th>One named; other(s) implied</th>
<th>Two named</th>
<th>More than two entities named</th>
<th>One named, multiple levels</th>
<th>Two named, multiple levels</th>
<th>More than two, multiple levels</th>
<th>Sub-totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alignment</td>
<td></td>
<td>23</td>
<td>50</td>
<td>18</td>
<td>14</td>
<td>105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relation specified</td>
<td></td>
<td>37</td>
<td>40</td>
<td>42</td>
<td>3</td>
<td>15</td>
<td>2</td>
<td>139</td>
</tr>
<tr>
<td>Sub-totals</td>
<td></td>
<td>60</td>
<td>90</td>
<td>60</td>
<td>3</td>
<td>14</td>
<td>2</td>
<td>244</td>
</tr>
</tbody>
</table>

Results and discussion

Comparisons were frequently made during the selected two days in this mathematics classroom. Casting a much wider and different net than Richland et al. (2004), 244 comparisons were identified in two days of class. Relatively few comparisons – only 16.4% of all comparisons identified – fit the definition of analogy used in Richland et al. (2004) – comparisons with two entities explicitly named and an explicit relationship. Although more comparisons had an explicit relationship (139 vs 105), several of the comparisons with explicit relationships also had ambiguous entities. Even though the most common type of entity explicitness was two explicit entities (90), more comparisons of this type had implicit (50) than explicit relationships (40).

The patterns of ambiguity of relations and entities outlined above reveal that comparisons in forms other than analogies were quite prevalent. Existing models of analogical reasoning already have ways of explaining how we map the entities and relations of a comparison with an explicit relation and explicit entities (e.g., Falkenheimer, Forbus & Gentner, 1989). However, such models do not currently address how we are able to process and accurately interpret comparative statements in which the relation and the entities are more ambiguous.

The implications of entity explicitness, relation explicitness and overall comparison ambiguity for how comparison supports learning are as of yet unclear, but there are a few possibilities. Like in everyday conversation and interactions, the more ambiguity in an action, the more likely it is to be misinterpreted. The same may be true for these ambiguous comparisons. It is likely true that these ambiguities require more in terms of mental resources to identify entities and test out plausible interpretations. One way that these alternative interpretations may affect learning outcomes is that students would not demonstrate as much improvement in their understanding, however it is measured, because processing these comparisons could require too much cognitive load (e.g., Richland, Begolli, Simms, Frausel & Lyons, 2016). With more mental resources devoted to
interpreting the comparison, fewer resources may be available for integrating the new information from the comparison into existing knowledge structures. Alternatively, if students are still able to integrate the comparison into their existing knowledge structures, they may incorporate some misalignments into their knowledge structures due to a misinterpretation.

However, another possibility is that ambiguity could lead to greater improvements in students’ understanding of whatever is compared. Students may learn more from processing ambiguous comparisons than from processing explicit comparisons for the very reason that students must do a lot more cognitive work trying to interpret ambiguity than they would for a more explicit comparison. This possibility relies on the tenets of constructivism (e.g., Piaget, 1964) that posit that no changes in knowledge occur unless a student does the work of integrating new knowledge with their prior knowledge. Greater ambiguity would likely require more effortful integration than explicit comparisons, so an ambiguous comparison would require at least some connection with existing structures just to interpret it at all as opposed to a more explicit comparison that may integrate less extensively with existing knowledge structures, if at all.

A third possible mechanism for how greater ambiguity could result in improved learning outcomes involves comparisons at multiple levels. It is possible that more ambiguous comparisons are initially more confusing and more likely to be misinterpreted than more explicit comparisons, but having to evaluate several plausible interpretations could reap the previously shown benefits of comparison twice over: testing how each plausible interpretation fits with existing knowledge would involve both comparing the fit across interpretations as well as comparing the entities within each interpretation of the comparison. This process seems to align with how the fit of an interpretation of an analogy is performed according to structure mapping models (Falkenheiner, Forbus, & Gentner, 1989). Future research that examines processing time as well as learning gains resulting from systematic variations in entity and relation ambiguity will help to elucidate which of these possibilities for the mechanism of how ambiguity of comparisons affects learning is most tenable.

Although these results are at present derived from only one classroom, they still have implications for teaching in math classrooms more broadly. Having a framework for the ambiguities of comparisons can aid teachers in identifying aspects of their own and students’ comparative statements that may be potentially confusing. Recognizing ambiguous comparisons and thinking through the possible ways that students might misinterpret them can help teachers deduce why a student might have a certain misconception. If less ambiguous comparisons are more beneficial for learning, then it becomes important for teachers to be more careful with their comparative language as well as encourage more explicit and precise communication of comparative statements by students.

References
Social Network Analysis for Signaling Pedagogical Shifts in Challenge-Based and Traditional Online STEM Courses

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Abstract: Challenge-based learning (CBL) supports students’ learning and transfer of key disciplinary principles, but students may need support when transitioning to the expectations of CBL. One way to provide support is for instructors to monitor students’ understanding of course challenges and content in discussion boards. Using SNA, we explored how two instructors participated in students’ discussions in CBL and traditional online courses to see how instructors adapted support with CBL courses. Instead of differences across pedagogies, we found differences across instructors: one instructor contributed on the periphery of students’ discussions, while another instructor directly contributed to students’ discussions. Based on sociograms and instructors’ feedback, we found that the instructors took different approaches to providing formative feedback (e.g., private communication versus public discussion) intended to scaffold students’ knowledge construction.

Introduction

Challenge-based learning (CBL) is an inquiry-learning approach that contextualizes learning within authentic challenges (Martin, Rivale, & Diller, 2007). Students develop real-world solutions that help them learn key disciplinary concepts and skills that are connected to future work. CBL’s benefits include improved attitudes about learning, conceptual outcomes, and knowledge sharing (Martin et al., 2007; O’Mahony et al., 2012).

Implementing CBL, however, can be challenging, as instructors must develop challenges that highlight key disciplinary principles that transfer to new situations (Martin et al., 2007). When adopting CBL within online courses, instructors often monitor discussion boards to assess students’ understanding of challenges and underlying principles, and to provide support as formative feedback (Wise & Paulus, 2016). Students’ participation in online discussions opens opportunities to co-construct knowledge with others. Interactions with instructors and classmates on online discussion boards can improve course satisfaction and perceived learning (Swan, 2001), but students may need guidance for engaging in online knowledge and community building (Covelli, 2017). One way to assess students’ discussions is through social network analysis, or SNA (Wasserman & Faust, 1994). SNA provides a lens for understanding the interactions between and roles of students and instructors. SNA also helps assess students’ sense of community (Stepanyan, Mather, & Dalrymple, 2014) as facilitated by the instructor to support online knowledge construction (Covelli, 2017).

To understand participation in online discussions, we created weekly SNA sociograms of discussion boards for two courses, each with a CBL and a traditional section. We examined sociograms for changes over time, especially students’ and instructors’ roles and connectedness within the course. We hypothesized that the shift from instructor-centered traditional course formats to a learner-centered pedagogy embodied by CBL would be signaled by differences in the positioning of the instructor within online discussion boards. Our research question was: How did the instructors situate themselves within students’ online discussions for CBL and traditional courses? This question has implications for how we understand patterns of interaction between students and instructors in different instructional approaches, and can help us determine the suitability of SNA as a tool for characterizing pedagogical shifts in online courses at scale.

Methods

Participants were two instructors and 40 undergraduate students participating in online courses in fall of 2017, offered by a university on the U.S. East Coast that hosts programs for post-traditional adult learners pursuing professional degrees. Instructor AJV taught two sections of a human-computer interaction course (Course 1), with 7 students enrolled in the CBL section and 8 students in the traditional section. Instructor BC taught two sections of a web development course (Course 2), with 18 students in the CBL section and 7 students in the traditional section. Students were assigned to CBL or traditional instruction using stratified random assignment and were informed of the new CBL approach in the course syllabus. Instructors received training on CBL, which focused on authentic assessments (“deliverables”) situated within challenges, and support from instructional designers. For CBL sections, the instructors shifted to a mentor and/or client role and expected students to take on greater agency in their learning. For traditional sections, instructors continued their business-as-usual approach of weekly lectures, quizzes, and assignments.
We collected student and instructor posts from discussion boards for each week from September 1 to October 29, the semester midpoint. Discussion participation was a grade requirement. We then performed an initial qualitative analysis of online discussions and instructor feedback about transitioning to CBL. For SNA, we created adjacency pairs of participants’ posts for each week, which we used to make directed network graphs with Gephi and to calculate mean degree centrality for each participant with the NetworkX library in Python.

**Findings**

Our initial qualitative analysis of online discussions and instructor feedback indicated that the instructors had different approaches to scaffolding students’ knowledge construction in their courses. Therefore, we examined the weekly sociograms for the CBL and traditional sections nested within the instructors.

Table 1 shows sociograms of interactions between students and Instructor AJV over time. With the CBL section (top), we see a strong connection between Instructor 1 and student RM in Week 1, and between students AB and MK in Week 2. However, the following weeks showed similar, decreased levels of interaction among participants, especially for weeks 4, 5, and 8. Also, students posted messages that did not receive replies (node NULL) in Weeks 1-7. With traditional instruction (bottom), we found strong connections between students JB and PF in Week 4 and JB and TS in Week 8. Overall, though, we found similar levels of interaction among participants. Students posted responses with no replies (node NULL) in weeks 4-8. In summary, both sections of Course 1 showed fairly balanced participation, but the traditional section showed more balanced participation over time compared to the CBL section.

Table 1: SNA sociograms of Course 1 online discussion posts during the first eight weeks

<table>
<thead>
<tr>
<th>Weekly Sociograms (Left to Right, Top to Bottom)</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Sociograms" /></td>
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</tbody>
</table>

Table 2 shows sociograms of interactions between students and Instructor BC over time. With the CBL section (top), we see that students’ discussion was often directed toward Instructor BC, resulting in connections with several students (NT, WR, SH, WCL, and WW) over time. Participation decreased slightly over time, but all students received replies to their posts. With traditional instruction (bottom), fewer students directed their
posts toward the instructor. The instructor still connected with several students (NG, RM, and MK) over time. Students NG, RM, and MK also connected with each other at different times. As with CBL, participation decreased slightly over time, but only week 8 included a posting without reply. Overall, we see greater interaction among participants in Course 2 (with Instructor BC) than Course 1 (with Instructor AJV).

Table 2: SNA sociograms of Course 2 online discussion posts during the first eight weeks

<table>
<thead>
<tr>
<th>Weekly Sociograms (Left to Right, Top to Bottom)</th>
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<tbody>
<tr>
<td><img src="image1" alt="Sociogram" /></td>
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<tr>
<td><img src="image2" alt="Sociogram" /></td>
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<tr>
<td><img src="image3" alt="Sociogram" /></td>
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</tbody>
</table>

*Only 6 discussions in Course 2 CBL.

<table>
<thead>
<tr>
<th>Table 3: Mean degree and centrality values for students in each section</th>
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<tr>
<td>Course</td>
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<tr>
<td>--------</td>
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<td>1</td>
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</tbody>
</table>

We also quantified connectedness as mean degree centrality, which indicated how closely connected each participant was to other participants over the eight weeks (see Table 3). In both sections of Course 1, Instructor AJV was less connected than her students, as indicated by values in bold font. In contrast, Instructor BC was the most connected participant in both sections of Course 2. This finding is echoed by our initial qualitative analysis, which found that Instructor AJV typically replied to students at the end of discussions, decentralizing her role in the discussion, and preferred private email communication for feedback. In contrast, Instructor BC replied to students’ posts throughout discussions, which more firmly centralized his role.
Discussion
This study leveraged SNA as an initial assessment of participation in online discussions as instructors began to adopt CBL for online courses targeted at post-traditional adult learners. CBL contextualizes learning by foregrounding authentic challenges and assessments, which help students to grasp key disciplinary concepts and skills (Martin et al., 2007). Online discussion boards encourage students to share and negotiate ideas about course content, and offer opportunities for formative feedback (Swan, 2001). To understand students’ and instructors’ roles and connectedness in online discussion boards, we created week-by-week SNA sociograms of online discussion participation for both CBL and traditional (i.e., business-as-usual) sections.

Regardless of the type of instruction, students demonstrated relatively balanced participation over time. The CBL section of Course 1 showed a decrease in participation over time, possibly explained by the instructor’s preference for email communication over discussion boards. This foregrounds our unexpected finding that differences among instructors were more salient. We found differences in the two instructors’ roles and connections with students in discussion participation, regardless of the type of instruction. This difference points to a need for future research about instructors’ approaches to scaffolding online courses, especially about formative feedback as public versus private communication.

Identifying patterns of participation, especially early in the adoption of a new instructional approach, may help instructors to support students by showing high or low levels of connectedness in discussion boards (Covelli, 2017). Analyzing sociograms may help instructors to adopt and/or reinforce effective knowledge and community building practices, such as revising discussion prompts or rotating responsibilities for leading discussions. Pedagogical feedback may also help reassure instructors adopting instructional approaches that are new to them. Implementing CBL is often difficult for instructors (Martin et al., 2007), and more objective feedback mechanisms like SNA may help instructors to identify areas for improvement as they arise. While this exploratory study is limited by its small sample size and focus on participation in discussion boards, we see this as a promising first step to support the identification of pedagogical shifts and practices as we integrate CBL into online courses at a larger scale.

Conclusion
Challenge-based learning (CBL) supports students’ conceptual outcomes, but students may need support as they transition to CBL instruction. For online courses, instructors may monitor students’ understanding and provide support via discussion boards. We used SNA as an early signal of the adoption of CBL in online courses to identify differences across instructional approaches. Instead, we found differences across instructors regarding their roles and level of connectedness to students over time. While we did not find notable differences across CBL and traditional instruction, we discovered a need to understand differences in instructors’ scaffolding approaches for online courses, especially when providing formative feedback.

References

Acknowledgments
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Sequencing Arithmetic, Area, and Algebraic Instruction for Teaching the Distributive Principle

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Abstract: The current study examined the effect of different instructional sequences for teaching the distributive principle for multi-digit multiplication. Third graders experienced one of four sequences: Algebra-Arithmetic, Algebra-Area, Arithmetic-Algebra, and Area-Algebra. All sequences produced improvements in solving practiced 2D × 2D problems. Critically, the Area-Algebra and Arithmetic-Algebra sequences had the largest learning effects, with the former better for participants with some prior knowledge of 2D × 2D multiplication and the latter better for participants with no prior knowledge. All sequences also produced improvements on unpracticed transfer problems, with the Area-Algebra sequence producing the largest learning effects. Finally, improvements were most associated with prior knowledge of single-digit addition and subtraction – but not multiplication – facts. The implications of these results are discussed and future directions outlined.

Keywords: multi-digit multiplication, distributive principle, mathematics education

Introduction

The current study implemented three instructional approaches for teaching the distributive principle for solving multi-digit multiplication problems. In particular, it investigated the optimal combination and sequencing of arithmetic, area (i.e., spatial), and algebra instructional approaches (Schwartz & Bransford, 1998).

The distributive principle for multi-digit multiplications refers to the fact that one of two factors can be split into two or more parts, each part multiplied by the other factor separately, and the partial products added (Anghileri, 1999). This principle is important for learning to solve multi-digit multiplication problems. For example, Liu, Ding, Gao, and Zhang (2015) found that fourth graders solved distributive-format problems (e.g., 25 × (10 + 2)) more quickly and accurately than conventional-format problems (e.g., 25 × 12). This finding suggests that recognizing and applying the distributive property to compute partial products (e.g., 25 × 10 and 25 × 2) improves performance of solving multi-digit multiplication problems.

Previous studies have implemented a variety of instructional approaches to teach the distributive principle (Baroody, 1999; Lee, 2014). The current study focused on three – arithmetic, area, and algebra. The arithmetic approach takes advantage of concepts such as repeated addition and relational arithmetic fact knowledge (Baroody, 1999). The area approach is often promoted by mathematics educators as being the most comprehensible to students (Lee, 2014). It takes advantage of visualizing partial products and decomposing factors. In particular, it supports the shift from repeated addition reasoning into multiplicative reasoning (i.e., factoring) (Cooney, Swanson, & Ladd, 1988). The algebra approach applies the distributive property to re-express multi-digit multiplication as the sum of a series of simpler multiplications, and can be seen as an elementary form of symbolic algebraic reasoning. The arithmetic and area approaches are more concrete to students in making use of familiar arithmetic expressions and visual diagrams. The algebra approach is more abstract to students in employing unfamiliar arithmetic expressions with missing operands.

The goal of the current study was to determine the optimal combination and sequencing of the different approaches for teaching the distributive principle in multi-digit multiplication. Candidate sequences were evaluated by changes in arithmetic proficiency across a pre-test and two post-tests. There were three research questions: (1) Do different instructional combinations and sequences lead to better performance on practiced multi-digit multiplication problems? (2) Do different instructional approaches and sequences lead to better performance on transfer multiplication problems? (3) What is the relationship between prior knowledge of single-digit arithmetic facts for the four operations and proficiency in multi-digit multiplication?

Methods

Participants

The original participants were 120 3rd graders at an elementary school in Seoul, South Korea. We only analyzed the data of the 96 participants who (1) completed all pre- and post-tests, (2) completed two weeks of practice,
and (3) had scores on the final assessment of practiced $2D \times 2D$ multiplication within ± 2 SDs of the overall sample. Among the final 96 participants, 61 students had already learned $2D \times 2D$ multiplication in advance through a private academy or tutor. Thus, we separately analyzed the effect of our instruction on the prior learning group and the no-prior learning group.

Design
We used a pretest-intervention-posttest design. Participants were randomly assigned to four different sequences: 1) Algebra-Arithmetic, 2) Algebra-Area, 3) Arithmetic-Algebra, and 4) Area-Algebra. We also considered participants’ prior learning of $2D \times 2D$ multiplication, i.e., the prior learning vs. no-prior learning grouping factor. Students practiced one instructional approach in the first week and the other in the second week according to their instruction condition. On the final day of each week, they were administered post-test assessments measuring arithmetic proficiency in multi-digit multiplication.

Materials

Instructions for teaching distributive principle
We developed Arithmetic, Area, and Algebra instructional approaches for teaching the distributive principle for multi-digit multiplication (see Figure 1). In the arithmetic version, students solved multi-digit multiplication problems by retrieving arithmetic facts, recognizing relations between several given multiplication equations. In the area version, they solved problem by computing partial products by counting the number of squares in a grid. In the algebra version, they solved problems by decomposing factors based on their place value.

<table>
<thead>
<tr>
<th>Arithmetic</th>
<th>Area</th>
<th>Algebra</th>
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<tbody>
<tr>
<td><strong>Worked example</strong></td>
<td></td>
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</tr>
<tr>
<td>$11 \times 1 = 11$</td>
<td>$11 \times 15 = 165$</td>
<td>$11 \times 15 = 165$</td>
</tr>
<tr>
<td>$11 \times 5 = 55$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$11 \times 10 = 110$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$11 \times 15 = 165$</td>
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</table>

**Practice**

Figure 1. Arithmetic, area, and algebra instructional approaches for teaching the distributive principle.

For each instructional approach, practice items were formed by factors ranging between 11 and 19. Across a week of instruction, the difficulty of the items increased: the “easiness” of the factors decreased (e.g., $11 \times 15 \rightarrow 13 \times 14$) and the size of the products increased (e.g., $11 \times 13 \rightarrow 18 \times 19$). The three approaches were combined into four sequences of *a priori* interest: Algebra-Arithmetic, Algebra-Area, Arithmetic-Algebra, and Area-Algebra. Importantly, the algebra approach was included in each sequence.

Assessment
We developed assessments to measure arithmetic factual knowledge and arithmetical proficiency in multi-digit multiplication. Twenty $2D \times 2D$ multiplication problems with factors in the range 11-19 were used at pre-test and at post-tests 1 and 2. The number of correct answers produced in fifteen minutes was the dependent variable. This measure was used to evaluate research question (1) concerning learning. Five $2D \times 2D$ problems which factors greater than 20, five $2D \times 2D$ algebra format problems (e.g., $12 \times \_ = 156$), and five $3D \times 1D$ problems were used at both post-tests to evaluate research question (2) concerning transfer. The number of correct answers produced in ten minutes was the dependent variable. Finally, single-digit addition/subtraction, multiplication, and division (40 items each) were used to measure arithmetical factual knowledge at pre-test. For each of these three measures, the number of correct answers produced in one minute was coded. This measure was used to investigate research question (3) concerning individual differences.
Procedure
Prior to the intervention, participants completed the pre-test measures of 1D arithmetic and 2D x 2D multiplication. They then solved 36 multi-digit multiplication problems every day during the first week using the approach indicated by the workbook of the condition to which they had been assigned. On the final day of the first week, they completed the learning and transfer measures of post-test 1. The second week followed the same structure, but for a different approach, and finished with post-test 2.

Findings
Preliminary analysis showed that there were no significant differences in the pre-test scores across the four sequences in each of the prior learning and the no-prior learning groups. This indicates that our random assignment was successful.

The first research question was whether different instructional combinations and sequences lead to better performance on practiced multi-digit multiplication problems. We addressed this in a three-way repeated measures ANCOVA on post-test scores of practiced 2D x 2D multiplication problems with time, sequence, and prior learning as factors and pre-test scores as a covariate (see Figure 2). There was a main effect of time ($F(1, 87) = 63.577, p < .001, \eta_p^2 = .422$) and prior learning ($F(1, 87) = 4.846, p = .030, \eta_p^2 = .053$). Although there was no main effect of sequence ($p = .545$), scores on post-test 2 were significantly improved compared to pre-test scores for all four sequences. Follow-up one-way repeated measures ANOVAs on students’ scores on practiced 2D x 2D multiplication problems showed significant improvement for each sequence. The effect sizes were largest in the Arithmetic-Algebra ($\eta_p^2 = .582$) and Area-Algebra ($\eta_p^2 = .568$) sequences, which experienced the algebra approach in the second week after experiencing one of the concrete approaches in the first week. There were also interaction effects of prior learning × time ($F(1, 87) = 4.363, p = .040, \eta_p^2 = .048$) and prior learning × time × condition ($F(3, 87) = 3.599, p = .017, \eta_p^2 = .110$). Participants in the no-prior learning group benefitted most from the Arithmetic-Algebra sequence, whereas those in the prior learning group benefitted most from the Area-Algebra sequence.

The second research question was whether different instructional approaches and sequences lead to better performance on transfer multiplication problems. We addressed this in three-way repeated measures ANOVAs with time, sequence, and prior learning as factors and post-test scores on the three transfer measures as dependent variables: (a) unpracticed 2D x 2D problems, (b) 2D x 2D algebra format problems (e.g., $12 \times \_ = 156$), and (c) 3D x 1D problems. There was no main effect of sequence, and therefore Figure 3 collapses across this factor. There was a main effect of prior learning on all transferred multiplication problems ($F_{a}(1, 88)$...

We additionally conducted a linear regression analysis to assess the overall relationship between single-digit arithmetic performance and practiced 2D × 2D multiplication at post-test 2 after controlling for prior learning. The results showed that 27.4% of the variance in the dependent measure was accounted for by single-digit arithmetic performance (F (4,91) = 8.580, p < .001), with single-digit addition/subtraction knowledge the only significant predictor (stand.β = .417, p = .003).

Conclusions and implications

The first research question was whether different instructional sequences lead to better performance on practiced multi-digit multiplication problems. In fact, all four sequences resulted in improved performance at post-test 2 on the practiced 2D × 2D problems. However, the Area-Algebra and Arithmetic-Algebra sequences had the largest learning effects. This suggests that there may be some advantage to first practicing with more familiar arithmetic representations or more concrete area representations before practicing with more abstract algebra representations (Fyfe, McNeil, & Borjas, 2015). Moreover, the effect of instructional sequence differed as a function of prior learning. For participants with prior learning of 2D × 2D multiplication, the Area-Algebra sequence produced the largest improvements, whereas for those with no-prior learning, the Arithmetic-Algebra sequence produced the largest improvements. Future research should follow up on these findings.

The second research question was whether different instructional sequences lead to better performance on novel transfer problems. All four sequences produced improved performance from post-test 1 to post-test 2 on the unpracticed 2D × 2D problems and the 2D × 2D algebra format problems. Again, there were some differences in efficacy. The Area-Algebra sequence led to the greatest improvement in solving unpracticed 2D × 2D multiplication problems. One possible explanation of this finding is that using an area approach to visualize decomposed factors produced a positive transfer effect on dealing with large unpracticed multiplicands. Future research should evaluate this possibility.

The third research question was whether there is a relationship between knowledge of single-digit arithmetic facts at pre-test and proficiency in multi-digit multiplication at post-test 2, after two weeks of practice learning the distributive principle. A regression analysis revealed that there is a relationship and, surprisingly, it is driven by knowledge of single-digit addition and subtraction facts, not single-digit multiplication or division facts. One interpretation of this finding is that multi-digit multiplication depends less on using multiplication to compute partial products and more on using addition and subtraction to combine partial products. Future research should evaluate this interpretation.

References


Indoor Positioning Technology and Enhanced Engagement in Early Elementary Systems Thinking and Science Learning

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Indiana University

Abstract: Indoor positioning (IP) technology is sought after for applications in gaming, commercial spaces, and education. While several types of IP systems have become available, none offer tracking of multiple agents that balances high accuracy with low cost. This paper highlights new 3D IP technology designed for educational contexts, which coordinates as few as 4 and as many as 80 physical “tags.” The tags act both as anchors to delineate the play space and as trackers that send high-accuracy location data to a server in real time that can later be played back. To test the impact of the technology on learning, we compared it to a parallel non-IP environment that approximates locations between two points in classroom settings. Findings demonstrate how the IP technology supports students in engaging deeply with complex systems concepts that require students to look closely at the local behavior of an organism such as an ant.

Introduction
Systems thinking is the ability to recognize and reason about complex systems. This difficult skill is rarely taught explicitly in schools (Hmelo-Silver & Azevedo, 2006; Resnick, 1999), and is rarely taught in early elementary school. While previous work has shown success in teaching early systems thinking concepts related through traditional and participatory simulations (Danish, 2014; Colella, 2000), efforts are ongoing to enhance these learning experiences and make use of children’s play practices.

Participatory simulations (Colella, 2000) based on agent-based modeling simulations have been shown to be useful for helping children think about complex systems from a first-person perspective. Similar to role-playing games, actors in a participatory simulation enact the roles of individuals in a system, enabling them to make personally meaningful connections to the behaviors that make up that system (see Klopfer, Yoon & Rivas, 2004). Work has also shown that young children can deeply explore a variety of scientific concepts when interacting with technologies that leverage physicality and embodiment (see Montemayor et al., 2002). Thus, we have developed two versions of a participatory simulation (Colella, 2000), that offer a first-person look into the complexity of honeybee and army ant colonies. Representing two design iterations, our army ant participatory simulation integrated indoor positioning (IP) technology to further leverage how young children learn from play and embodiment.

Here, we explore the affordances of the IP environment used in a systems-thinking curriculum centered around army ants in relationship to an earlier iteration centered around honeybees. First grade students engaged in 10-day implementations focused on systems thinking through the lens of honeybees or army ants in ways that utilized both first-person and third-person perspective taking. Emergent findings indicate that the IP technology supports new kinds of engagement because of the way it allows students to engage with high-resolution data. This work has implications for designing for increased engagement in systems thinking among early elementary students in ways that utilize technology in making systems elements salient.

Social insects and systems thinking
Both honeybees and army ants are social insects with similar structures, including one egg-laying female and massive numbers of workers that gather food and protect the colony. For bees, this food is gathered from flowers while army ants forage on the forest floor. Both must search to locate plentiful food sources and have developed methods to communicate the location of these food sources to others. Honeybees use the waggle dance, a phenomenon in which bees move their bodies in particular patterns that use the sun as a reference point to communicate direction, distance, and quality of a flower. Army ants leave pheromone trails as they walk. These trails are not directional, and as more ants walk along the trail between the food source and the colony, the trail becomes stronger, encouraging more and more ants to continue following the trail.

Conceptually, both honeybees and army ants represent the systems thinking concept of a feedback loop created in the process of food gathering. In both cases, a lack of food is conveyed through the absence of the positive feedback action. Additionally, both insects have physical constraints on how long they can search for
food and how much food they can carry. Accurately simulating the ants’ non-directional pheromone trail was the main influence of the IP technology and the main difference between the two implementations.

**Indoor positioning technology**

Indoor positioning (IP) technology is sought after for applications in gaming, commercial, and educational spaces. While several types of IP systems have become available, few are able to track multiple agents in a way that balances high accuracy with low cost - a necessary quality for educational uses. Consequently, we designed a new 3D IP technology (patent pending) for such educational contexts that is capable of coordinating many actors in a space. In this system, “tags” act both as anchors to delineate the play space and as trackers that send high-accuracy location data to a server in real time that can later be played back.

We adopted ultra-wideband (UWB) technology for our purposes. UWB can provide highly accurate (Karbownik, et al., 2015) distances through a computation of time-of-flight of the wireless signals. In our approach, at least 3 UWB anchors need to sit at the corners of the tracking area. These physical locations can be predetermined, as we use a trilateration (Cook, et al., 2005) algorithm to compute the tracked positions from the precise distance data provided by the anchors. As an UWB tag device moves within the tracking area or the communication ranges of the anchors, the distances of the tag to all the anchors are reported to a designated computer in real-time for trilateration computation and visualization.

**Study design and data sources**

Four first-grade classrooms participated in the IP ant implementations (n = 71), while three first-grade classrooms and one mixed first- and second-grade classroom (n = 85) participated in the non-IP bee implementations. All classrooms were located in a mid-sized, midwestern city. Both implementations were based on a previously successful bee curriculum (Danish, Thoroughgood, Thompson, & Peppler, 2017), moving from simple to more complex systems thinking concepts over 10 sessions.

In the bee non-IP implementations, students moved around the room with an electronic bee puppet (see Figure 1) to collect virtual nectar from larger-than-life flowers. The flowers held RFID tags that the puppets could scan; LEDs on the puppet provided information on how much nectar the bee was holding and how much energy it had available. The ant IP implementations proceeded similarly -- the ant push toys (Figure 1) also contained RFID scanners and LEDs. Additionally, each ant puppet contained a UWB tag that allowed the puppet’s movements to be tracked in real time. iPads revealed whether a source had food available when an ant puppet approached. Students needed to leave virtual pheromone trails for other ants to follow to food sources through pushing a button on the ant-toy handle when students thought appropriate. The IP system tracked each ant to identify where students left trails. Additional LEDs on the ant provided information about when an ant was close to or following an existing trail. Students could then review their activities using a birds-eye view projected onto a screen. While both approaches visualize information, the specificity and gesture of the movement is maintained in the IP condition (i.e., learners can “see themselves” in the tracking data). This added nuance was introduced to help students explore the nature of the pheromone trails in ways that we felt the earlier technology would not have supported. This shift in designs represents both a shift in conceptual focus (on the movement path instead of the destination) along with the technology needed to support that shift in focus.

**Figure 1. Army ant push toy and bee puppet.**

All sessions were video and audio recorded. Here, we look at excerpts from video recorded debriefing discussions where teachers and students reflected upon the game play. As systems thinking is difficult for learners at all stages, we looked for evidence of engagement with complex systems thinking concepts. Rather than assuming students will approach systems thinking in adult ways, we define engagement for early elementary students here as talk about and reflection on how movements and actions have consequences in the
Here we focus primarily on moments related to the Playback feature that allows participants to rewatch their own prior movements and actions played on a screen in real time. This is a particularly fruitful time for teacher-supported noticing and reasoning, and is where we found that the high resolution information provided by the IP technology added the most value.

Findings

Comparisons of the discussions in the non-IP and the IP versions of Playback indicate that the IP technology affords new and different reasoning about systems thinking concepts by allowing students to explore this new context (pheromone trails) where those nuances are highly relevant. See Table 1 for a representative example of a conversation in the non-IP classroom. Here, the student uses general terms to describe paths and locations. For example, the phrase “around to this side” in line 2 indicates a general area, rather than a specific location. Similarly, “hopping from place to place” in line 1 does not reference specific paths or locations, but does reflect the images on the Playback. The bees do in fact appear to be “hopping” from flower to flower, as there is no data about the paths between flowers. For example, a student with a bee puppet could walk up to a number of flowers before scanning an RFID tag - in this case the Playback would portray the bee as waiting at the first flower until the second tag is scanned.

Table 1: Noticing Bee Actions on Playback, non-IP

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<tr>
<td>1</td>
<td>Ms. Kay</td>
</tr>
<tr>
<td>2</td>
<td>Ezekiel</td>
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<tr>
<td>3</td>
<td>Ms. Kay</td>
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</tbody>
</table>

It is important to note that this is considered a high quality interaction in the bee implementation. In the honeybee system, concepts such as feedback and emergence are not necessarily embedded in the exact movements and locations of the individual actors. This exchange demonstrates exciting evidence of emerging understanding of relationships between systems elements and actor behaviors.

Table 2: Noticing Ant Pathways on Playback, IP

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<tbody>
<tr>
<td>1</td>
<td>Mrs. Arrow</td>
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<tr>
<td>2</td>
<td>Stanley</td>
</tr>
<tr>
<td>3</td>
<td>Mrs. Arrow</td>
</tr>
<tr>
<td>4</td>
<td>Class</td>
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<td>Mrs. Arrow</td>
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<td>6</td>
<td>Stanley</td>
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<td>7</td>
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<td>8</td>
<td>Class</td>
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<tr>
<td>9</td>
<td>Mrs. Arrow</td>
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Table 2 shows a discussion about ants in the IP version of Playback. Here, the teachers and students are able to discuss in much more detail where the ants went in the room, and make judgments about the usefulness or efficiency of those paths. Here, “all over the place” line 2 refers to real time, on the ground movements rather than “hopping from place to place.” The students are also able to talk about, visualize, and reflect on the importance of following a trail as a more efficient strategy for food collection, which is not possible in the non-IP version. With the IP technology, children can notice when their path was inefficient, when they missed a fruitful food source, or did not pick up on a nearby pheromone trail.

The differences between these two exchanges may be subtle, but are highly consequential. The discussion in Table 2 sets the students in this classroom up to make additional conjectures about the
consequences of “going all over the place.” They can make predictions about why the ant acted in that way, and what might have been different had the path been more efficient. With the previous technology used in the bee implementations, this type of discussion would not have been possible. While the interaction in Table 1 is promising as related to the honeybee system, it would not be enough to highlight the specific phenomena of the pheromone trails present in the army ant system where movement and location are key. Here, the unique blend of consequential system elements and technology leads to new support for classroom reasoning.

**Discussion**

The early evidence seen here suggests new affordances for using indoor positioning technology to explore systems concepts that are tied to a nuanced understanding of where students move throughout a physical space. Participatory simulations have long made use of technology to enhance learning environments through new affordances and productive constraints (e.g., Colella, 2000). Here, it seems that specific types of reflection are possible by this unique combination of IP technology and the Playback feature. It has been noted that both first-person and third-person perspectives play important and complementary roles in systems thinking education for young learners (Danish et al., 2017). The Playback feature provides an intersection of these perspectives, wherein learners can see themselves and their actions reflected in the data, while also viewing the simulation from a detached, bird’s eye view. The IP technology deepens this interaction where movement and location was particularly consequential, making the first-person perspective more accurate and realistic.

While approximations of actor location in a classroom were useful when location was not a key component of the system, the addition of the indoor positioning technology allowed us to explore a different physical phenomenon that required a more nuanced understanding of the movement around the classroom. The IP technology discussed here has potential for use in educational spaces, and more research is needed as we continue to consider how technology can be used in systems thinking education to highlight system elements and phenomena. It will be important for researchers to continue to explore what information needs to be made visible across systems as we build and utilize technologies that support learning through embodied interaction.

**References**


**Acknowledgments**

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Qualitative Measures of Equity in Small Groups

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Abstract: We investigate the utility of two qualitative measures of equity. Our data are videos of groups of first-generation and Deaf or hard-of-hearing students in a pre-matriculation university program designed to help them persist in STEM fields by developing their metacognitive practices. We analyze video data of students in small groups trying to accomplish various tasks. We analyze how groups engage with proposed ideas (inchargeness) and create a space of open sharing (civility). By capturing different aspects of each group, these measures combine to help our understanding of what an equitable group could look like.

Introduction

Many research-based instructional strategies require small-group work for problem solving or laboratory experiments. We focus on how differences in individuals’ behavior within a group affect the participation patterns of all group members. Students’ behavior can be harmful or beneficial for their peers, which can hinder or encourage others’ willingness to engage with their groupmates. If groups have distributed leadership, all students are more likely to engage with their work (Oliveira, Boz, Broadwell, & Sadler, 2014). However, students who are perceived as less popular or less smart are offered fewer opportunities to participate (Bianchini, 1997) and learn less (Marbach-Ad, Rietschel, Saluja, Carleton, & Haag, 2016).

Esmonde (2009) defines equity “as a fair distribution of opportunities to learn or opportunities to participate.” We adapt this definition into two aspects of equity: each group member feels comfortable sharing with their group, and their voice is heard by all group members. The first reflects whether a group allows ideas and opinions to come from all members or only one: if one person is the sole source of ideas, the group is not equitable. The second relates to how members’ ideas are taken up within the group: if a group member presents ideas and the rest of the group ignores the ideas, this is also inequitable. In this paper, we draw from Incivility Theory (Cortina et al, 2001) and Positioning Theory (Harré & van Langenhove, 1999) to develop two qualitative measures of equity in small group interactions, and apply them to groups of four undergraduate students modeling climate change in a laboratory setting.

Theory

Our first aspect of equity is inchargeness, which is rooted in Positioning Theory. Positioning Theory explores how people’s communication acts influence and are influenced by what is socially allowed or expected of them (positions) within negotiated storylines (Harré & van Langenhove, 1999). In Positioning Theory, multiple storylines can occur simultaneously, e.g. there could be one storyline between two group members and a different storyline for the whole group that happen concurrently and look very different. This paper focuses on the storyline of the whole group. Inchargeness describes the position of each person in a group and says who controls the flow and topic of conversation (Kustusch et al, 2018). Deitrick (2016) measured positioning between students by counting questions asked and commands given. We analyzed the video itself, not transcripts, and took into account a broader range of communication acts (spoken words, gestures, facial expressions, etc.) to analyze the relative positions of the group in selected segments.

Our second aspect of equity is called civility and is based in Incivility Theory, which focuses on how uncivil acts are ambiguous but are seen as disrespectful or a violation of social norms, including overt behaviors, calling a peer stupid, and covert behaviors, like condescension and social exclusion (Cortina et al., 2001). A group is civil if its members actively seek to include their peer’s opinions and ideas. Active civility is essential because incivility is frequently experienced but seldom overt (Cortina et al., 2001).

To segment videos, we developed a method which divides a video based on speaking duration changes of group members (Archibeque et al., 2018). These segments vary in size because of that dependence on speaking duration. We analyze the same groups from our previous work.

The research question addressed here is: How do inchargeness and civility inform important aspects of a group’s interactions? We will look at both measures for two groups, compare the groups to each other, then compare the measures to one another. Finally, we will discuss future research with these methods.
Context and methods
The participants are from a private, doctoral granting technical institute in a two week, pre-matriculation program for first generation (FG) and d/Deaf or hard-of-hearing (DHH) individuals who intend to major in STEM. The program supports their persistence in STEM through metacognitive skill development and community building. Each student identifies with at least one (and often several) underrepresented or marginalized group in higher education. Overall, the race and gender composition of the participants are approximately representative of the general US population in terms of race and gender, with an oversampling of DHH individuals.

This paper analyzes video of two groups (four students in each) developing models for climate change lasting approximately 30 minutes: one group which seemed inequitable and one which seemed equitable based on previous work using quantitative measures of equity (Archibeque et al., 2018); however, the quantitative analysis felt insufficient alone because it did not completely reflect our intuition of the groups. Our intuition was that both groups were inequitable. Here we turn to qualitative measures. In the first group, the students are trying to develop an equation for the amount of carbon dioxide entering the atmosphere annually. In the second group, the students begin by individually journaling “everything they know” about climate change. Then, they were told to reconcile their understandings with their groupmates and develop a model of the atmosphere with the supplies on the table. The groups are from different days in the program, and one student appears in both groups.

To rate inchargeness, multiple raters collaboratively analyzed the communication acts in each segment and rated the inchargeness of each participant during each segment, coming to consensus each time. To operationalize civility, we developed a coding scheme which scores (in)civil behavior across nine axes. For each segment, multiple independent raters select whether that segment was civil, uncivil, and/or neutral on each axis. One axis, for example, is “Group members did not talk over one another more than is socially expected; Group members talked over one another more than is socially expected; Group members did not talk.” Because participants might be mixed in their (in)civil behavior, two categories might be selected for the same time segment on the same axis. After rating the video, raters discussed and came to agreement for each segment.

Results

Group one
This group consists of Brittany, Jessica, Justin, and Pat. In the first segment, Justin is clearly leading what the group is talking about. When he gets off topic, the others get off topic and vice versa. When he drops a topic, it might be discussed by others, but only briefly before they engage with his new topic. Pat was rated with the next most inchargeness. This is because she is treated as a sage of the group. Whenever there is an idea that someone is unsure of, they ask Pat to make sure it “makes sense.” She is also mostly responsible for writing the group’s ideas; this is not assigned to her but she does it while Justin is frequently pulling the group toward non-task oriented talk and she engages in off-topic talk less frequently than others. The person with the next most inchargeness in this segment is Brittany. There are several times when Brittany makes a bid to the floor and it is picked up by Justin or Jessica, although not all her bids are picked up. This is true both for task and non-task related bids. Jessica has the least inchargeness. There are several times when she makes bids directly to Justin but is ignored. When they are not directed to Justin, she still has to repeat herself to be acknowledged. There is one point where Justin tells the group to list things which emit carbon dioxide and has his supplies like he will write the ideas down. Then Brittany and Jessica, mostly Brittany, list off ideas but instead of writing down their ideas verbatim, he adapts them (e.g., cars become technology), but when Pat joins in the listing, Justin does not verbalize that he is changing her words like he did for the other two. This showcases Justin’s higher positioning overall, Pat’s status in the group as someone who is knowledgeable, and Brittany and Jessica’s lower positioning overall.

At the end of the episode, an interesting event happens which had potential to change the inchargeness distribution, but did not. After they realized Pat was incorrect and they needed new ideas, Brittany saw an opportunity include Jessica, saying “Why don’t we ask Jessica. She is our math person.” (Jessica is going to be an applied math major.) Jessica begins speaking, but Justin quickly appears disinterested and writes in his journal, which is a significant departure from how he has been engaging. Shortly after Brittany invites Jessica to speak, the group returns to their original norms: Justin controls the conversation flow, Pat does not interact much but is treated as knowledgeable, and Brittany and Jessica’s inchargeness is mostly unchanged. Throughout, Jessica appears to have little say in what the group does or talks about.

This group’s speaking time is so heavily dominated by one person that it is difficult to contextualize other people’s interactions. Justin is uncivil but the others are, mostly, civil to each other. In the first segment, there were seven uncivil, three civil, and two neutral statements. An exemplar interaction of this segment is between Justin and Jessica. In the span of a few minutes, Justin proposes a few topics to which Brittany and Jessica
respond, but only Brittany’s response gets feedback from Justin. However, even when he responds, he is clearly looking for her to make specific responses to him and cuts Brittany off frequently.

In the final segment, the event which could have changed the positioning is a two-sided action. On one side, it is civil because Brittany makes an active attempt to include a group member who has been quiet throughout the activity. On the other side, Justin ignores Jessica, which is uncivil. This segment had five civil, five uncivil, and four neutral statements. This segment largely consists of the group sitting in silence. Pat and Justin write separately in their journals and Brittany and Jessica watch them. Eventually Justin asks if what he wrote is okay. It appears as though he shares his journal with Brittany, who holds it so Jessica can see it simultaneously. However, Jessica’s inclusion seems to be a result of Brittany’s action, not a result of Justin trying to include Jessica.

This group is inequitable according to both qualitative measures. This group has a centralized inchargeness distribution throughout the episode with only slight variations between the people who have smaller amounts of inchargeness, which makes the group very inequitable. The group averages five uncivil, four civil, and three neutral statements, which also makes them inequitable. However, the group also has many neutral statements from the codebook because they speak infrequently. The combination of concentrated inchargeness and incivility show this group as both unwelcoming and silencing. This was the group which we perceived as inequitable, so these measures align with our intuition and quantitative measures.

### Group two

The second group consists of Brock, Herb, Jakob, and Justin. In the first segment, Justin has the most inchargeness but only slightly more than Jakob. When Justin makes bids to the floor, someone in the group always responds to him. He also proposes the most ideas. Jakob’s inchargeness is slightly lower because his bids are mostly responses to other bids. It is still high because he openly disagrees with Justin and defends Justin’s ideas to Brock and Herb. Herb has the next most inchargeness because he proposes ideas which are occasionally accepted by the group, although he does not speak much. Brock has the least inchargeness because he speaks frequently, but his ideas are ignored by the group. There is one point where he asks “Can I suggest something?” to the group and proposes an idea he had already suggested four times. Only when he asked permission was he allowed to engage with the group. In other cases, he does not ask permission but still has to repeat himself to get his ideas into the group space. Being ignored represents less inchargeness because it shows he has less control over what is talked about and must be allowed into the group. In contrast, Jakob and Justin’s ideas are, at worst, acknowledged by the other.

Near the end of the first segment, Jakob begins to explain an idea and indicates he wants to monologue. Before he begins, the teacher comes over to ask what the group is doing. Brock says they are still deciding. Jakob responds with “that is what I am doing” and proceeds to elaborate his thoughts to the instructor. In this case, he uses the instructor’s question to state his ideas with minimal interruption and take more inchargeness. When the second segment begins, Jakob is a few seconds into his lengthy explanation. In this segment, Jakob and Justin have equal amounts of inchargeness. It is clear that Jakob’s push to be heard in the group is received. Justin still has as much inchargeness, however, because even though he is not proposing ideas, he is clearly open to providing Jakob feedback. Herb’s inchargeness has shifted down, below Brock, in this segment. There is little to no time allotted here for him to engage with his group; the other group members dominate discussion. Brock’s role has not changed because he is still making bids which are mostly ignored.

In terms of civility, in the first segment, Brock is ignored by his peers as he repeatedly brings up an idea but is only acknowledged after several bids; he literally asks to make a suggestion at one point. Another example of the group’s civility is when Justin and Jakob are simultaneously talking and clearly want to say something about what to do next. They talk over each other until Jakob begins to make a ‘baap’ noise any time Justin tries to say something. Eventually Justin stops talking and Jakob begins to explain what he wanted to. In this segment there are four civil, seven uncivil and no neutral statements.

The second segment is mostly Jakob explaining to the instructor. This group is kind about Jakob’s explanation, mostly does not interrupt him, and occasionally contributes to the discussion instead of holding fast to their opinions without reason. This segment has five civil, four uncivil, and five neutral statements.

We expected this group to be more equitable based on the quantitative measures but inequitable according to our intuition. According to these two qualitative measures, it is inequitable. Inchargeness is distributed between two people, which means it is more equitable than the first group, but is clearly not evenly distributed, which means it is still inequitable. Brock and Herb clearly do not have a voice in the group. This group averages five civil, five uncivil, and two neutral statements, which is slightly more civil than Group One but has the same amount of incivility. The civility of the group was difficult to reconcile because they were inconsistent in their actions. Brock was both ignored and acknowledged by the same people in a short period of time; they all talked over one another but, some of this time, they were engaging with one another’s ideas.
Discussion and conclusion

The first measure of equity was the distribution of in chargeness. In both groups, there was a concentration of in chargeness, as opposed to an imagined, highly equitable group, which has an even distribution of in chargeness. This measure shows who holds the power of the group. In G1, Justin had the most in chargeness, which put more weight on his actions. Thus, when Jessica was encouraged by Brittany to have a voice in the group and he ignored her, his actions had a bigger impact than Brittany’s, so Jessica quickly stopped speaking. In chargeness could be further developed and verified as an effective tool to measure the positioning of students in contrast to Dietrick’s “Commands” and “Questions” operationalization. In both cases, the concentration of in chargeness still negatively impacted those who did not have it. Those with less in chargeness spoke less and engaged less, which could mean they will learn less (Marbach-Ad et al., 2016) from this program.

The second measure was the civility of the group. Both groups were similarly uncivil. In G1, it was due to some individuals being civil and a different individual being uncivil. For G2, this was due to a group member’s persistence; if Brock was ignored, he repeated himself until he was acknowledged. Getting ignored is uncivil, but later getting acknowledged is civil. We choose to analyze on the group level because if a group member is being silenced, it matters that the group allows that incivility to be a part of the discourse. This method helpfully describes how comfortable a group is for all its members. A solely civil group is probably comfortable for all members. Both groups we analyzed average around fifty percent civil (ignoring neutral statements).

When we look at how uncivility was moderated by in chargeness, Justin in G1 left little room for others to have authority so any civil motion (without his support) was insignificant. In G2, it is possible that the division of power made Brock feel comfortable repeating himself.

These groups were chosen because they seemed dissimilar quantitatively, but our intuition about them was that they were more alike in terms of inequity, which was validated by the qualitative measures described here. We hope to see a continued use of comprehensive measures of equity so that classroom interactions can be understood more holistically. We developed these methods with the hope for more rapid, possibly in vivo, analysis of any type of group (various sizes, different settings, etc.) and that individuals’ group experiences in the program can be related to their persistence in it. One weakness of this study is that we selected these data because they stood out. Work should be done to see if these methods effectively characterize groups which are more typical.

References


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Bringing Static Code to Life: The Instructional Work of Animating Computer Programs With the Body

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Abstract: In this preliminary report, we propose a previously unidentified role that instructors’ gestures may play in helping students evaluate existing computer code. We find that instructors use gesture to animate processes encoded in the static inscriptions of computer programs in order to make invisible, dynamic phenomena perceptible to students. Our findings contribute to a better understanding of the embodied instructional work of teaching programming.

Introduction
The role of the body for communication in science and mathematics instruction is now a central focus in the learning sciences, with numerous investigations appearing over the last twenty years (e.g., Alibali et al., 2014; Hwang & Roth, 2010; Kress et al., 2001; for a review see Singer, 2017). However, studies examining the nature of teachers’ embodied, discursive instructional tactics in computer science instruction are rare (Grover & Pea, 2013). In this paper, we report on a novel function of teachers’ bodies in programming instruction—animating processes encoded in the static inscriptions of computer programs. We present two examples of how instructors use gesture to make dynamic phenomena perceptible that are essential to successfully comprehending and evaluating computer code.

Animating processes encoded in static inscriptions
Teaching programming is challenging (Milne & Rowe, 2002) and students face a number of difficulties both in comprehending and creating programs (Robins, Rountree, & Rountree, 2010). Many innovative tools have been developed and studied to make programming more accessible (e.g., block-based programming languages), but more research is needed to understand how instructors use discursive tactics to make programming concepts and practices intelligible (Grover & Pea, 2013). While there is substantial evidence that students use bodily resources to reason and communicate as they program (e.g., body syntonicity—Fadjo et al., 2009; Papert, 1980), we know little about the communicative role teachers’ bodies play during programming instruction.

Case studies by Kwah and Goldman of a high school robotics instructor have shown that pedagogical gesture plays an important role in guiding students’ program creation (Kwah, 2013; Kwah & Goldman, 2011). The focal instructor they study used gestures to diagram programming concepts for students based on metaphorical and iconic image schemas. He also shifted points of view while gesturing (between first-, second- and third-person), providing opportunities for students to recognize when ideas generalized beyond particular situations. The authors conclude that teachers’ use of embodied communicative resources is a vital yet critically understudied dimension of computer science instruction.

In this study, we complement Kwah and Goldman’s work by exploring additional ways programming instructors use multimodal resources (e.g., gaze, gesture, posture, talk, object manipulation, etc.). In particular, we focus on resources used to help students interpret code in existing programs (i.e., in program comprehension). Experienced programmers can evaluate code to make swift, accurate predictions about how a computer will interpret and execute the instructions. However, these same lines of symbolic notation create a perplexing perceptual field for newcomers, with a multitude of potentially relevant features to attend to. To impart disciplinary ways of perceiving phenomena, experienced practitioners and instructors rely on a variety of bodily practices to separate signal from noise for newcomers (Goodwin, 1994; Lindwall & Lymer, 2008; Stevens & Hall, 1998). For example, a mathematics tutor may deny visual access to irrelevant features of a graph (Stevens & Hall, 1998) or an archeologist might enhance focal features in the soil by outlining them (Goodwin, 1994).

In programming, however, shaping how students perceive programs cannot be readily accomplished by merely highlighting or hiding lines of code. When evaluating programs, instructors must help students to “see” dynamic future processes that have no immediate spatio-temporal correlates in the static list of inscribed instructions that is present. Instructors can show students code, but from its inscription alone, it is impossible for students to tangibly appreciate the active event of executing this passive list of instructions—i.e. the processes encoded in the instructions. Instead, we propose that in order to highlight these invisible processes of code, instructors must make them perceivable and quasi-present to students by conjuring them through gesture (Nemirovsky, 2012).
We note that this challenge is similar to one presented by mathematics. At first, mathematics, too, only seems accessible to the senses through inscriptions. However, Nemirovsky and colleagues argue that mathematicians and students use their hands and bodies as key resources for “bringing to life” the static symbols and inscriptions of mathematics, making dynamic processes perceptually available to both animator and audience, and allowing for the collaborative imagining of possibilities (Nemirovsky, 2014; Nemirovsky & Smith, 2013). Inspired by Nemirovsky’s work in mathematics, we set out to investigate how instructors use similar resources to make invisible, dynamic processes perceptible in static inscriptions of code.

**Analytical approach to investigating instructors’ use of multimodal resources**

Our example episodes come from an 18-hour video corpus of an eight-week-long, Saturday coding program at an urban nonprofit STEM learning center. In the program, students create emojis using Pixelbots, an in-house-developed programming environment (Figure 1) and were instructed by local undergraduate computer science majors.

We examined this corpus to locate instructional sequences where depictive gestures occurred during explanations about existing programs. Following Streeck (2008), we consider embodied activity depictive if it provides a construal that bears recognizable perceptual similarity to objects or processes in the world. From this initial collection of instructional episodes, we selected two examples to present that we believe provide insight into how instructors animate static inscriptions of computer code for students.

Our multimodal microanalysis of video is inspired by ethnomethodological conversation analysis (Mondada, 2012). Using ELAN we annotated episodes frame-by-frame to determine co-occurring segments of talk and embodied activity. This allowed us to richly characterize the interactional resources instructors use to communicate programming concepts. Video episodes were subject to group analysis to mitigate threats to reliability and validity.

**Two examples of animating processes hidden in static computer code**

1. **Bringing flow of control to life**

Our first episode occurs in Ari’s class as students learn to evaluate and write code to move a “pixelbot” that paints grid-squares (see Figure 1). Ari writes students’ code on the board for the class to evaluate. As they examine different examples together, Ari explains that shorter code is more desirable because a program with fewer lines runs faster.

During this explanation, Ari makes the dynamic flow of control in the program salient for students, elaborating his verbal description of the process with his hands (Figure 2). Perceiving different control structures in a program (like sequence, selection, and repetition) is an essential component of evaluating a program (K-12 CSF, 2016) that students must be trained to recognize.

![Figure 1](image1.png) In Pixelbots, students write code to move a square-painting pixelbot around a grid to create an emoji like this eyeball.

![Figure 2](image2.png) (a) Ari, the instructor, performs a series of jumps with his hand over code written on the board to animate the sequential flow of control. (b) He turns to students and re-creates this gesture away from the board while asking students if they remember what this phenomenon was called. Highlighted text shows speech that co-occurs with the gesture depicted.

To make the order in which statements are executed visible, Ari uses an environmentally coupled gesture (Goodwin, 2007) to laminate a series of curved jumps with the inscribed statements, embodying the dynamic
sequential flow of control (Figure 2a). Then, he repeats this gesture in the air (Figure 2b) as he asks students for its name. Using his hand to animate the static code on the board, Ari is able to make a dynamic phenomenon temporarily present for students to consider.

2. Illuminating the dynamic process of accessing data structures
In our second example, a student is working in Pixelbots with his instructor, Dex. They are examining some code that will randomly select a value (a color) from an array. Dex realizes the student is unclear on how data is retrieved from the array.

Arrays are a type of variable that can store multiple values—e.g., “green,” “blue,” and “red.” Values are accessed by referring to their position, or their index, in the list: e.g., 0, 1, or 2. The array Dex and the student consider is declared on the computer screen as follows:

```
var list = ['green', 'blue', 'red']
```

To make the difference between values and indices perceptible, Dex uses his hands to animate what the computer does with each. First, Dex lifts his left hand from the screen and uses his index finger as if tracing down a column, conjuring up the use of an imaginary table (Figure 3a).

Keeping his left hand steady on this imaginary table, Dex raises his right index finger high in the air, squints up at it, and glides it diagonally across the imaginary table, pantomiming a visual search of table contents (Figure 3b). Then, Dex uses both index fingers to locate three different vertical positions on the imaginary table corresponding to the indices “zero, one, and two” (Figure 3c). Lastly, Dex makes a precision grip gesture (Streeck, 2009) with his left hand. This momentarily makes present a new imaginary object—a “value”—in the negative space of his grip (Nemirovsky et al., 2012) and places it in the imaginary table (Figure 3d). Dex then points back to the computer screen (not shown) to link the performance to the code.

By using his hands and gaze, Dex brings to life an analogy to animate how data is accessed in the array. He contrasts the process of using the indices of a table to coordinate a search for items with the actual items (the values) themselves. Through this enactment, Dex provides embodied resources for the student to perceive the different roles of indices and values.

Conclusions
We have shown how programming instructors bring the passive instructions of code to life for students while they examine the static inscriptions of programs together. Instructors animate processes using their hands and bodies to make important, dynamic phenomena perceptible to students. This provides resources for students to evaluate and comprehend computer code in ways that resemble experts’. Our future work will seek to better understand if students take up these resources and how they influence students’ comprehension of code over time.

Our findings contribute to a growing body of evidence that STEM instruction, including computer science, is irreducible to written and verbal discourse alone. Multimodal semiotic resources appear to be a pervasive, crucial component in programming instruction. In particular, we add to Kwah and Goldman’s studies of pedagogical gesture in programming by contributing a novel function of embodied communicative resources.
in teaching students to read code. Our study also extends Nemirovsky and colleagues’ findings to a new domain, suggesting that the practice of animating static inscriptions to collaboratively imagine possibilities may be a universal strategy across STEM disciplines. Our ongoing efforts to characterize the range of functions of pedagogical gestures in programming instruction in the wild are important first steps towards more systematically understanding how teachers’ use of embodied communicative resources may impact students’ learning. We also hope to identify more parallels, as well as distinctions, in the role multimodal communication plays in programming instruction as compared to mathematics and other scientific disciplines.

References

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Third Graders’ Use of Digital Tools Designed for Multimodal Communication in Project-based Science

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Abstract: This short paper describes a study conducted in the context of a larger design-based research project focused on investigating the integration of science, English language arts, and mathematics in elementary grades project-based learning (PBL). This study focuses on one third-grade unit (How can we help the birds that live around here grow up and thrive?), in which student groups developed and presented digital, multimodal artifacts, using a suite of digital tools. We asked: (1) What did third-graders’ digital artifacts reveal about their use of multiple modes to communicate information? (2) How did students describe their modal use as they shared their digital artifacts? Findings suggest that third-graders were strategic and flexible in their modal selection and use. In sharing presentations, there was variability in students’ descriptions of multimodal features and rationale for modal use.

Keywords: Multimodal literacy, instructional design, learning technologies, project-based learning

Introduction and purpose
Designers of Project-based Learning (PBL) environments and curriculum have been theorizing important roles for technology in PBL for more than two decades (Blumenfeld et al., 1991). The 2017 NMC Horizon Report (Freeman, Adams Becker, Cummins, Davis, & Hall Giesinger, 2017) identified deeper learning approaches, such as PBL, as driving the adoption of educational technology, and predicted that these approaches will have long-term impacts on technology planning and decision-making in K-12 education during the coming years. While implementation literature frequently cites technology tools as integral for supporting inquiry and scaffolding learning, we know very little about how elementary-grade learners use technology tools to create artifacts in the context of PBL (Condliffe, Visher, Bangser, Drohojowska, & Saco, 2016).

This study is part of a larger, design-based research project focused on investigating the integration of science, English language arts (ELA), and mathematics in elementary grades PBL, called Multiple Literacies in Project-based Learning (MLs). In addition to iterative curriculum design, we have been engaged in the iterative design of a suite of digital tools (e.g., Collabrify Writer, Collabrify Flipbook), which play a key role in learners’ self-expression, reflection, and collaboration. This study’s focus on the use of digital tools in an elementary classroom is consistent with the International Conference of the Learning Sciences’ 2018 focus on exploring learning in real-world settings and understanding how learning may be facilitated with technology. This study focuses on one third-grade project-based unit (How can we help the birds that live around here grow up and thrive?), in which students participated in an “ornithology lab” (OL) that culminated in students developing and presenting digital, multimodal artifacts. In this context, we ask: (1) What did third-graders’ digital OL artifacts reveal about their use of multiple modes – image, video, and writing – to communicate information? (2) How did students describe their modal use as they shared their digital artifacts with the class?

The Common Core State Standards for ELA support the integration of multimodal reading and writing in K-12 classrooms (CCSS 2010). However, there is little research evidence to guide elementary-teachers’ use of digital, multimodal literacies with their students, as most research on multimodal literacy has been conducted at the secondary level (Smith, 2013). In one exception, Dalton et al. (2015) investigated fifth-graders’ digital retellings of folktales, composed in a scaffolded PowerPoint environment. Researchers found that all students’ retellings included both written and visual information. Furthermore, student interviews revealed intentionality regarding design choices and an awareness of how different modes work together. While this research is promising, we know little about elementary students’ use of digital tools to compose multimodal writing, especially in the context of communicating disciplinary knowledge in PBL.

Theoretical perspectives
Learner-Centered Design (LCD) is an approach to software design, focused on tailoring software specifically for student use (Soloway, Guzdial, & Hay, 1994). LCD draws upon ideas of user-centered design, but also addresses
the specific needs of learners: (a) how they will learn to use the software tools, (b) how the software will support learners’ motivation, (c) how to design for diverse learners, and (d) how to account for learner growth. The design of the Collabrify Tools, featured in this study, is guided by these principles.

Both LCD and PBL are grounded in social constructivist theories of teaching and learning. Based on these perspectives, students actively construct knowledge by working together to solve problems and by manipulating and using ideas, a variety of information sources, and cognitive tools (Brown, Collins, & Duguid, 1989; Palincsar, 1998). The tenets of social constructivist theory also suggest that learners benefit from software that scaffolds the construction of artifacts, creates opportunities for collaboration and communicating with others, and includes supports for reflecting on constructed artifacts (Soloway et al., 1994).

Finally, this study focuses on third-graders use of multiple modes and sources of information (e.g., firsthand observations, print and digital text, videos, images) to create digital, multimodal artifacts using researcher-designed technology tools. Multimodal perspectives on literacy assume that people use many representational resources or modes (images, audio, video) to make meaning and that different modes have affordances and constraints for representing and communicating ideas, which influence sense-making (Jewitt, 2008).

Methods, data sources, and instructional context

This study took place in one third-grade classroom with 32 students in a K-5 elementary school in the Midwest United States. On state achievement measures, only 20% of students demonstrated proficiency in ELA. The teacher is an experienced third-grade teacher, and a second-year Multiple Literacies in Project-based learning (MLs) participant and user of Collabrify Tools.

The instructional context of the study is one MLs PBL unit of instruction, framed by the driving question: How can we help the birds around here grow up and thrive? In the unit, students learned about birds that live in their community, structure-function relationships, physical and behavioral traits, and how traits interact with birds’ habitats. As part of the unit, students engaged in an “ornithology lab” (OL), which culminated in the development and presentation of digital, multimodal artifacts to communicate information about a student-selected local bird. Students created the digital artifacts using the suite of Collabrify Tools. The digital applications with which students worked on Chromebooks included: (a) Lesson Launcher (used to support navigation of the digital tools, see Figure 1), (b) WeRead (an e-reader), (c) Collabrify Writer (a multimodal writing tool, in which students enter their own drawings, photographs, videos, and animations, or conduct online searches for images and videos), and (d) Collabrify Flipbook (a drawing and animation tool). Collabrify Writer, the primary tool considered in this study, has the affordance that the user can easily incorporate text, images, and video in a single document, in contrast with other word processing tools. The apps are labeled “Collabrify” because they are designed to support synchronous collaboration among learners.

Figure 1. Screenshot of the Ornithology Lab Lesson Launcher.

For the OL, students used multiple print and digital multimodal resources (e.g., field guides, tables, charts, videos, audio, etc.) in order to engage in the work of ornithologists: classifying and describing their bird’s physical (feet, wings, beak) and behavioral (migration) traits, and planning and designing solutions to help local birds survive and thrive in their community. Similar to Dalton et al.’s (2015) work with fifth-graders, we
hypothesized that providing a basic structure for third-grade students’ digital, multimodal writing within the Collabrify Writer files would support the third-graders to focus on core science ideas in their writing, and alert them to their modal options. For instance, in addition to written prompts that focused on the content of the entries (e.g., Describe your bird’s beak), we embedded prompts within students’ Collabrify Writer files that alerted them to options for incorporating multimodal features: (a) take new photos or insert video, (b) select existing photos or videos, or (c) add YouTube video. In addition, students could choose to embed additional multimodal features at any other point within their digital artifacts.

Data sources for this study included student pairs’ digital artifacts (e.g., Lesson Launcher, Collabrify Writer, and Collabrify Flipbook files) and field notes, as well as transcribed video/audio recordings of students’ presentations of their digital artifacts in class. One goal of this study was to describe the range and frequency of the third-graders’ use of modes in their digital writing. We created a modal-use coding system that included the set of modes available to students: writing, image, animation, and video. We analyzed 14 sets of OL artifacts (all entries within 14 groups’ Lesson Launcher files) using the four code categories. We then expanded these categories to include subcategories that emerged from the data set (e.g., YouTube videos, own videos, Google Images, etc.). We were also interested in the extent to which students’ modal selections were relevant to the written information in their artifacts. Thus, we developed a rubric to assign a score to each image, video, or animation included. A total of 3 points was possible for each multimodal feature: 0 – no feature included; 1 – feature not relevant (e.g., image of a different bird than described) or purely decorative (e.g., “The End”); 2 – feature relevant but not specific (e.g., image of focal bird, but not reflective of description); 3 – feature relevant and specific (e.g., image of focal bird and reflective of written description).

Another goal of this study was to determine whether and how students described their artifacts’ multimodal features and modal use as they shared their OL artifacts with their peers. For each presentation, students selected and projected one or more Collabrify files using a SMART Board. First, we viewed and transcribed video recordings of students’ OL presentations (8 groups volunteered to present). We read each transcript line-by-line and wrote open-ended analytic memos, and then engaged in open and axial coding (Corbin & Strauss, 2008) specific to modes (e.g., writing, image, video) as well as codes that emerged from the data, such as whether presenters described multimodal features with or without prompting, and how students explained their rationale for including certain multimodal features.

**Findings**

In response to our first research question, we found that all 14 groups incorporated a variety of multimodal features within their OL presentations: all groups included text; 8 groups included at least one YouTube video; 1 group recorded and included their own video; 10 groups created drawings and 4 of those groups combined their drawings with other modes; 3 groups created animations; 11 groups captured and included their own photographs; all groups completed Google searches for, selected, and embedded images; and 1 group captured and included a screenshot. Also, analyses suggest that the majority of the multimodal features included in groups’ presentations received a score of 3 (relevant and specific). For example, of the 102 Google Images included across presentations, 66% received a score of 3 (67 images), 23% received a score of 2 (23 images), and 12% received a score of 1 (12 images). Of the images receiving a score of 1, the majority were purely decorative. These findings suggest that students were strategic (i.e., purposefully choosing multimodal features) and selective (i.e., choosing relevant features that were responsive to embedded prompts and illustrative of their written entries) in the incorporation of multimodal features.

While scaffolds were included to prompt students to incorporate multimodal features (e.g., images, videos, photographs) at specific points in their presentations, all 14 groups included more multimodal features than were prompted for, suggesting that students went beyond the scaffolds in their selection and inclusion of multimodal features. Further, while not all groups used every modal option available to them, all groups did include multiple types of multimodal features in their OL presentations, demonstrating flexibility in modal use.

In response to our second research question, analyses of groups’ oral presentations revealed variability in the ways in which students incorporated and addressed their modal use when sharing their OL presentations. While some groups did not point out or describe multimodal features as they presented, without prompting from the teacher or other students, other groups independently pointed out and described embedded multimodal features as they shared their presentations with the class. When YouTube videos were included, some groups engaged their peers in viewing and discussing video excerpts. Analyses of groups’ oral presentations sometimes revealed students’ rationale for including specific multimodal features. Some groups independently described this rationale. On other occasions, the teacher or student audience members prompted groups to explain why they included certain multimodal features in presentations (e.g., Student: “Why’d you wanna [sic] choose those pictures?”).
Finally, groups provided a variety of explanations for incorporating specific multimodal features, including that the multimodal features (a) illustrated ideas in their written description (e.g., “We chose this picture because we thought it was going on its migration path and it stopped to get some food.”), (b) looked cool (e.g., “…we liked the picture and it looked cool.”), or (c) that they were unsure why they included the feature (e.g., “I don’t know why…”).

Significance
This work is significant because, as Lemke (2004) urged, students need to be able to interpret, analyze, and produce multiple modes of representation in service of communicating disciplinary knowledge. The research literature tells us very little about how to support young students, in particular, to learn to interpret and generate multimodal texts. This study provides evidence that, even in the elementary grades, learners can be supported to strategically and flexibly select, use, and combine multiple modes of representation to communicate disciplinary knowledge. This work also has the potential to inform the design of technology tools that may scaffold students’ development of digital, multimodal compositions.

References
Common Core State Standards for English Language Arts, K-5. (2010).

Acknowledgements
The research and development reported in this paper is being supported by a generous grant awarded to Joseph Krajcik, Annemarie Palincsar, and Emily Miller from the George Lucas Educational Fund entitled, Multiple Literacies in Project-based Learning. The authors gratefully acknowledge Emily Miller, who led the design of this unit of study. Any opinions, findings, and recommendations expressed in this paper are those of the authors.
Guiding Intent Participation at an Art Crating Company

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Abstract: This paper presents the theoretical concept of guiding intent participation. Grounded in a sociocultural perspective of learning and analytically guided by methods of multimodal and interaction analysis, guiding intent participation is a distinct category of guided participation (Kirshner, 2008; Rogoff, 1995). Guiding intent participation takes as relevant both the coordinated efforts of oldtimers and relative newcomers to make contributions to ongoing work and learning, as well as the observational activities by the oldtimers that are precursors to guidance. The analytic implications of the concept in support of rethinking assessment to consider social context are discussed.

Introduction

This paper presents a secondary analysis of data from a larger study of an art crating company called CratEx that designs and builds crates for the transport and storage of art objects. We look to guided participation (Rogoff, 1995) as a lens through which to analyze interactions between new employees (newcomers) and managers (oldtimers) during work activity and with a focus on how these interactions relate to newcomer learning. We recognize the work done by Kirshner (2008) in describing categories of guided participation as relevant when investigating newcomer-oldtimer interactions. In an effort to add to these works, the following question drives this case: What other kinds of guided participation are observable in this setting? We introduce the theoretical concept of guiding intent participation as a new and distinct category of guided participation.

Guiding intent participation is reminiscent of intent participation (Rogoff, et. al, 2003) in that keen observation with the expectation of participation in the future is still the participation structure of focus. However, it diverges from the original concept in that it focuses on the relative old timers and their observational activities rather than on those of the learner. Additionally, guiding intent participation is methodologically consequential as an analytical lens in reconsidering assessment during work activity because it illuminates moments of shift from inherent to discursive assessment (Jordan & Putz, 2004).

Theoretical framework

In this paper we take a sociocultural view, allowing us to take seriously the roles that participation in social interactions and culturally organized activities play in learning at CratEx. Furthermore, we draw on Rogoff’s (1995) theory of guided participation, a developmental process at the interpersonal level of activity - the second of three planes of analysis between personal and community processes. This interpersonal plane is comprised of everyday activities engaged in and managed collaboratively by individuals within a particular setting. Rather than being an operational definition, guided participation offers a perspective on interpersonal interactions that focuses on, “mutual involvement of individuals and their social partners, communicating and coordinating their involvement as they participate in socioculturally structured collective activity” (p.146).

The term guided refers to direct and indirect structuring of participation possibilities through cultural, social, and interpersonal values. Moreover, by participation Rogoff is referring to both explicit involvements in an activity and observation of said activity. Central to the concept of guided participation is that more experienced members of a community support the participation of relative newcomers, through “a system of interpersonal engagements and arrangements that are involved in participation activities,” (Rogoff, 1995, p.146). This may be done, for example, by encouraging involvement in some aspects of activity and restricting it for others. This is of primary concern in this paper because the interactions of focus are frequently asymmetric in terms of experience.

Lave and Wenger’s (1991) theory of learning as a process of legitimate peripheral participation is useful in understanding these types of asymmetric interactions. It brings into focus the intimate connection between learning and participation in a community of practice by focusing on the social situations in which activity occurs. Possible forms of participation to which newcomers have access mediate membership. In particular, the authors argue that learning is best supported when newcomers have full access to the practices of experts. This means having opportunities to complete low-risk tasks, but also to observe and participate in more complex activity with the support of more experienced participants. In doing so, newcomers begin to “gradually assemble a general idea of what constitutes the practice of the community,” and how their activities fit within it (p.95).

Using guided participation and legitimate peripheral participation as his lens of analysis, Kirshner’s (2008) study of youth activist groups distinguished between three categories of guided participation: facilitation,
apprenticeship, and joint work. Briefly stated, guidance through facilitation highlighted adults as having a neutral role that supported youth leadership and input. Here, the youth were given a say in regards to the content of meetings, focus of projects, and adults stepped in only “as needed.” Guidance through apprenticeship consisted of adults being seen more as veteran activists who participated in youth-centered mutual endeavors. Lastly, guidance through joint work also had the collaborative characteristic similar to apprenticeship, but activities were not youth-centered. Here, categories of adult or youth did not drive the tasks participants were assigned. Rather, divisions defined by experience (regardless of age) were more salient. Kirshner’s categories of guided participation are relevant because they offer examples of how the efforts of oldtimers and relative newcomers might be coordinated to make contributions to the work and learning occurring in a community.

Methods and data
Presented here are findings based on a secondary analysis of data originally collected as part of a study that investigated spatial reasoning practices. In the primary study, both researchers held observational roles and did not take part in any of the building activities. Methods of multimodal and interaction analysis (Goodwin, 2010; Jordan & Henderson, 1995) were used to examine instances of guided participation by CratEx employees during work activity. Data include ethnographic field notes, audio and video recordings, images of material representations used by participants in their work, and informal interviews, collected over an 8-month period.

The original study observed interactions and activities within all the departments of CratEx. This included the Project Managers who designed crates, the Crate Shop who built each crate’s exterior, the Packing Department who created the interiors and packed the art, and Transport who were responsible for shipping management. The analysis presented here focused solely on interactions that occurred in the Packing Department. This department was responsible for “building out” the interior of the wooden crates. Packers cut and installed anything that went inside the crate (e.g., foam, braces, shims) and were responsible for ensuring the security of the crate’s contents. Previous research found that work in the Packing Department was more often collaboratively, rather than hierarchically or individually, undertaken (Radke & Ma, 2015). For example, teams of packers often worked on large or complicated crates and when questions came up, the help of additional packers was often sought.

Analytically, we focus on interactions where there was some amount of new employee - manager interaction during work activity. Because work at CratEx is often collaborative, this type of interaction was pervasive. In this study we selected for analysis those episodes which highlighted aspects of guided participation, but could not be explained by Kirshner’s three categories. The episodes examined in this paper were chosen to best illustrate our findings. They occurred across our time at CratEx and together, include all the Crate Shop managers as well as both new and seasoned employees.

Findings
More experienced packers often took a guiding role; however, the collaborative structure also supported relative newcomers sharing and applying what they had learned in the Packing Department and in previous experiences outside of CratEx. This allowed them to show initiative or take leadership roles with the support of their more experienced colleagues. For example, after receiving some assistance from Nick (a more experienced packer) about how to safely pack a large piece of artwork, Brenda (a relative newcomer) offered a suggestion about how to accurately and efficiently measure for extra padding. Nick accepted her suggestion and emphasized her position as a leader in that moment when he stated to the group, “she is showing us how to do our job!”

Many of these episodes of newcomer initiative occurred after they spent time observing more experienced packers as they worked. It became clear that the more knowledgeable packers were not only mindful they were being observed, but routinely initiated the observations as potential teaching episodes. In an interview, one Packing Department manager framed these opportunities for observation as key to how processes and standards were learned. He shared that, “the way you communicate it [the knowledge to be learned] is just by having someone watch you work.” Rogoff and her colleagues (2003) argue that these kinds of newcomer (or learner) observations are not passive occurrences, but an “aspect of participation” (p.178) that they call intent participation. They describe intent participation as, “observ[ing] and listen[ing] with intent concentration and initiative,” where, “collaborative participation is expected when they are ready to help in shared endeavors” (p.176). The concept emphasizes a type of observation motivated by expectations of eventual collaboration and participation.

Our focus in this paper, guiding intent participation, combines aspects of intent participation described above and guiding participation. In our term, guiding refers to participation by the more experienced member in an interaction that is in support of newcomer learning. Intent indicates that there is “keen observation” (Rogoff, 1995) of participants with the expectation to participate in the not so distant future. However, here we turn our
attention to observations made by more experienced members rather than by relative newcomers. Finally, *participation* of oldtimers may come in the form of “overseeing” or “checking in on” without interjection, or suggestions, corrections, clarifications, etc., which can occur both as an injection into interactions and during ongoing collaborative work activity.

Common to work activity in the Packing Department were instances of relative oldtimers observing, or listening in on, newcomers as they worked, often injecting themselves into the ongoing activity to clarify, correct, or otherwise offer assistance. Often times this was connected to assessment of learner’s actions or reasoning during collaborative work in an effort to support learning, while ensuring work tasks were accomplished correctly. For example, managers would routinely walk the Packing Department to check on progress of all the ongoing projects, listening or looking in from a distance (See Figure 1).

![Figure 1. Manager (Nan) Observing multiple ongoing projects](image)

Sometimes self-injections following observations occurred when they saw something of concern (e.g., On a walk around the department floor, an oldtimer stopped at the workbench of a newcomer with the exclamation, “Whoa! What happened here?”). However, they were also part of routine assessment of ongoing work activity. For example, in the following excerpt, Nan (the manager) has been observing Fred (a Packing Department employee) as he frames the interior of a crate with foam. After several non-verbal observations, Nan makes her way over to his workspace.

Nan: So? (2 seconds) What does it need on the sides?
Fred: Just this piece. ((Holds a short piece of foam inside the crate where he plans to glue it.))
Nan: Yeah. Perfect.

Oldtimers also injected themselves into ongoing activity with a guiding recommendation or to offer assistance (e.g., “Make sure you measure both sides, there might be something funky going on with that foam”). When they were already part of collaborative activity, more experienced packers would stop their own work to check on the work of their less experienced project partner(s). For example, in the following excerpt, newcomer (Nancy) and an oldtimer (Chuck) worked to frame the inside of a crate with foam. As they work, Chuck stops, watches Nancy, and after five seconds of silence makes a suggestion about her work efforts.

Chuck: ((Pauses in his work to watch Nancy; he looks up [Figure 2a] and down her length of foam.))
Chuck: Go ahead and [Figure 2b] push that down if you can. They’re cut – you cut them a little short.
Nancy: Oh. Sorry. ((Pushes down on [Figure 2c] the foam)).

![Figure 2. Chuck, in the midst of his own work, a) stops to observe while Nancy inserts foam into her side of the crate, b) interjects a suggestion, and c) watches as Nancy responds.](image)
Reviewing two decades of research coming out of the Palo Alto Research Center and the Institute for Research on Learning, Jordan and Putz (2004) presented a three-part framework for rethinking assessment as a ubiquitous social practice. They described the framework as a tripod of inherent, discursive, and documentary assessment. Relevant to this analysis are the first two categories in which they describe assessments, “produced on the fly, as natural parts of mundane social activities by individuals and groups” (p.346). Some of the nonverbal observations the managers make of their employees fall into this first category, inherent assessment. For example, the time spent moving around the Packing Department observing ongoing activity and assessing project progress. At other times however, these nonverbal observations, or inherent assessments, result in a verbal communication with one or more employees; these explicit communications Jordan and Putz label as discursive assessments. The shift from inherent to discursive is a transformation of individual, nonverbal assessment, to assessment that is public, verbal, and now exists as an object that can be referred back to, or talked about. In these ways, the discursive assessments are critical for the learning of ongoing activity.

**Significance**

Guiding intent participation is distinct from Kirshner’s three categories of guided participation. On a surface level, aspects of each of Kirshner’s categories are relevant within guiding intent participation (e.g., “veteran” packers participating collaboratively with newcomers; newcomers taking charge of their own learning; etc.). However, it is distinct because it is a hybrid of guided and intent participation that describes the actions and participation of the relative old-timers in the interactions. As such, it considers both the interactions that support and coordinate efforts of old-timers and relative newcomers to make contributions to the work and learning occurring in a community as well as the observation activities by the oldtimers that are precursors to guidance. Guiding intent participation, as a category of guided participation, provides insight into how learning occurs in everyday, routine interactions as it highlights ways oldtimers both recognize the need for guidance and interact in order to support the learning of newcomers.

Guiding intent participation could also serve as a methodological frame in support of the call made by Jordan and Putz (2004) for research to “turn its attention to the task of gathering systematic empirical data on assessment practices as they occur naturally in various organizational contexts” (p. 355). Giving systematic, analytical attention to moments of guiding intent participation would help pinpoint and elucidate shifts in assessments from inherent to discursive.

**References**


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Using Phenomenography in Educational Technology Research
From 2003 to 2017: A Systematic Review and Content Analysis

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Abstract: Educational technology has been tremendously growing and there are many potentials for investigations. Phenomenography is known as a useful strategy to investigate variations in conceptual understandings of different phenomena. The paper aims to: (1) examine the research papers in educational technology studies over the past 15 years (2003-2017), and (2) evaluate the feasibility of phenomenography in the field of educational technology studies. A systematic review is done to the educational technology research papers that involve the use of phenomenography. A systematic literature search in the 14 SSCI journal websites produced 35 articles. Although there were only few papers which used phenomenography as research approach in educational technology studies, there was a gradual rise in the number of studies using phenomenography across years, with more focus on studying students’ learning experiences, especially in the higher education sector. Implications about the use of phenomenography in educational technology field will be discussed.

Introduction
Educational technology is defined as “the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources” (Januszewski & Molenda, 2008, p.1). Educational technology is also associated with other terms like instructional technology, information technology (IT), information technology and communication (ICT), computer-supported collaborative learning, online learning, distance education and computer education (Pelgrum & Plomp, 2002). Educational technology is a rapidly growing research area with the big leaps of technology development in the 21st century. This represents that the field of educational technology, also known as instructional technology, is potentially a fast-growing pool for research development concerning the facilitation of learning and teaching with the application of technology. Therefore, there is a need for evidence-based approach to inform ‘better’ practices of educational technology. Interestingly, most educational technology studies were design-based and quasi-experimental (Amiel & Reeves, 2008).

Systematic review: An overview
Various literature reviews were carried out to investigate different applications of educational technology such as hypermedia (e.g. Dillon & Gabbard, 1998), games (e.g. Randel et al., 1992), and so on. Some attempted to inquire the factors affecting the effectiveness of the use of educational technology, including learning environments (e.g. Winn, 2002), professional training and development (e.g. Daly, Pachler, & Pelletier, 2009), while some investigated the factors that affect the implementation of educational technology (e.g. Durlak & DuPre, 2008). Still, most of these reviews were either narrowly studied or loosely organized. Few were doubted for the trustworthiness as they might contain ‘questionable findings’ due to ‘under-examined assumptions’ (Kirkwood, & Price, 2013, p.536). Systematic review has received much attention in scientific and academic fields for its great power in providing ‘high level of evidence’ to inform recommendations and contribute to the development of new knowledge (Higgins & Green, 2011). Recently, systematic reviews have been done to find out the recent trends on the application of different learning approaches, for example, problem-based learning approach (Tsai & Chiang, 2013). They are also used to study the applications and impacts of different types of educational technologies such as flipped classrooms (e.g. Karabulut-Ilgü, Jaramillo & Jahren, 2017), games (e.g. Graafland, Schraagen, & Schijven, 2012).

Phenomenography: Origins and usage
The use of phenomenography as a research approach has gradually received much attention from educational researchers (e.g. Entwistle, 1997), which is known as ‘a research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and various phenomena in, the world around them’ (Marton, 1986, p.31). This approach is regarded as an effective approach to investigate variations in conceptual understandings of different phenomena (Bowden, & Walsh, 2000). Phenomenography is also recommended in studying educational technology due to its potential impact that
phenomenography and the relational perspectives have on pedagogical practices’ (Andretta, 2007, p.152). However, little is known about to what extent phenomenography can be applied in the context of educational technology. To our knowledge, there is a lack of systematic review on the use of phenomenography in the field of educational technology research. Therefore, the objectives of this paper are: 1) to examine the research papers in educational technology studies over the past 15 years (2003-2017), and (2) to evaluate the feasibility of phenomenography in the field of educational technology studies, with the following research questions: (1) How is phenomenography applied in studying educational technology?, and (2) What are the key limitations and possible future development in the use of phenomenography in educational technology studies as stated in the published articles in the SSCI journals?.

**Methods**
The review process involves data collection, data analysis and synthesis. Data were collected by the researchers who identified the relevant papers from the Social Science Citation Index (SSCI) journals in the field of educational technology. We selected SSCI journals for review because these journals are of high quality and impacts in the field. In order to identify the trend of the publication, we first targeted at finding the papers which were published in the recent 15 years (2003-2017). We then used keywords and search terms (e.g. phenomenographic study, phenomenography) in the SSCI journal websites. Only full-text available papers, which were written in English, were selected for review. After obtaining the set of papers, we organized the contents of these selected papers according to the origin (location) of study, year of publication, data collection method, targeted groups in the study, research questions, objectives of the study, open space, structural aspect, referential aspect and limitations of study. Data analysis include: (1) descriptive analysis (i.e. counting the number of published papers, origin of papers, targeted groups, data collection methods) with the use of MS Excel software, as well as (2) content analysis (i.e. thematic analysis) using coding strategies with the use of NVivo (version 11.0) software that enables to generate and search for patterns as emerged from the contents of the papers (i.e. limitations of the study, future research directions) (Bazeley, 2013; Clarke & Braun, 2013). A preset coding system was initially used to identify and construct themes. Examples of codes included generalization of the study, challenges, solutions, forms of data collection, perspectives of stakeholders) and number of participants (sample size).

**Preliminary findings**

**Research question 1: How is phenomenography applied in studying educational technology?**
A total of 35 articles were identified in the systematic literature search from the 14 SSCI journal websites. There was a gradual increase in the number of studies using phenomenography across years (Table 1). Most of these studies focused on inquiring students’ learning experiences when using educational technology, whilst these studies were mostly conducted in the higher education sector.

**Table 1. Number of papers using phenomenography in educational technology studies.**

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Research question 2: What are the key limitations and possible future development in the use of phenomenography in educational technology studies as stated in the published articles in the SSCI journals?

The key limitations of the use of phenomenography in the educational technology studies mainly included the small sample size and single perspective on the object of the study (e.g. students’ conceptions of using multimedia). However, it is commonly revealed that such phenomenographic studies help enrich our understandings of learning and teaching with the use of educational technology and therefore provide insights into preparing for future pedagogical applications of educational technology.

Significance of the study
The systematic review of the study will add to the current literature. First of all, this helps extend our knowledge about the use of phenomenography in the field of educational technology research by assessing its methodological rigors and practices. Second, the study provides evidence-based investigations of the feasibility of phenomenographic approach and further improvise how this approach can be used and strengthened in the educational technology field.

References


Teachers’ Views on Supporting Self-Regulated Learning in Early Childhood Science Education


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Abstract: There are few in-depth qualitative investigations evaluating the challenges of child-led learning programs that might support children’s self-regulated learning. We conducted focus group workshops with kindergarten and first grade teachers in the UK and found that, while teachers recognized potential benefits of child-led approaches in science education, they also expressed challenges that were novel in the literature on teacher views. In particular, teachers had a more detailed consideration of EF skill development, and reflected on the consequences to children’s learning of how much instructional guidance they provided. Moreover, we found differences in challenges reported by kindergarten and first grade teachers. Future research is needed with teachers of low-income children and a broader range of education stakeholders, in programs that produce a measurable change in teachers’ and children’s learning.

Introduction

Classrooms which give children some control over their learning – an approach often called “child-led learning” – have existed for some time. Yet only recently has there been systematic study of the specific learning benefits that child-led learning might provide. Some early childhood educational programs which emphasize child-led learning – such as Montessori and Tools of the Mind – are associated with enhanced self-regulated learning (“SRL”, the ability to control one’s behavior and guide one’s own learning), and the related ability of executive function (“EF”, e.g. the ability to adapt to changing contexts) (Lillard & Else-Quest, 2006; Blair & Raver, 2014). Both SRL and EF are associated with children’s school achievement and various positive outcomes later in life (e.g. Moffitt et al., 2011), and are implicated in the flexible thinking skills on the international PISA test (Ramos & Schleicher, 2016).

Existing child-led educational programs that support SRL and EF require a huge investment of resources in extensive training for teachers (Hsueh, Lowenstein, Morris, Mattera, & Bangster, 2014). As efforts to get teachers in everyday schools to adopt child-led approaches have been known to fail dramatically (Bakkenes, Vermunt, & Wubbels, 2010), it is critical to develop a better understanding of the challenges teachers face when trying to adopt child-led methods without extensive teacher training. We focus on child-led methods in playful science education, because science involves skills that embody SRL and EF (such as reflecting on evidence; e.g. Nayfeld, Fucillo, & Greenfield, 2013), and play may motivate children to use such skills (Golinkoff, Hirsh-Pasek, & Singer, 2006). There is a small literature on teacher views of child-led learning programs, but none of these specifically focus on developing SRL and EF in early science learning.

We assessed UK teacher views on the feasibility of child-led learning in science. We ensured that teachers’ views were evidence-based by engaging them in practice-based focus group workshops. Our workshops had features of professional development, such as teachers reflecting on their own practice together. Furthermore, we engaged teachers as co-researchers, to mirror the learner-led approach that teachers were encouraged to use. Unlike most other research on teacher views, we explicitly compared teachers from both kindergarten and first grade because they tend to differ in their use of child-led learning: First grade in the UK is more curriculum-bound than kindergarten, and subsequently tends to be less child-led (Wood & Bennett, 1999).

Methods

Participants

Workshop participants included 8 female teachers (see Table 1), 6 researchers (5 female), and 1 female Early Years Adviser from the Cambridgeshire County Council. We recruited kindergarten and first grade teachers from each school (one kindergarten teacher was unable to represent her school in the workshops due to illness).

Table 1: Teacher participants
### Year group | Teacher codes | Schools represented | Years of experience | Average | Median | Range |
---|---|---|---|---|---|---|
Kindergarten | K-S1, KS-2, KS-3 | S1, S2, S3 | | 7 | 6 | 3-12 |
First grade | F-S1, F-S2, F-S3-1, F-S3-2, F-S4 | S1, S2, S3, S4 | | 2 | 2 | 1-5 |

## Schools

Schools were a convenience sample, selected because of their interest in the project and their proximity to the researchers. Additional demographic and contextual information is presented in Table 2.

### Table 2: School demographics (Higher Derivation Pupil Premium percentage indicates lower family incomes)

| School code | Location (UK county) | No. of students | Student:Teacher ratio | Students eligible for Deprivation Pupil Premium | Government inspection rating | Proportion of students of white British heritage |
---|---|---|---|---|---|---|
S1 | Cambridgeshire | 207 | 24.3:1 | 8.2% | Outstanding | 2/3 |
S2 | Norfolk | 139 | 20.5:1 | 12.9% | Good | Majority |
S3 | Cambridgeshire | 295 | 23.5:1 | 7.5% | Good | Majority |
S4 | Cambridgeshire | 202 | 23.2:1 | 13.9% | Requires Improvement | Not available |

## Procedure

Workshop Participants met four times in seven weeks. Each workshop was four hours long, and consisted of researcher-led interactive activities, short researcher presentations, teacher reflections (both individual and in year groups), and collaborative planning sessions. Workshops were audio- and video-recorded.

Throughout the series of workshops the researchers would lay the theoretical framework, which aimed to simultaneously encourage the use of child-led practices and support for children’s SRL. Researchers presented evidence on child-led practices associated with developing SRL and EF (e.g. Perry, Hutchinson, & Thauberger, 2008), as well as classroom-relevant examples of child-led learning (e.g. using hooks to elicit children’s interest in science). Teachers were encouraged to share relevant experiences in their practice (e.g. examples of SRL in their classrooms), highlighting opportunities and challenges. They were then asked to plan child-led activities across the next two weeks, which they often did collaboratively. At the next workshop, many teachers brought evidence in the form of photos from their classrooms, and reflected as a group on their recent experiences trying child-led learning methods in the classroom. The workshop topics became gradually more teacher-led, mirroring our theme of child-led learning: In the first two workshops teachers planned activities with shared goals (e.g. supporting children’s SRL with a scientific investigation), and in the third workshop teachers chose a specific issue to focus on in their classroom. While we did not specifically aim to induce change in teachers’ practice or learning, because our workshops had elements of professional development, they symbiotically met the needs of both researchers and teachers.

## Data coding and analysis

Transcription of audio files was done partly by our research team and partly outsourced to a company. Teachers were identified by researchers present at the workshops, who recognized voices in audio recordings and linked them to transcripts, cross-checking with video recordings as necessary. Only passages which included teacher discussion (as opposed to researcher-only discussions) were included in the final analysis.

In total, six researchers (three of whom participated in the workshops) were involved in thematic analysis using NVivo 11. In the first stage of analysis, the second author and a research assistant coded the transcribed workshop recordings for instances of Challenges (either obstacles that teachers see arising during child-led learning which may prevent them from implementing the approach, or things that teachers identified as desirable but not something they currently had). These instances were then grouped into commonly recurring themes (Braun & Clarke, 2006) by the authors. Then the third author and another research assistant, supervised by the first author, recoded Challenges to ensure systematicity and classified each instance of a Challenge according to a final list of themes derived from the first stage of analysis. They also identified instances of Benefits (positive consequences of using a child-led approach). They did this by first coding data from the first workshop, checking reliability until a sufficient rate of agreement (at least 86%) was reached. Then the research assistant coded the remaining data. This paper presents a subset of the coded themes to which all teachers in at least one of the year groups contributed to.
Results and discussion
Teachers expressed the view that the child-led learning methods they had adopted resulted in numerous benefits, as in previous research (e.g. Sak, Erden, & Morrison, 2016), but also identified many challenges.

Researcher-initiated themes: Challenges in supporting children’s SRL and EF
The workshops focused on aspects of teaching that were not common in teachers’ current practice, such as consciously focusing on practicing children’s SRL. As in prior work, teachers felt that appropriate help-seeking to further one’s own learning (an SRL strategy) was lacking in their children (e.g. Sak et al., 2016). Teachers in our workshops also discussed a novel challenge, the ability to be flexible mentally (similar to the EF of “cognitive flexibility” or “switching”) in science problem-solving: K-S3: “It’s hard for them to process how to do it in a different way, […] the ice melting in the sun, where else can the ice melt?”. Teachers also reflected on other novel themes, such as classroom organization barriers to supporting children’s SRL: K-S1: “I know that they won’t just think, “Oh, I’d better go and do that”, and then go and grab the resources. […] it’s sort of like the way the room is set up, to a certain extent. And I think then, that’s a barrier, isn’t it?”

Emergent themes: Challenges of instructional guidance and individual needs
While the themes of SRL and EF were initiated by researchers, there were many themes that teachers initiated in their discussions. Teachers discussed a lack of appropriate resources (e.g. space, materials, budgets) that resonated strongly with previous research (e.g. Sak et al., 2016). They also focused on how much instructional guidance to give, an open, hotly debated question in psychology research (e.g. DeCaro, DeCaro & Rittle-Johnson, 2015). Both our teachers and others note a tension between children’s interests and teachers’ learning goals (Jónsdóttir, 2017). However, while other studies discuss the consequences of providing less guidance for students’ enjoyment of activities (Jónsdóttir, 2017), our teachers focused on the consequences of providing less guidance for children’s learning. For instance, they focused on opportunities for knowledge assessment, scientific misconceptions, and acquiring knowledge different from the original learning goal: K-S2: “I think it’s important to […] be careful not to jump in too quickly, you can find out what they know by listening to them….” Our teachers thus contributed a novel emphasis on children’s learning to teacher views on instructional guidance, which aligns with psychology researchers’ focus on learning goals (e.g. DeCaro et al., 2015).

Some children’s needs prevented them from reaping the benefit of child-led activities. In particular, teachers in our workshops emphasized the barrier of language difficulties in child-led learning, in contrast to previous research which reports benefits of child-led learning for language skills (Beneke & Ostrosky, 2009): F-S1: “We really didn’t want to lead him to use any particular language, so it was a bit of a challenge for us to allow him to be open-minded and to allow him to decide what he wants to do. If he doesn’t have the vocabulary, he can’t explain to us.” Our teachers’ attention to individual differences in children’s response to less instructional guidance is noteworthy, as this is an active topic of psychology research (e.g. DeCaro et al., 2015).

Differences between kindergarten and first grade teachers
Several themes were more prevalent in one year group (i.e. over ¾ of the instances of the theme came from teachers in one year group). Kindergarten teachers voiced challenges with lesson planning more than first grade teachers, perhaps because of less practice structuring activities around learning goals (other work has mainly noted such planning challenges in older classrooms; So et al., 2014). First grade teachers, by contrast, were overwhelmingly more frustrated with classroom-external constraints. They were more than nine times as likely as kindergarten teachers to discuss challenges of national curriculum and assessment, school-level rules, timetables, and staffing issues. First grade teachers were also vocal about challenges in trying to follow children’s interests and, perhaps because these were different from their usual practice. These themes echo much past research (e.g. Sak et al., 2016), but the contrast with kindergarten teachers is novel.

Conclusion
These novel challenges with child-led learning that teachers voiced in our workshops were not trivial, and the differences between kindergarten and first grade teachers underscore the difficulty of using a child-led approach in more curriculum-focused first grade classrooms (Wood & Bennett, 1999). Taken together with the perceived benefits of child-led learning, these findings can inform efforts to improve early childhood education. Future work could draw on larger samples of teachers, and focus on including teachers of children from different demographics to assess the generalizability of these findings. Future research could also evaluate whether other stakeholders such as children, parents, senior school leadership, and policy makers share similar views on the challenges of child-led learning. Moreover, as teachers need to change in their own professional learning and
behavior to see a change in children’s learning and behavior (Vrikki, Warwick, Vermunt, Mercer, & Van Halem, 2017), future work should systematically evaluate challenges of child-led learning in programs that cause a measurable change in both teacher learning and children’s SRL and EF skills.

References

Exploring the Margins of the Field: Rethinking STEM in Education

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Abstract: As a cohort of Learning Sciences doctoral students, we are at the crux of shaping new possibilities for STEM in education. We share key learnings gleaned around critical notions of STEM (science, technology, engineering, mathematics) after participating in a conference that explored marginalized groups and ideas in STEM education. Key ideas we distilled for further deliberation include: 1) How is STEM identified and who is part of it?; 2) Why is critical discourse essential in STEM? and; 3) How do we attend to affect and aesthetic experience in STEM? We argue considering such issues and fostering epistemic fluency will allow STEM to grow and diversify. In presenting our understandings of STEM as it exists, and where we feel it is moving, our learning provokes dialogue about how critical research can impact STEM and educational research.

Keywords: STEM, Critical, Marginalization, Affect

Introduction
We are a multidisciplinary and international cohort of Learning Sciences doctoral students in Western Canada. Here, we discuss current trends and critical issues in STEM (science, technology, engineering, mathematics), how it is taken up in society, who has access to it, what it says about our world, and where STEM is headed. Our participation in a conference on critical and marginalized areas of STEM motivated us to reflect on the norms of STEM in literature, ideas of how to stretch and reconsider STEM, and how we, as emerging scholars, position ourselves relative to STEM and its future. We ground our discussion in established STEM and Learning Sciences literature, and three resonances from the conference: 1) How is STEM identified and who is part of it?; 2) Why is critical discourse essential in STEM? and; 3) How do we attend to affect and aesthetics in STEM? Our intent is to advance ways educators and scholars can rethink how STEM is taught, learned, and experienced.

Background
The term STEM originated in the United States in the 1990s as a strategy to strengthen the political presence of science, technology, engineering, and mathematics practitioners (Moore & Smith, 2014). Historically, STEM has been a mostly Western discourse based on labour productivity, Eurocentric paradigms, economic efficiency, and economic growth (Bhabha, 1985; Smith, 2012). As STEM evolves, there is disagreement of what constitutes STEM, calling for a rethinking of the field and its scope (Bybee, 2013; English, 2016). Scholars advocate for integrating STEM disciplines; however, the lack of a “common operational definition or conceptualization of STEM” (Breiner, Harkness, Johnson & Koehler, 2012, p. 9) and implementation issues in education settings, are a challenge.

Educators have struggled to overcome subject-specific thinking in STEM (Sochacka, Guyotte, & Walther, 2016). Linking art with STEM, to form STEAM, is one way to integrate multiple disciplines and is argued as fundamental for innovation and creativity (Bailey, 2015). The arts, and more broadly, aesthetic experiences can foster opportunities to teach and learn through transforming materials into unique forms and engendering continuity across disciplines and experiences (Farris & Sengupta, 2016). However, gluing more disciplines to the STEM moniker may encourage further compartmentalization rather than holistic integration. At the same time, blending disciplines together may dilute disciplinary ways of knowing and being, causing a “jack of all trades, master of none” effect. This tension needs further exploration. To move beyond the traditional discourse of STEM as separate disciplines motivated by human capital (increased production), scholars need to envision STEM in terms of human capability (holistic lives of personal value) (Sen, 1997).

Critical questions
How is STEM identified and who is part of it?
Identity is inseparable from how researchers, students, and educators shape their beliefs, values, and how they characterize STEM. For example, “fantasy worlds” describe how students and educators position themselves within STEM and how it is defined within various contexts (Holland, Lachicotte, Skinner, & Cain, 1998; Rahm, 2008). In fantasy worlds, identity is shaped in how a person can see themselves and the way others see them. These perceptions are in constant flux and are affected by contexts and environments. Integrating STEM within a person’s identity strongly shapes learning experiences (Battiste, 2004; Shanahan, 2009). Unfortunately, learners in many communities are discriminated against because of identity prejudices and beliefs that identity is problematic for learning processes (Montejo, 2010). For instance, traits such as gender, class, and ethnic background are often used to predict success or failure in science careers (Archer, 2011; Wong, 2015). Traditionally, the sciences have promoted Caucasian, privileged, Euro-American men (Baker, 1998). Many factors perpetuate this promotion, including lucrative industry sponsorships welcomed by educational institutions to prepare the next generation of STEM experts and benefit industry. Thus, scholars may be (implicitly) drawn to maintain the systemic inertia of STEM. Attempts to overcome these inequalities need to be addressed more openly. Fortunately, science identities are fluid and educators and students can overcome these traditional notions (Shanahan & Nieswandt, 2011; Wong, 2015). This leads to questions of how someone embodies or rejects STEM as part of their identity (e.g., who gets to be a ‘science person’?).

Current Western curriculums commonly give lesser priority to non-dominant perspectives. Fortunately, STEM is evolving to better appreciate marginalized groups and critical perspectives such as indigenous knowledge, decolonization, disabilities, and gender in how STEM is defined (Battiste, 2004; Hwang & Taylor, 2016; Smith, 2012). For example, from an indigenous perspective, there is a mutual interest to integrate Western and indigenous notions of science, technology, engineering, and mathematics, even if they go by different names (Hatcher, Bartlett, Marshall, & Marshall, 2009). Identity is becoming the foci of re-thinking and re-designing STEM as past and current inequalities are confronted (Esmonde & Booker, 2017).

“All people need STEM understanding in order to make sound decisions for themselves, their families, and their communities” (Marrero, Gunning, & Germain-Williams, 2014, p. 2). In providing varied access to STEM learning opportunities, not only do students “reshape their ways of thinking about what science is, how it gets done, and who might pursue it” (Rham & Moore, 2016, p. 771), they create moments for students to develop and question their own identities as scientists and STEM contributors. This can lead to STEM learning that builds on the lived experiences of participants within their communities, while promoting public action in solving societal problems (Adams & Gupta, 2013; Rham & Moore, 2016).

Why is critical discourse essential in STEM?

STEM is interdisciplinary but (often) not inclusionary. STEM has traditionally turned a blind eye to issues of equity, access, and cultural diversity (Esmonde & Booker, 2017; Takeuchi, 2016). It has privileged Eurocentric ways of knowing, where scientists are objective owners of knowledge who share what they know, devoid of cultures and contexts (M. C. Shanahan, personal communication, September 28, 2017). However, cultural practices are intertwined with STEM and accounting for diversity and critical discourse are becoming educational imperatives (Strong, Adams, Bellino, Pieroni, Stoops, & Das, 2016). Incorporating multiple ways of knowing, showcasing ways to navigate diverse ways of knowing, and establishing epistemological fluency are ongoing challenges for STEM educators.

Unfortunately, marginalized groups and ideas are often treated as a complication and there is resistance in upsetting carefully crafted ways of teaching, learning, and knowing STEM (Bang & Medin, 2010). We argue diversity is crucial for advancing the field and not a problem to overcome. Like identity, heterogeneity in people and perspectives is inseparable from teaching and learning (Rosebery, Ogonowski, DiSchino, & Warren, 2010). For example, virtual avatars with customizable sex, gender, and appearance challenge the traditional heteronormativity of STEM, giving a space and a place for identities to be rethought about how biology is taught and learned (Shanahan, 2009). Gender fluidity also opens avenues to integrate affective dimensions of STEM (McWilliams, 2016). For example, how does gender, desire, and emotion change sex education? How do biology curricula address social relationships as understood in other species? If the next great scientists are to make sense of the world, STEM educators cannot ignore deviations to heteronormativity nor ignore how ingrained heteronormativity is in everyday repertoires of teaching and learning practices (Sumara & Davis, 1999). Broadly, STEM educators need to consider how disciplinary norms can evolve toward greater inclusion, equity, and access.

How do we attend to affect and aesthetic in STEM?

A pervasive, but glossed over, component of teaching and learning is aesthetic and affect. Emotions have a strong connection to the design of learning environments (e.g., digital games), and to students’ thinking and...
actions (Kim & Kim, 2010). Emotions are also situated and distributed among people, places, and knowledge. For example, professional game developers strive to balance levels of challenge, reward, advancement, and enjoyment to keep players enthralled for hours, days, and months. Engagement is key for learning; therefore, in the world of coding, game-based learning, and digital experiences, not only does emotion matter for design, it is also part of the learning process. Moreover, playing a game is only the start. Critique and interpretation of a game is where students can get at the heart of its content, ideas, and perspectives. For digital environments and code to mean something, they have to connect with the world around it. As people experience virtual, physical, and augmented environments, emotions are the threads that weave these experiences together and support learning transfer across contexts.

STEM also needs to integrate values and ethics in how it is taught and learned. For example, when an engineer designs a militarized drone, how can educators prepare engineers to grapple with the moral and ethical issues of how their work can save or end the lives of people they may never know (Philip, Gupta, Elby, & Turpen, 2017)? Design embodies sociocultural norms and identities. It represents an aesthetic of what counts as legitimate repertoires of practice, priorities of teaching and learning, and individual ideologies. Students and educators of STEM need ways to navigate the beliefs and values of others and how they strengthen, pull, and knit the fabric of STEM in education.

Future directions
As emerging scholars in the Learning Sciences, and future educators in STEM, we remain sensitive to the field’s development and our role in addressing critical issues in STEM research and learning. We anticipate disciplines outside of STEM will benefit from similar critical discussions in current and future research. By exploring common interests such as curriculum development, educational leadership, or lifelong learning in STEM, researchers foster a shared goal of understanding the mechanisms of learning. We believe critical research showcases the potential integrative power of STEM, while addressing the diverse needs and perspectives of learners found in classrooms. Considering that, we question if a focus on critical research can push the compartmentalization and stratification that exists within STEM to the margins, opening up possibilities for integrated research beyond STEM as it exists today. Could this critical focus be the end of STEM as we know it? We are excited to be part of a fluid, developing field, that questions established beliefs, pushes and shifts boundaries, and promotes diverse, holistic, and powerful ways of knowing.

Conclusion
Exploring critical ideas has expanded our STEM epistemologies and our personal ontologies of what it means to be a STEM scholar. We came to STEM through the traditional routes, so we try to reconcile our biases for rethinking the field, while acknowledging our skewed perspectives associated with a Western education model. We are also aware of the thorny relationships between critical change and the fiscal realities associated with implicit or explicit exclusion to retain these privileges. We argue for STEM and the Learning Sciences to grow and advance, scholars, educators, and students need to consider how STEM is defined, who it includes, and how it can attend to affect. Engaging in these issues has influenced our academic pursuits by heightening our awareness of the complexities of teaching and learning across disciplines, epistemological perspectives, and research approaches. By having a shared trajectory for STEM, future researchers can address significant problems, expand the field, and have a positive impact on students’ lives and their communities.

References


Multimodal Learning Analytics for the Qualitative Researcher

Abstract: The area of learning analytics is often viewed as a tool for supporting quantitative analysis. Based on previous research, this association between quantitative analysis and learning analytics does seem to be the trend. However, certain researchers have proposed the use of multimodal learning analytic techniques as a viable and valuable contribution to more qualitative research methodologies. This paper examines that idea by trying to use the output from an algorithm that learns discriminating features, as the starting point for video observations. Ultimately, the analysis suggests that there is utility in leaning on machine learning to help identify important patterns in the data, provided that those patterns are contextualized and studied using the original video data. Additionally, the work makes clear the need for better tools for conducting these types of multimodal analyses.

Introduction
The past decade has seen the emergence and expansion of research at the intersection of data mining and education research. In particularly, the fields of educational data mining, and learning analytics have gained increased traction as novel ways for studying learning (Baker & Yacef, 2009; Martin & Sherin, 2013). While educational data mining and learning analytics have traditionally focused on data derived from cognitive tutors, learning management systems and other computer mediated experiences, multimodal learning analytics (Blikstein & Worsley, 2016), a growing subfield of learning analytics, has been proposed to study more collaborative, human-to-human interactions. Moreover, researchers within this sub-field have positioned multimodal learning analytics as a set of techniques that have relevance for qualitative researchers. The goal of this paper is to examine this claim. In particular, the analysis will use techniques from multimodal learning analytics to learn an algorithm that can distinguish between students who recorded positive learning gains, from those who recorded negative learning gains. Key elements of the algorithm are then used to extract segments of video that correspond to behaviors that positively and negatively correlate with learning gains. Finally, these video segments are used to qualitatively draw inferences about how students learned from the experience.

Prior literature
Multimodal learning analytics uses non-traditional sensory data (gestures, gaze, speech, emotions, digital pen traces, etc.) to study and model student learning. As with any sub-field involving “analytics,” there is a presumed reliance on computational techniques, as well as an assumed level of automaticity. Despite this assumed automaticity, multimodal learning analytics is heavily influenced by human intuitions with many researchers adopting mixed-method approaches (Prieto & Rodriguez-Triana, 2017). From the design and implementation of the specific algorithms, to the labelling of training data, human intelligence plays is essential. However, the mere inclusion of human input at some point during the analytic process does not truly speak to the disposition of qualitative research. Instead, we seek is a high level of intimacy with the data.

Worsley & Blikstein (2014) provide an interpretation of research that combines learning analytics and qualitative analysis. Within this study, the researchers hand-coded student actions into one of five possible states (build, test, adjust, undo or plan). They then used machine learning to identify patterns within each user’s processes, and studied how those processes differed by the participant’s level of expertise.

Prieto & Sharma (2017) and Liu & Stamper (2017) take an approach that is motivated by reducing the amount of human coding required. Prieto & Sharma (2017) leverages four measures for cognitive load in the context of mobile eye tracking in classrooms. They use those measures to identify regions of the video that have high agreement, and, in this way reduce the amount of data that they analyze. Liu & Stamper (2017) take a similar approach in identifying regions of video that have been tagged within a cognitive tutor. Their tool then allows them to automatically extract video segments that correspond to any number of important events.

The aforementioned papers offer potential paradigms for multimodal learning analytics to integrate with qualitative research practices. This paper presents another paradigm, that, in a sense, sits at the intersection of these two approaches. More specifically, the approach will rely on machine learning to identify characteristics or behaviors that seem to correlate with learning, and then generate a subset of videos that a human can study to better understand the semantics of the behaviors.
Methods

The analysis presented in this paper is based on a subset of the Engineering Design with Everyday Materials Multi-modal Dataset (Worsley, 2017). This dataset includes 54 students from a community college in the United States and features nearly 27 hours data. Participants worked in pairs to complete two engineering design tasks. The first task asked students to use one sheet of printer paper to construct a structure that could support one or more engineering textbooks at least three inches above a table. Students had six minutes to complete this task. In the second task, students had 10 minutes to build a structure that could support a mass of 0.5 lb. as high off the table as possible using limited household materials. This task involved similar engineering principles as the first task, but with greater variability in the materials, and with the added goal of height optimization. While scores for how well each structure performed are included in the dataset, they are not used within this analysis. Instead, this analysis focuses on learning gains. The learning gains are based on the student’s identification of principles or mechanisms that confer stability to three example structures (a bridge, a ladder and an igloo). The recorded learning gains are the change in the proportion of a student’s responses that refer to a structure’s configuration or geometry (i.e. triangles, wide base, and symmetry). Referring to a structure’s geometry contrasted with references to a structure’s material (i.e. metal, wood). Students who increased the proportion of configuration/geometry-based principles on the post-test, relative to their pre-test, were classified as having learned. Explaining why some students seem to recognize the relative importance of geometry while others did not is the primary focus of this analysis. Along with the learning gains information, the dataset also includes multi-modal data. The focal data for this study is derived from the Xbox Kinect Sensor which generated skeletal tracking, head pose and audio data. For the sake of simplicity, this analysis focuses head pose, or, more generally, eye gaze, as derived from frontal images of each student. Head pose was calculated using OpenFace (Baltrušaitis, Robinson, & Morency, 2016). The section that follows briefly describes how the data was used.

Analytics summary

The initial dataset of 54 students was reduced to ten students due to missing head pose data for several students. The head pose data is recorded as values for pitch, roll and yaw. These values correspond to looking up and down, left and right and tilting one’s head. Values for yaw (looking left or right) were transformed such that they corresponded to looking away from one’s partner or looking towards one’s partner. This transformation aims to eliminate the positional dependence of seating arrangement, as students were seated one next to the other. Values for pitch were left unchanged, but were included within the analysis because they could proxy for identifying when a participant is looking more towards the materials, or elsewhere. Values for roll (tilting one’s head left or right) were omitted because they did not have a clear significance in this analysis.

The next step was to automatically cluster the data. Before clustering, however, data underwent column-based normalization. Each value was divided by the standard deviation of the column to minimize bias. K-means (N=5) was used to cluster the data from both of the tasks. In this way, it is assumed that the postural enactments are sufficiently similar across the two tasks as to warrant a combined clustering step. After the clustering step, every time step, for each participant was associated with one of five possible clusters.

The clustered data was used to compute the proportion of time participants spent using each cluster across each task. This analysis focuses on cluster frequency from the second task.

The proportion of time in each cluster was used to train a decision tree classifier that learns cluster frequency values that correlate with positive and negative learning gains. Note: This process did not follow the usual machine learning convention of cross-validation or doing a training-testing split. The reason for this is an explicit interest in identifying the differences between those with differential learning gains in this dataset.

The nodes of the decision tree were used to identify which clusters would be worthwhile to examine via human coding. Specifically, a custom script was used to identify contiguous segments of video that included the cluster of interest. Extracted segments were a minimum of three seconds long. A random selection of no more than five video segments per participant were extracted for human observation.

Finally, a team of researchers performed open coding on the videos to determine how the videos from different clusters were semantically different from one another. Conducting this process involved repeated observation of the videos among the team of five researchers.

Results

A key, and somewhat surprising, result that emerged from looking at the output of the cluster frequency aggregation step, was that the cluster frequencies for several of the clusters perfectly correlated with learning. Table 1 indicates that participants with a c3 (cluster 3) proportion of less than 0.2 all recorded negative learning gains. Similarly, participants with larger c3 proportions recorded higher learning gains. On the other hand, lower c1 (cluster 1) scores seem to correlate with positive learning gains.
Table 1: Participant cluster frequencies and learning gains

<table>
<thead>
<tr>
<th>USER</th>
<th>LEARNING</th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.302</td>
<td>0.132</td>
<td>0.266</td>
<td>0.139</td>
<td>0.161</td>
</tr>
<tr>
<td>10_2</td>
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<td>0.192</td>
<td>0.261</td>
<td>0.129</td>
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<td>0.180</td>
<td>0.152</td>
<td>0.168</td>
<td>0.133</td>
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<tr>
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<td>0.208</td>
<td>0.323</td>
<td>0.148</td>
<td>0.167</td>
<td>0.248</td>
<td>0.113</td>
</tr>
<tr>
<td>14_1</td>
<td>0.000</td>
<td>0.245</td>
<td>0.118</td>
<td>0.143</td>
<td>0.332</td>
<td>0.162</td>
</tr>
<tr>
<td>14_2</td>
<td>0.193</td>
<td>0.280</td>
<td>0.107</td>
<td>0.112</td>
<td>0.398</td>
<td>0.103</td>
</tr>
<tr>
<td>27_1</td>
<td>0.381</td>
<td>0.393</td>
<td>0.070</td>
<td>0.137</td>
<td>0.232</td>
<td>0.168</td>
</tr>
<tr>
<td>27_2</td>
<td>0.444</td>
<td>0.437</td>
<td>0.057</td>
<td>0.098</td>
<td>0.247</td>
<td>0.162</td>
</tr>
<tr>
<td>23_1</td>
<td>0.178</td>
<td>0.306</td>
<td>0.012</td>
<td>0.082</td>
<td>0.424</td>
<td>0.176</td>
</tr>
<tr>
<td>23_2</td>
<td>0.533</td>
<td>0.512</td>
<td>0.012</td>
<td>0.048</td>
<td>0.298</td>
<td>0.131</td>
</tr>
</tbody>
</table>

With the apparent observation that cluster 1 and cluster 3 frequency appear to correlate with student learning on this activity, the next step was to study the values that characterize those clusters and delve into the videos. Table 2 highlights the pitch and yaw values for each cluster.

Table 2: Cluster centroid values (positive pitch corresponds to up, positive yaw is towards their partner)

<table>
<thead>
<tr>
<th>CLUSTER</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PITCH</td>
<td>-0.72517</td>
<td>0.475809</td>
<td>-1.24574</td>
<td>0.391357</td>
<td>-2.00303</td>
</tr>
<tr>
<td>YAW</td>
<td>1.630276</td>
<td>0.331196</td>
<td>-0.09873</td>
<td>2.031234</td>
<td>1.652582</td>
</tr>
</tbody>
</table>

While the numbers suggest some difference between the clusters, the numbers are not of much benefit in determining how the different head poses would result in, or correlate with, differential learning gains on the activity. Hence, video coding was used to gain more detailed insights.

In studying the videos, the first step was to consider if the types of actions (e.g., building, planning, undoing, etc.) that students were taking in the different clusters were substantively different. However, no clear differences emerged across the different groups along this dimension. Instead, the key difference had everything to do with where the participants were looking, or, more importantly, where they were working. Looking at the figures (Figure 1) we see one potential difference between the two head poses. Namely, in cluster 1, the student’s attention is focused on building higher off the table than in cluster 3. We saw this difference across a number of participants in the sample. The other key difference that we observed was that in cluster 1, more of the frames involved the student looking forward, while in cluster 3, the students spent more time looking toward their partner.

Figure 1. Images a,b,c,d (from left to right) provide examples of cluster 1 (a and c) and cluster 3 (b and d).
Discussion
In summary, the analysis above relied on machine learning and multimodal data to pinpoint behavioral differences between participants with differential learning gains during a set of engineering design activities. Identification of those behavioral differences emerged based on unsupervised clustering of head pose data. When we examined the numeric data for the salient differences, it was unclear as to what was occurring. One could certainly postulate plausible arguments about learner engagement based on those numbers, but this would ultimately have been unsatisfying. Instead, a closer look at the video data made it apparent that differences existed in the height at which students were building and/or designing, as well as in the extent of engagement with their collaborator. This may point to differences in how much students were focusing on the base of the structure, something that is important to conferring stability to a design, as well as non-content related issues of collaboration quality. Hence, the differences in pose, while represented in the form of two clusters, corresponded to a larger set of behaviors that necessitated thoroughly engaging the video.

The above analysis is not intended to provide the only explanation for the observed differential learning gains. Moreover, the qualitative analysis of the videos was in no way exhaustive. Instead, this work aims to provide an example of how to make use of multimodal learning analytic techniques for supporting qualitative analysis. The algorithm took care of the discrimination between those who learned and those who did not, while the task of making sense of those differences rested on the researcher.

An additional point of discussion is the noted challenges in doing this work. Even after collecting and synchronizing the data, both of which relied on custom developed computer programs, there was the task of extracting the salient features, and subsequently identifying a subset of videos to analyze via human inference. These steps involved custom Python scripts and a number of machine learning libraries. Adopting this strategy more broadly will likely require robust, interpretable, and easy to use analysis and visualization tools (Liu & Stamper, 2017; Rodríguez-Triana, Prieto, Holzer, & Gillet, 2017).

Conclusion
Data mining and computational techniques are gaining increasing prevalence within the education research community. However, these strategies and tools are primarily being utilized by researchers with more of a quantitative orientation. It is the goal of this paper to demonstrate one way for leveraging multimodal learning analytics in a more qualitative fashion. While there remains a need for more robust and easy to use tools, there is a profound opportunity for researchers to deeply examine their data through a different set of lenses. Furthermore, as more qualitative researchers look to these tools to support and facilitate their analysis, technology designers will be able to better tailor the tools to the needs of qualitative researchers.

References
Exploring Teacher Learning through STEM Teachers’ Exploration of Data Using a Domain Specific Coding Language

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Abstract: In the following paper we outline a method that endeavors to understand how teachers can systematically utilize data in classroom teaching. Informed by Cultural Historical Activity Theory and teacher education, we interview teachers about how they think about data and use it in their everyday workflow. From these interviews we develop semantic models of actions that teachers take in the classroom to learn about their students. We then convert those semantic models into computer code that can be utilized to both aid teachers’ exploration of data and study the teachers’ usage patterns.

Background
When teachers engage meaningfully with the data produced by multiple sources (test scores, online programming, classroom observations) they can better respond to the educational needs of students and advocate for them within educational systems. However, these efforts have been met with a mixed response from teachers themselves. This challenge is a matter of balancing both (1) the capacity of teachers to process and utilize growing amounts of data in a meaningful way for instructional purposes and (2) the capacity of software developers and researchers to design teacher-centered, usable, and useful analytic tools. However, while teachers are increasingly collecting data from a variety of assessments and being asked to use this data to inform their instructional decisions, they have very little input about the type of data they collect nor the frequency in which data is collected. This issue is compounded by the tremendous growth in the amount and variety of data collected about students through the advent of online and mobile computing and use of technology in the classroom (Mandinach & Gummer, 2013). We are at the very early stages of utilizing these new forms of data for educational purposes (Ferguson, 2012) and are faced with the daunting task of both determining the utility of new data sources, disseminating that information throughout education systems and ensuring that teachers have the skills to interpret and use it to meaningfully impact instruction.

As the sociotechnical landscape continues to evolve, opportunities for developing innovative STEM curricula that denote multiple data collection points, informed by the needs of classroom teachers could create space for evidence-based decision making that better supports daily instruction. To begin this process, classroom teachers need a systematic and intuitive way to collect, analyze, and disaggregate assessment data to inform real-time decision-making as they teach. This requires not only new skills, but flexible systems in which teachers can creatively incorporate data into their practice. This is particularly true within STEM education that is proofed to be the vanguard of these technological changes. STEM is inundated by new technology-based pedagogical aides such as online tutoring platforms for math and science (Kulik & Fletcher, 2016), blended learning applications (Tempelaar, Rienties, & Giesbers, 2015), Virtual Reality for whole body experiences (Potkonjak et al., 2016), and Augmented Reality laboratories (Chang, Chung, & Huang, 2016).

Evidence based improvement cycles have been encouraged as part of teacher training programs for over a decade (Lewis, 2015). Despite this large scale implementation results have been mixed (Mor, Ferguson, & Wasson, 2015). Similarly, teacher utilization of the data dashboards that accompany technology products is highly variable (Molenaar & Campen, 2017). In a substantial review of the utilization of data in education Marsh (Marsh, 2012) outlines four sequential components of the practices adopted by teachers: data, information, knowledge, and action. Marsh is critical of the focus on the professional development of teacher data skills absent focus on the translation of knowledge into action. However Mandinach and Gummer are wary of data dashboards that automate actions without teachers having gained the understanding or skills required to make effective use of what is being presented to them. On the one hand, inquiry cycle-style strategies for incorporating data into teachers’ practice are too focused on skills and not on action, on the other hand dashboards seem to be too focused on action absent skills. There is no in-between space in which actions and skills can be suitably matched.

Theoretical approach
For this study, we draw upon Cultural Historical Activity Theory (CHAT) (Engeström, 2001; Vygotsky & Cole, 1978) as a heuristic for analyzing how STEM teachers learn to develop data skills. CHAT scholars posit that learning must be viewed within sociocultural, historical and institutional contexts (Wertsch & Rupert, 1993).
Importantly for this work are three aspects of the framework, 1.) that humans learn through actions, 2.) that they communicate those actions via tools and that community is essential to the act of learning. For the purpose of this study, those contexts converge in a school-based activity system in which classroom teachers draw upon a myriad of tools, rules, and community interactions to facilitate their learning about data literacy and data tool development. This theoretical stance attends both the conceptual and practical tools teachers bring to their teaching, as well as the ideas, theories, and frameworks about teaching and learning.

Computer science, and in particular the domain of computer language construction, has been engaged in the problem of communicating technical information about data with non-technical users for the last 50 years (Najd, Lindley, Svenningsson, & Wadler, 2016). In part, data-driven instruction is the most recent wave of a conversation about how technologies, designed and built by experts in those technologies, can communicate with non-expert users to aid productive use. One particular area, that of domain specific languages, has developed similar more general models to that of Marsh that look to solve similar issues, broadly, to balance user needs with technical constraints (Evans & Szpoton, 2015).

These models are language based, Fowler (2010) introduces a framework for thinking about the relationship between code, user actions and computer actions made up of three components:

- **Target code** - the computer program that executes actions
- **Semantic model** - the model that conveys meaning
- **Script** - the user input

In this model, what Marsh describes as the conversion of information into knowledge is represented as the “semantic model” or sometimes the “domain model”. In a programming language, the semantic model is a representation of the constructs that computer code populates. It is an abstraction or framework that links the real world with the virtual world through code.

If we overlay Marsh’s data use model with the Fowler’s computer language model (Fig.1) we can produce a useful understanding of how a computer language could be used to organize data use by educators and the division of complexity between the teacher and the engineer. Within this framework, the semantic model is what converts data into information, it is how we organize our understanding of data. The semantic model could be informed by teachers, researchers and software developers. It might be as simple as “failure to do homework = unable to complete in-class activity” but could be hugely complex, incorporating theories of validity, psychological or neuroscientific theories, teacher expertise, school contextual factors or cultural factors. Target code is the machinery that does not need to concern the teacher as long as the script reflects the semantic model accurately and the target code enacts that model with fidelity. In this way Marsh’s knowledge is represented in a script, the way that a teacher instructs a machine to behave in response to data. The script should be an abbreviation of the semantic model, it converts the semantic model into instructions. This could be a menu item or button in a Graphical User Interface (GUI) but could also be a scripting language. The script is the point of communication between the teacher and the engineer. A script that is both interpretable and accurately reflects the semantic model is a very valuable tool.

![Figure 1. Mapping the Marsh data model onto the Fowler computer language framework.](image)

The value of a script over and above other implementations such as graphical buttons in a dashboard are many fold. Scripts require less effort to generate than graphical elements and are easier to alter or retire if they are not useful or do not reflect the semantic model accurately. Scripts are more extensible, they can be combined to produce new functionality. They provide more autonomy for users to interact in ways that have not been explicitly considered by engineers. Script use can more easily be analyzed as it is already parsed into meaningful chunks, unlike mouse movements on a dashboard. Scripts can also be more intuitive than other
forms of graphical interface if they use words that have constrained meanings within a domain such as teaching. But most importantly scripts allow for a common language to exist between technical expert and domain expert so that ideas about functionality can be communicated more effectively (Fowler, 2010).

Methods
In the first phase of the project, we are gaining a deep understanding of the baseline data practices of a cohort of 30 elementary STEM teachers by inductively generating semantic models through an iterative process (Glaser & Strauss, 1967). Teachers are interviewed about what they consider data to be and what they use it for. These interviews work through hypothetical data scenarios to unearth and visualize a.) the data teachers currently engage with, b.) the data teachers want to engage with but do not have access to, and c.) the questions teachers use to interrogate this data and d.) make meaning from it. We then engage in repeated readings of the interviews and focus group transcripts to identity components of semantic models. Next, we will take the semantic models and reduce them to abbreviations. In follow up interviews we then test the interpretability of these scripts with the original teachers and then with a cohort of 100 STEM teachers from different schools. These abbreviations will then form the basis for the domain specific language.

Preliminary results
Currently we have isolated three semantic models and preliminary abbreviations to accompany them. They are visualized in Figure 2 as “summary.complete[X]”, “summary.error[X]” and “funnel[X]”. “summary.complete[X]” queries a database and produces two pieces of information: 1. How many students have completed a task X, 2. The names of students who have not completed the task X. “summary.error[X]” queries a database and produces two pieces of information: 1. The percentage correct for the class and the lowest scoring students. “Funnel[X.Y.Z]” is a function that clusters students into groups for task Y according to task completion on task X, then again on task Z according to completion on task Y. so as to direct the teachers’ attention to clusters of students who need specific help.

![Figure 2. “Funnel” model clustering students based on performance on activity X, Y, Z.](image)

Future work
We hope to have a collection of 100 semantic models such as these by early 2018. Using the initial scripts, we will develop a survey style instrument for a larger distribution to test the scripts on real teachers for difficulty of interpretation and complexity of analysis and provide feedback about their usability. Scripts that cannot be interpreted by teachers in the new sample will be discarded or altered based on feedback. The validated scripts will form the basis of the syntax, grammar and code for the domain specific educational programming language and will be encoded in the Julia language (julialang.org). We will implement through an Interactive Development Environment capable of capturing teacher usage patterns of the language to study aspects of teacher analytic practices.
References
Conceptual Patterns of Changes in University Students’ Explanations During DC-Circuit Tasks

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Abstract: At the advanced level of learning, the ability to use relational knowledge becomes essential. In this study, the changes in the use of scientific concepts in the university students’ explanations were examined in the context of direct current (DC) circuits. The students participated in three small group sessions with several predict-test-explain-tasks. The use of scientific concepts and their relations were analysed from session transcripts using content analysis and categories of explanatory power were formed. Then, the changes in explanatory power during DC-tasks were analysed and three categories of conceptual patterns were formed. In first category, no conceptual development occurred, students used simple explanations and were not able to apply relational knowledge. In second category, conceptual development occurred: students explanations became more scientific and their explanatory power increased. In third category, the students have learned to use relational knowledge and the conceptual pattern shows flexibility in providing explanations.

Keywords: concept learning, relational knowledge, explanatory power, cognitive utility, science education

Introduction

One difficulty in learning advanced scientific concepts are that students often have idiosyncratic, intuitive knowledge about the target concepts that can be wrong from the scientific point of view. Hence, learning entails that learner modifies his or her prior knowledge, which is difficult and can take a long time. Furthermore, learning physics, for example, entails learning a complex knowledge system (i.e. theory), which consists of concepts and information about the concepts’ covariation, which is embedded in laws and models of physics. Learning of scientific concepts differs from learning everyday concepts (such as “a dog”) typically examined in cognitive science in that scientific concepts (or nomic concepts in Kuhn’s terms) are out of reach of direct inspection; instead complex situations of applying laws and theories (relational knowledge) are used, which means that several scientific concepts are used at the same time (Andersen, Barker & Chen, 2006; Hoyningen-Huene, 1993). Concept learning also typically involves solving gradually more challenging problem situations, which involve the application of the nomic concepts and the related laws (Hoyningen-Huene, 1993). The learning has occurred, when the concept is used correctly, i.e. in the way of the scientific community (Hoyningen-Huene, 1993). An important aspect in this is that the correct use of the concept requires also the correct use of the related concepts, because a concept is always a part of a conceptual network, a “lexicon” of a domain (Hoyningen-Huene, 1993). Here the learning of scientific concepts are examined in the contexts of DC-circuits, where university students solve gradually more challenging tasks, where they have to predict and explain the brightnesses of the bulbs. The research interest is to see how scientific concepts and their relations change in university students’ explanations during solving the tasks and how it relates to their developing understanding of DC-circuits.

Background

Within science education, recent research about students’ concept learning and understanding has paid attention to students’ understanding of the various relational patterns that connect the concepts together. It has been found that students’ are often inclined towards simple linear causality and chain-like relational patterns (A causes B which causes C and so forth) instead of more complex patterns needed to learn the concepts (Kokkonen & Mäntylä, 2017; Perkins & Grotzer, 2005). In analyzing university students’ explanations concerning concepts related to DC circuits, we identified three generic relational patterns and used these to analyse students’ explanations and the concept learning process. It seems that in the university context, the key element in learning the concepts and constructing successful explanations is flexibility in using and modifying different relational patterns (Kokkonen & Mäntylä, 2017).

Furthermore, recent research in cognitive science has focused on the role of relational knowledge in concept learning. It has been suggested that relations and relational knowledge form a fundamental part of our understanding of the world and underlie many of our higher cognitive competences, such as categorization,
reasoning and planning (Goldwater & Schalk, 2016; Halford et al, 2010). So-called relational concepts are concepts whose meaning is based on the relational structure of the concept or on the relations the concept bears to other concepts (Gentner, 2005). Goldwater and Schalk (2016) have proposed that research on relational concepts offers a fruitful way to examine concept learning especially in STEM context. For example, in physics, it is possible to design authentic problem solving contexts, that are rich and complex regarding the amount of concepts and their relations and at the same time restricted and controllable (only certain concepts can be applied and there are clear results to the problems).

Recent research has only begun to shed light on the cognitive processes related to learning of advanced concepts in science (Authors, 2017). One important open question concerns how the connected, coherent and abstract knowledge structure that is the hallmark of expert knowledge is learned (Goldwater & Schalk, 2016; Kokkonen, 2017). Towards this end we examine learning of concepts regarding DC circuits, which can be taken as an instance of learning a simple theory. In this kind of context, which entails learning multiple concepts and their interrelations, using the whole “lexicon” in explanations is not always effective. Instead, the simpler explanation could work better. This means that at the certain level of learning, the cognitive utility (Ohlsson, 2009) plays a part. Cognitive utility can be described as a trade-off measure between the complexity and the explanatory power of a concept or an explanation model (Ohlsson, 2009). The underlying idea is that in simple situations, simple explanations are adequate and more complex ones are deemed necessary only in contexts that are sufficiently complex. Complexity of a concept (or an explanation) is here thought to arise from its relational complexity (Halford et al, 2010).

**Methodology**

The research question is: What are the conceptual patterns of students’ explanations during the DC-circuit tasks?

The context of the study was a course called “Physics concept formation” aimed at pre-service physics teachers at the physics department. The participants were 2nd to 4th year university students who already had studied the introductory physics courses. The students participated in three small group sessions consisting predict-observe-explain-tasks about the brightnesses of the bulbs in DC-circuits. There was a week between each session. First two sessions consisted of gradually more challenging tasks (e.g. unidentical bulbs instead of identical bulbs). The third session consisted of two repetition tasks and one task in new context, where the connections of batteries were varied instead of the connections of bulbs. The reason for repeating the previous tasks was to make possible the evaluation of the stability of the changes emerged in the explanations during the first sessions.

The sessions were videoed and transcribed. The transcripts were analysed using content analysis, which concentrated on the use of different scientific concepts and their relations in students’ explanations. The scientific concepts in this study refers to the relevant quantities related to the DC-circuits: electric current, voltage, resistance and electric power. The analysed data consists of three student groups (two 3 member groups and one 4 member group), altogether 10 students. The three sessions from the four-member group were cross-checked (approximately one-third of the material). Inter-rater agreement of 73 % was considered adequate. The explanations were categorized regarding their explanatory power as it is presented in Table 1. Here the explanatory power is determined by the number of scientific concepts and the relations between the concepts. The explanatory power describes how many different situations can be explained using a certain explanation. The explanatory power is also tied to the complexity of explanation, usually the simpler the explanation (fewer concepts, less relations), the less situations can be explained. In addition, it is also less scientific. The explanation in category of explanatory power at the level 1 does not use a scientific concept and therefore, it has a very limited explanatory power. At the level 5, the explanation contains four concepts, it is the most complex explanation. However, it is also the most scientific one and it explains all tasks. The students’ explanations through the different tasks in sessions were presented according to their explanatory power. Further, these representations were categorized through different conceptual patterns of changes that occurred during the tasks.

![Table 1: The categories of explanatory power of explanations. The number or letter in the parentheses refers to category of explanation](image)
Findings

In Figure 1, explanations of two students from the same group are presented as examples of results of analysis. As can be seen, in case of student S7, the amount of explanations decreased when the tasks became more challenging. On the other hand, student S8 provided more explanations and in various levels of explanatory power. The emerging overall conceptual patterns of changes in explanations were identified and categorized on the bases of the individual analysis such as presented in Figure 1.

There were three different categories of conceptual patterns of changes students’ explanations according to the explanatory power and their schematic features are presented in Figure 2. The categories are:

1. **No development** (3 students). Although the explanations vary in different tasks, they are at the same level of explanatory power (1-3). The explanations are (rather) simple. Therefore, no conceptual development occurs. The students were not able to apply the relational knowledge to their explanations. An example of this is student S7 presented in Figure 1a.

2. **Conceptual development** (5 students). The explanatory power of students’ explanations increases when they solve gradually more challenging tasks. The explanations become more complex and scientific, students learn to apply relational knowledge to their explanations and conceptual development occurs.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rule of thumb, very limited explanatory power (Explanation S)</td>
<td>When the bulbs are in a series, they have the same brightness.</td>
</tr>
<tr>
<td>2</td>
<td>Only one concept is used, limited explanatory power (Explanations 1, 3, 5 and 8)</td>
<td>There is current (I) in the circuit, which makes the bulbs burn. There should be some loss of voltage (U). If the bulbs are similar.</td>
</tr>
<tr>
<td>3</td>
<td>Two concepts are used, simple tasks can be explained (Explanations 2, 4, 6 and 9)</td>
<td>There is current in the circuit, which makes the bulbs burn. Its magnitude depends on the resistance (R).</td>
</tr>
<tr>
<td>4</td>
<td>Three concepts are used, the model is scientific.</td>
<td>There is current in the circuit, which makes the bulbs burn. The current depends on the resistance of the circuit and the voltage between the ends of the battery or component. If they have the same resistance and voltage, current should be the same.</td>
</tr>
<tr>
<td>5</td>
<td>Four concepts are used, the model is scientific and the most complex one. All tasks can be explained. Power depends on current, voltage and resistance, which in turn depend on each other.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.** Students S7’s (a.) and S8’s (b.) explanations (S, 1-11) during the DC-tasks categorized by their explanatory power. w refers to false prediction or explanation. Few examples of explanations were given in Table 1 (S, 1, 2, 7 and 11).
3. **Conceptual mastery** (2 students). Students use explanations with varying levels of explanatory power already from the first tasks. The pattern reveals the flexibility to adjust the explanations: sometimes it is easier to use simpler explanation instead of more complex and scientific explanation. This is seen as a sign of cognitive utility and thereby, it is concluded that these students already master the topic. An example of this is student S8 presented in Figure 1b.

The explaining and understanding the given tasks requires use of relational knowledge. However, the students in first category are still in the early stage of learning to use the relational knowledge. The students in second category are learning during the tasks to apply the relational knowledge, nevertheless, they are still in the stage of learning compared to the conceptual pattern of students who already master the topic.

![Figure 2. Schematic features of conceptual patterns of changes in students’ explanations.](image)

**Conclusions**

At the advanced level of learning, the key issue is to learn to use relational knowledge, which means the use of scientific concepts relations with each other in form of models, laws and more broadly theories. The findings show, that the gradually more challenging DC-circuit tasks can help students to develop their theoretical understanding. At the level of mastering the use of relational knowledge, new phenomena, such as cognitive utility emerge and there is flexibility of providing explanations at different levels of complexity. The initial findings of this study suggest that more effort should be put in the role of relational knowledge in the advanced level of learning. However, the research is still in progress and further data analysis is still ongoing. There could be cases, were students only uses simpler explanations although they master more scientific explanations. One challenge in analysis is that some students are rather inactive during the group sessions and the analysis relies on students’ discussion.

**References**


**Acknowledgments**

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“It Didn’t Really Go Very Well”: Epistemological Framing and the Complexity of Interdisciplinary Computing Activities

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Abstract: There are a growing number of frameworks for integrating computing into the K-12 curriculum, but these do not provide much insight into what students’ thinking and learning is expected to look like at the interface between computing and the disciplines. Prior research suggests the success of disciplinary integration may lie in students’ epistemological framings, their expectations about what knowledge and goals are relevant for a given activity. Here we present a detailed analysis of one students’ efforts to investigate the relationship between coal consumption and production in the U.S. using RStudio to manage and visualize data. We found that the student, Audrey engaged in coding and debugging behavior that suggested that she was framing the activity as distinctly computational or statistical; when she focused on one domain, this inhibited or interfered with her sense making about the other.

The growth of computing as a field in its own right, and as a tool used within and across professional disciplines has been a major reason for the “rethinking of learning in the digital age”. Faced with a compressed curriculum and the emergence of new computational practices within disciplines (Chandrasekharan & Nersessian, 2015), learning scientists are beginning to explore how computing can be integrated across school subjects. This has led to the development of taxonomies and frameworks that highlight alignment between computational tools and methods, and the disciplinary concepts and practices they support (Barr & Stephenson, 2011; Weintrop et al., 2016). While such taxonomies shed light on what computationally-infused curricula may look like, they provide less insight into how thinking and learning might, or should, look as students engage with these curricula.

When it comes to student learning and sensemaking, however, infusing the tools and methods of one discipline into another may not be as straightforward as it seems. For example, Bing and Redish (2009) found that undergraduates exhibited a number of different understandings of how mathematics may function as a tool for physics problem solving. These included that mathematics provides a reliable method to obtain results through calculation; mathematics can be used to model physical relationships or observations; or that citing mathematical rules invokes authority to validate a solution. Depending on which role students expected mathematics to serve in their physics problem-solving, they were likely to make use of different knowledge and resources to solve problems; in this way, these expectations could significantly limit or support their progress.

Importantly, students’ expectations about the role of mathematics in Bing and Redish’s studies were not static. They reflected contextual understandings of “what is going on here” (Goffman, 1974), with respect to the physics and mathematics students believed they were doing. These epistemological framings, expectations about knowledge and learning, are dynamically activated in the context of different material and social configurations. Moreover, the epistemological framings available to students be tuned over time (McCormick & Hammer, 2016), and lead to connections across content areas and transfer (Hammer et al., 2002). Indeed, Bing and Redish (2009) suggested that one goal for education may be to create environments that allow students to blend or merge epistemological framings, thus expanding their available sets of knowledge and resources.

We are interested in learners’ epistemological framings concerning the role of computational tools in other disciplinary domains, and how those framings may shift when such tools are integrated into instruction. In particular, this study explores the ways in which high school statistics students might understand the RStudio data analysis environment as a tool for statistical investigation. Here we present a detailed analysis of one students’ efforts to investigate the relationship between coal consumption and production in the U.S. using RStudio to manage and visualize data. We found that the student, Audrey, moved between computing and statistics in ways that suggest distinct, at times conflicting epistemological framings of the activity.

Methods
The CodeR4Stats project explores the use of RStudio, a computational data analysis environment, as part of the high school statistics curriculum. The project seeks to introduce computing in statistics through collaborative activities that explore large-scale social and environmental datasets about familiar topics (local ecology, Star Wars fandom, college admissions patterns). In a multi-year collaboration with an urban New England public school teacher, CodeR4Stats activities were integrated into a general Statistics course over the academic year.
Here we focus on Audrey, a high performing student who ranked in the top of her class for homework completion and quiz scores, and seemed comfortable using RStudio. We found that despite apparent success in the course, Audrey engaged in coding and debugging behavior that suggested she was framing “computation” and “statistics” as distinct domains. When she focused on one domain, this at times inhibited or interfered with her sensemaking about the other. Our data are drawn from a 6-day unit toward the end of the year where student groups selected a dataset from seven options, developed a research question, and pursued the question through statistical analysis. The datasets were large and complex, which allowed students pursue a variety of questions and motivated the need for computational methods and the RStudio environment to clean, organize, and analyze data. Consenting groups’ screen activity and discussions were recorded and later synchronized for analysis.

We analyzed the data through the lens of epistemological framing as described above. Typically, research that explores framing uses linguistic markers or other discursive features as evidence for participants’ framings (Tannen 1993). However, epistemological framing can also be inferred from a variety of behavior, including para-verbal and nonverbal cues such as hand motions, facial aspect, body position and/or movement, and gaze (Scherr & Hammer, 2009). For this analysis we additionally attend to participants’ interactions with tools including the writing, editing, testing of computer code, referencing informational resources, self-talk, and verbal interactions with her class partner as sources to help identify Audrey’s epistemological framings.

Results
We examine shifts and stabilities in Audrey’s problem-solving behavior as she moves between rather disparate computational and statistical epistemological framings. We begin by establishing the nature of these two frames, and then trace how those frames affect Audrey’s debugging activities when she encounters a compilation error in her code. The compilation error leads Audrey to believe there is a problem in her code or data, but it in fact is the result of an attempt to create a histogram using plot two variables, rather than only one.

Part 1. Identifying computing and statistics as distinct frames
On the first day of the project, Audrey began writing code to import a dataset about U.S. energy production and consumption into RStudio. She created variables for production and consumption data for each energy source her group was interested in. These variables had names that corresponded to the data their referenced; for example, the coal consumption data was stored in variable ‘cc’ and the coal production data was stored in variable ‘cp.’

Once Audrey had transformed her data into a more manageable form, she created a variable called “setcc2015” to hold the coal consumption data for 2015 that she extracted from the larger data set (Table 1, Line 118). She created another variable called “setmo2015” to hold month values for that same subset of data, with the intention to plot coal consumption data over time for the year of 2015. Audrey’s facility manipulating these large datasets and using meaningful variable names suggests she was comfortably and stably engaged in computing, and leads us to conclude Audrey is framing this first part of her code as a computational resource.

However, after creating these subset variables, Audrey redefined the variables as “x” and “y” (Lines 119, 121). She used these new variables to build her plot (Line 122). This switch in variable names is inefficient from a computational standpoint, but reproduces mathematical/statistical convention. This provides tentative evidence that Audrey understands the production of plots as a statistical activity relatively distinct from computing, an epistemological framing that we find more evidence for later in her work on the project.

<table>
<thead>
<tr>
<th>Audrey’s code</th>
<th>What this line of code does</th>
</tr>
</thead>
<tbody>
<tr>
<td>118 <code>setcc2015 = subset(cc, year == 2015)</code></td>
<td>Creates list of coal consumption values for 2015</td>
</tr>
<tr>
<td>119 <code>x = setcc2015</code></td>
<td>Stores list of coal consumption values into variable x</td>
</tr>
<tr>
<td>120 <code>setmo2015 = subset(month, year == 2015)</code></td>
<td>Creates list of month values for 2015</td>
</tr>
<tr>
<td>121 <code>y = setmo2015</code></td>
<td>Stores list of month values into variable x</td>
</tr>
<tr>
<td>122 <code>plot(x,y)</code></td>
<td>Creates plot of coal consumption over 2015</td>
</tr>
</tbody>
</table>

Part 2. Computing frame obscures statistical misunderstanding
At the beginning of day 2, Audrey announced to her partner Zach, “Yeah, I wanna try, I wanna try to make a histogram. It didn’t really go very well, I tried it last night.” It is unclear from our records what, exactly, Audrey wanted to plot using the histogram function. She began to pursue the histogram by typing and executing the code `hist(year, cp)`. The `year` variable contained a list of the years of observation of each record in the dataset, and `cp` described the amount of coal production for each record. It seems Audrey wanted to create a
histogram using two separate variables, but the histogram function in R only accepts one variable, since histograms by definition display frequencies of single measure across a collection of observations.

When Audrey executed this line of code, RStudio outputted Error in hist.default(year, cp) : some 'x' not counted; maybe 'breaks' do not span range of 'x'. This is the result of the computer interpreting the second variable inside the parentheses, cp, as the number of breaks in the histogram, when cp actually contains a list of values and not a single integer. Audrey said to Zach, “It just said, like, the data, like for some of the data it says, like, zeroes, so that it wouldn’t work, so.” Here we posit Audrey interpreted the error to indicate something wrong with the data she wishes to graph. Audrey’s assumption that there is a discrepancy in the raw data that the function hist() is unable to process leads her to interpret the error as a computational, rather than statistical problem. This interpretation is reinforced by the use of the variable x in the error message, which we already know Audrey interprets to mean the first variable in an ordered pair.

Audrey’s first attempt at troubleshooting was to run the code x=hist(year,cp) (a revision to the original code that caused the error), and x (to print the data stored in variable x). The first line of code produced the same error, but this was quickly pushed off the screen by the list of data stored in x that was output next. Audrey scrolled through the outputted data, we presume based on her earlier mention of “zeros”, to look for zeros or null values. None were present, and she moved to the next step of troubleshooting. She attempted to create a scatterplot of x using the plot() function, which generated a cloud of points without any observable trend. Recall that Audrey had stored her own data using meaningful variable names and used x and y only transiently for plotting; the most recent use of x was as storage for the histogram itself. When the scatterplot appeared Audrey responded, “Okie doke, that’s not what I want.” Given that Audrey was confident plotting data the day before, we interpret these actions as efforts to check if her data was usable by a plotting function.

Audrey next referred to online help resources for the RStudio environment using the CodeR4Stats webpage. She scrolled past the examples that show how to build a histogram using R code, which illustrate that histograms only take a single variable, and instead stopped and read examples that demonstrate how to format data for use with plotting functions. Following these examples, she typed and ran a line of code, x=c(cp) (cp contains coal production values), which does not produce any error or output. Audrey added two more lines, y=c(year) and hist(x, y) and executed the three lines together. Because Audrey passed two lists of data to the histogram function, she again receives the error discussed above.

We interpret this segment of activity to reflect that Audrey’s initially ambiguous framing, evidenced by her declaration that she wants create a histogram, quickly shifted to one that emphasized computational aspects of the problem. When Audrey received a compilation error, she believed it was due to a corrupt data structure or some other computational mis-step, rather than a more fundamental misuse of histogram as a statistical representational tool. Given Audrey’s performance in the class, we have evidence to suggest that this does not reflect a misunderstanding of lack of awareness of what a histogram is. Rather, it seems that Audrey’s epistemological framing more strongly activates data and syntax as features of the situation than statistical ideas.

Part 3. Re-orienting to statistical activity

The error produced at the end of the last subsection is from Audrey’s passing multiple data columns into the hist() function, the same error she saw when first beginning to investigate histograms. She responds to this error again in the same way she did previously, by re-evaluating the raw data inputted into the function. However, this time Audrey revisited even earlier code, code that she used to initially import and structure the dataset for analysis. She read the data in anew, and re-constructed the relevant data columns. This section of Audrey’s code, however, also included the use of x and y variables that she typically used when moving to statistical (graphing) activity. She added and re-ran the histogram function again, with x and y as inputs. This code again produces the same error. However, this time Audrey changed the command to hist(x), perhaps imitating the examples on the resource website that use x as an input. Once Audrey executed this new line of code hist(x), a figure was generated (Figure 2). Upon producing the figure, Audrey spoke with Zach:

```r
my.data=read.csv("Energy.csv - Energy.csv.csv")
na.strings=c("energy.csv -Energ.csv.csv", "NA")
my.data=na.omit(my.data)
my.data
x=c(cp)
y=c(year)
hist(x, y)
```

Figure 2: Audrey’s R Code (from screen capture) and the resulting histogram (reconstructed to improve quality)
A: I did it! Oh my god.
Z: How did you do it?
A: Uh, let me think about how I just did that. Because that’s a great question and I don’t really know. [tracing histogram with cursor] Ok, so the x is the coal production [x variable definition in code], this is coal production [x axis of histogram] this is frequency [y axis of histogram]; but what we really want is to be year [x axis of histogram] and this to be coal production [y axis of histogram].

With Zach’s help, Audrey shifted from thinking about the computational problem of producing the histogram via code to thinking about the statistical problem of what the histogram actually means. This shift is evidenced in Audrey’s focus on mappings between data and the conventions of x and y axes; and her recognition that the histogram that was finally produced was not well-aligned with her actual goal. Indeed, Audrey had generated scatterplots earlier in the project, so the problem was not that she did not have access to the correct functions or difficulty conceptualizing scatterplots. Instead, we argue, a mis-step early in the day and the error message it produced oriented Audrey’s attention to computing, an epistemological frame that did not support thinking about the purpose and nature of statistical plots. Since histograms only display frequency of a single variable, RStudio had not allowed Audrey to produce a figure that did not make statistical sense, but Audrey treated the computer feedback and other available resources as a computational problem rather than a statistical one.

Discussion and conclusions
Computing tools, especially those designed for data analysis, are powerful in statistics investigations—they can process large amounts of data, quickly produce plots, and have a low overhead since commands map easily to statistical convention. However, integration and even clear alignment between a tool and its application does not mean students will recognize connections between the two. Educators should focus on developing hybrid framings that allow computing and disciplinary practice to co-develop.

Without such attention, we run the risk of the computer acting as gatekeeper or source of statistical knowledge, depending on whether students choose to focus on the computer as an end in itself. For example, in the case above, RStudio would not let Audrey make an incorrect histogram. One might assume this is a good thing—it provides Audrey with feedback that a histogram displays frequencies of only one variable. However, the error led Audrey, through a shift of frames, to de-emphasize statistical knowledge. While this paper presents only a single case study, we are analyzing these dimensions of epistemological framing across students repeated exposures to integrated activity, with interest in students’ development of integrated epistemological frames.

References

Acknowledgements
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Exploring Relevant Problem-Solving Processes in Learning From Productive Failure

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Abstract: Productive Failure (PF) is an instructional design which uses a problem-solving phase to support the acquisition of conceptual knowledge from a following instruction phase. By activating prior knowledge and raising awareness of knowledge gaps, the PF problem-solving phase is assumed to help students acquire conceptual knowledge. However, it is still unclear which specific problem-solving processes prepare learning from the subsequent instruction. To explore the role of problem-solving behaviours during the initial phase of PF, the process data of 24 participants of a quasi-experimental study were analysed. We hypothesised that evaluating their own problem-solving during the initial phase of PF facilitates students’ awareness of their knowledge gaps and, thus, is associated with learning from the subsequent instruction. However, our data analyses did not support this hypothesis. Further explorations showed the importance of students achieving some understanding of the goal state of the problem they solve in the initial phase of PF.

Theoretical background

Previous research has already provided a large amount of evidence that the instructional design of productive failure (PF) facilitates conceptual knowledge acquisition in the mathematical domain (cf. Kapur 2012, Kapur & Bielaczyc, 2012). In order to support learning of previously unknown content, PF uses a problem-solving phase to prepare the students for a subsequent instruction phase. This paper focuses on the preparatory mechanisms involved in the initial problem-solving phase of PF. During the problem-solving phase, students are instructed to generate as many solutions to a problem as possible (Kapur & Bielaczyc, 2012). It is assumed that this, students activate relevant prior knowledge (Kapur, 2012; Loibl, Roll & Rummel, 2017). However, as the students do not have sufficient prior knowledge for solving the given problem, their solutions are mostly flawed or incomplete (Kapur & Bielaczyc, 2012). Due to the erroneousness of the students’ solutions and their lack of prior knowledge, students might realise that their solutions were insufficient and become aware of their knowledge gaps (Loibl et al., 2017). Yet, it is unclear how exactly students become aware of their lack of knowledge. Loibl et al. (2017) presume that these preparatory mechanisms, the activation of prior knowledge and an awareness of knowledge gaps, prepare students for learning from the subsequent instruction during the problem-solving phase. In line with this assumption, a study by Loibl and Rummel (2014) reveals that the subsequent instruction becomes more effective if the students’ knowledge gaps are addressed by discussing typical student solutions. Nevertheless, the premises by Loibl et al. (2017) still lack empirical evidence. However, to gain empirical evidence, firstly, it is necessary to acquire further details about specific problem-solving behaviours that are relevant for preparing learning from the subsequent instruction during the PF problem-solving phase.

The work presented in this paper therefore explores the PF problem-solving process to address the question what kinds of problem-solving behaviours prepare students for learning from the following instruction phase. For a theoretical foundation, research on problem solving is reconsidered and placed into the context of PF research. Our aim was to explore the theoretical assumptions by Loibl et al. (2017) in further detail to generate more insights into the relevance of the problem-solving process in PF.

Problem solving is defined as a process in which a problem is solved by finding an operator that can reduce the previously examined gap between the current state of a problem and its expected goal state (Sweller, 1998). In PF, the goal state represents the canonical solution of the given mathematical problem. In this study, the mathematical problem deals with the concept of variance, i.e. the reliability of the performance of football players. Therefore, the canonical solution and goal state of this problem is the formula for standard deviation. However, as the students face a completely unknown content (Loibl & Rummel, 2014), they cannot be certain which kind of goal state is to be expected, nor can they be sure that the operators they might be able to apply to the problem are appropriate. Even though students likely come up with a set of intuitive ideas that might guide the problem-solving process (cf. Jonasson, 2000), this lack of knowledge makes it necessary to rely on further strategies in order to monitor one’s own problem-solving process. Firstly, to reduce the range of possible operators, students’ intuitive ideas need to be structured and formed into criteria for the desired goal state, that
is, what it looks like and how it might be achievable. Based on these criteria, the problem solvers are able to select the first problem-solving operator and generate the first solution of their set of solutions to the given problem during the PF problem-solving phase. Nevertheless, as the students’ prior knowledge is limited, an assessment of the quality of the generated solution is required. For this, the students need to evaluate the current state of the problem produced by their selected operator(s). Schoenfeld (1992) emphasised the significance of evaluating one’s own problem-solving behaviour for successful problem solving. However, in PF, students’ problem-solving processes are generally not successful, but rather erroneous and incomplete due to the lack of prior knowledge and information at hand (Kapur, 2012). For this reason, it is likely that already while facing their solutions’ results, students become aware of conflicts in their solutions. This awareness of conflicts might trigger a thorough analysis and evaluation of the own problem-solving process and the selected operator(s).

Placing these theoretical assumptions into the context of the above discussed preparatory mechanisms that are assumed to be relevant to PF, leads to hypotheses concerning specific required PF problem-solving processes: Firstly, upon receiving the problem, students might begin with a planning phase. For this, they would generate intuitive ideas for their solutions by activating relevant prior knowledge. Next, they would need to form criteria for the desired goal state of the problem in order to be able to choose from available problem-solving operators. In a following implementation phase, they would then select an operator and apply it to the problem. Subsequently, students would evaluate the outcome of their action. At this point, students might detect conflicts in their erroneous solution and possibly engage in an analysis of these. An analysis of conflicts could raise the students’ awareness of their knowledge gaps and thus play an essential part in the preparation for learning from the following instruction phase (Roll, Holmes, Day & Bonn, 2012; Loibl et al., 2017). Based on this theoretical conceptualisation of specific required PF problem-solving processes we formulated three hypotheses. First, we assumed that the more solutions include conclusions drawn from the results, the more learning from the following instruction phase (Roll, Holmes, Day & Bonn, 2012; Loibl et al., 2017). Based on these theoretical assumptions, we hypothesized that the higher the amount of solutions with conflict awareness and analyses, the higher the students’ awareness of knowledge gaps (hypothesis 2). Lastly, we assumed that the amount of solutions including conflict analyses is associated with the students’ conceptual knowledge at the end of the instruction phase (hypothesis 3).

Method
To investigate our hypotheses, we drew from the data of a quasi-experimental study (Hartmann, Rummel & Van Gog, 2017) with 75 10th-graders of two secondary schools in Germany. However, this paper focusses on the data of 24 students who worked in the PF condition as described above. The study was conducted in a school setting on two different days. On the first day, the participants received a short prior-knowledge test in order to assess their knowledge on different concepts of variance. Subsequently, the students engaged in the initial phase of the study, the problem-solving phase. In this phase, the students received a task on the concept of standard deviation, which was so far unknown to them. The task demanded to find the most reliable football player amongst three players. The students received a list of each of the player’s amount of goals per year over a period of ten years. They were instructed to work on this problem individually and to find as many solutions to it as possible. In order to capture the problem-solving process, the students were asked to write their solutions on tablets and to express all of their thoughts out loud. Both students’ thoughts and solutions were recorded. After 45 minutes, the participants received a short test in order to measure, among other variables, their awareness of knowledge gaps by self-report with a 6-point Likert scale. On the second day of the study, the participants commenced the subsequent phase, in which they received an instruction about the concept of standard deviation. The instruction was built on typical student solutions, picked up common mistakes and misconceptions and contrasted them with the conceptual features of the canonical solution (see Loibl et al., 2017). After this, a short practice phase was implemented before the students engaged in a 40-minute post-test, which measured, besides other types of knowledge, the students’ conceptual knowledge. The validity of the used tests, as well as the internal consistency was revised in Loibl and Rummel (2014) and found satisfactory. However, in this study, the internal consistency slightly decreased for the awareness of knowledge gaps (Cronbach’s alpha = .71) and plummeted for conceptual knowledge (Cronbach’s alpha = .41).

As a means to make central cognitive processes visible, we used think-aloud data (Ericsson & Simon, 1980) for the following process analysis. The analysis was conducted with the help of a self-constructed coding scheme. The coding scheme divides the problem-solving process into three phases: a planning phase, an implementation and an evaluation phase. Each phase describes different problem-solving behaviours based on the theoretical outline discussed earlier e.g. criteria for desired goal state (phase 1), drawing conclusions (phase 2) and conflict awareness or analysis (phase 3). Students’ problem-solving behaviour was coded dichotomously
(1 = present; 0 = non-present). The coding scheme was applied to each solution of each student. As the students each generated two to seven solutions, the coding scheme was applied multiple times per person.

**Findings**

The coded data was analysed in three ways. First, we analysed the data descriptively. Then, for hypotheses testing we ran a series of correlations. Finally, we explored the data in order to gain more insights into the problem-solving behaviour of PF students. The descriptive analyses of the problem-solving variables revealed that all students drew conclusions in at least one of their solutions to the problem. Furthermore, for 91.7% of the participants, conflict awareness or conflict analyses could be identified in one or more solutions. However, conflict analyses were only implemented by 54.2% of the students.

For hypothesis testing, we used the rank correlation coefficient Spearman’s rho, as none of the variables were normally distributed. The relationship between the variables was calculated by using the sum of solutions per person in which a specific problem-solving behaviour could be found. However, we did not find significant correlations for our four hypotheses (see Table 1).

**Table 1: Hypotheses Testing (Spearman’s rho; N=24)**

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>$r_s$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing conclusions</td>
<td>Conflict awareness &amp; analysis</td>
<td>.105</td>
<td>ns</td>
</tr>
<tr>
<td>Conflict awareness</td>
<td>Awareness of knowledge gaps</td>
<td>-.120</td>
<td>ns</td>
</tr>
<tr>
<td>Conflict analysis</td>
<td>Conceptual knowledge</td>
<td>.023</td>
<td>ns</td>
</tr>
</tbody>
</table>

In the last step of the data analysis, the data was explored beyond the hypotheses of this paper. Our aim was to examine further problem-solving behaviours that could be relevant for learning in PF. For this, a series of correlation matrices was generated. As in hypothesis testing, we used the sum of solutions per person with a specific problem-solving behaviour. However, of all variables, none could be associated with awareness of knowledge gaps and only one with conceptual knowledge. This variable measured the amount of solutions that included criteria for the desired goal state of the problem. Between the variables criteria for the goal state and conceptual knowledge, we found a moderate positive correlation ($r_s = .462$) as well as a moderate negative relationship between criteria for the desired goal state and the number of solutions ($r_s = -.446$). This means that a higher number of solutions, which include criteria for the desired goal state, goes along with a fewer number of solutions. On a descriptive level, nine out of 24 participants formulated criteria in at least one solution, whereas 15 out of 24 participants did not name criteria for the desired goal state at all. Thus, this nearly presents a naturally occurring median split with almost half of the participants showing this behaviour. When comparing these two groups, it becomes evident that those students who formulated criteria for the desired goal state performed almost one point better in the conceptual knowledge test than those who did not use criteria (see Table 2 for means and standard deviations).

**Table 2: Descriptive Analysis – Conceptual Knowledge of Students With/Without Criteria for the Desired Goal State**

<table>
<thead>
<tr>
<th>Manifestation of the variable ‘criteria for desired goal state’</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No criteria for desired goal state</td>
<td>15</td>
<td>2.87</td>
<td>1.37</td>
</tr>
<tr>
<td>Criteria for desired goal state (in at least one solution)</td>
<td>9</td>
<td>3.83</td>
<td>1.30</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>3.23</td>
<td>1.40</td>
</tr>
</tbody>
</table>

**Discussion**

Prior to the discussion of results, some limitations of the study need to be considered. Firstly, as this paper only focused on 24 participants, the small sample size has to be noted. This ultimately reduces the statistical power of the study, which may be an explanation why none of the stated hypotheses could be confirmed. Another reason for this could be the debatable internal consistency of the scale measuring conceptual knowledge. Furthermore, the gathered think-aloud data needs to be regarded with caution. As Nisbett & Wilson (1997) indicated, it is unclear to what extent students are aware of their cognitive processes and are able to verbalise them sufficiently. Thus, central cognitive processes could remain concealed in the analyses. As it is generally unclear how
beneficial problem-solving processes might manifest, this ultimately also impedes the validation of the constructed coding scheme. As this study was a first attempt at taking a closer look at students problem-solving process in PF, the newly constructed coding scheme needs yet to be tested for validity and (interrater) reliability in further uses.

Even though we did not find significant results in support of our hypotheses, further data exploration presented valuable insights into the PF problem-solving process that need closer examination. The correlation between criteria for the desired goal state and conceptual knowledge as well as the clear descriptive performance differences between the participants who did and did not use identified criteria in their solutions, highlight this type of planning behaviour in PF. This finding is in line with the findings of Roll et al. (2012) and Schoenfeld (1992), who stressed the importance of planning in math problem solving. It could be assumed that the construction of criteria for the desired goal state has a central function in the problem-solving process as a means to structure it. A deeper understanding of the desired goal state might help to guide the problem-solving process – and particularly the search of an adequate problem-solving operator – despite the limited amount of prior knowledge for and information about the given problem. Furthermore, the moderate negative correlation between criteria for the desired goal state and the number of solutions suggest the possible efficiency of posing criteria. As a high number of solutions with criteria for the desired goal state is associated with a low number of solutions but also a high conceptual knowledge score, this gives rise to the assumption that, in a structured problem-solving process, a small number of efficient solutions suffices to prepare learning from the subsequent instruction phase successfully during the problem-solving phase. This might result from a deeper processing and higher awareness of one’s own solutions and their shortcomings when generating only a small amount of structured solutions, supporting the integration of new knowledge during the instruction. Though this idea stands out against current research, which presumes that a higher diversity of solutions fosters learning (Kapur & Bielaczyc, 2012), it might allow to deduce fruitful new hypotheses on PF problem solving.

PF research still largely neglects a thorough analysis of tangible problem-solving behaviours during the problem-solving phase. This study served as a first exploration into this area. Future research will need to further investigate the potential relevance of students’ planning behaviour that relates to the problem’s goal state for the PF problem-solving phase. Even though finding criteria for the desired goal state appeared in our explorative analyses to promote the acquisition of conceptual knowledge, it was not linked to an awareness of knowledge gaps. As this awareness is, however, assumed to be essential for the preparation for learning from the subsequent instruction phase (Loibl et al., 2017), this opens up further questions about the validity of the used instruments and if there might be more suitable ways to operationalise awareness of knowledge gaps. The results of this study show that, despite a theoretically founded examination of the PF problem-solving phase, it is difficult to reliably and validly assess specific problem-solving behaviours, and to identify behaviours that prepare for subsequent learning. This highlights the necessity of further research for a deeper understanding of essential prerequisites in the problem-solving phase for a successful PF effect.

References
Reflecting on Epistemic Ideals and Processes: Designing Opportunities for Teachers’ Epistemic Growth

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Abstract: This paper reports on a design experiment that explored designs for supporting teachers’ epistemic growth. Specifically, the study examined how reflective activities contribute to growth in understanding and caring about epistemic ideals and processes. The context of the study was an online course on digital information literacy. Teacher participants engaged in two types of reflective activities designed to promote epistemic growth: reflective experience tasks and reflective journals. Analysis of the journals revealed that participants experienced growth in understanding of epistemic ideals and processes, in pedagogical knowledge about teaching epistemic ideals and processes, and in appreciation of the importance and value of using and teaching epistemic ideals and processes. Participants described the course readings and the reflective experience tasks as the main contributors to growth. These activities jointly enabled them to significantly expand their understandings of epistemic ideals and processes in ways that were personally and professionally meaningful.

Introduction

The increasingly complex epistemic environments that await learners out of school make it ever more important to seek better ways of promoting learners’ epistemic growth, that is, growth in learners’ ways of knowing and their understandings of how people know (Barzilai & Chinn, 2018). Teachers are central to this project because the ways in which they engage in instruction and dialog have a formative impact on learners’ epistemologies. An important current challenge of epistemic cognition research is, therefore, to clarify the ways in which teachers’ epistemic growth can be supported. Teachers’ epistemic growth has the dual nature of involving growth of oneself and of one’s capacity to promote the growth of others (Buehl & Fives, 2016). Many researchers argue that reflection is key to supporting teachers’ epistemic growth (e.g., Feucht, Lunn Brownlee & Schraw, 2017). However, there is scant empirical evidence of whether reflection can indeed effectively promote teachers’ epistemic growth and, relatedly, little understanding of how to design meaningful reflective activities.

Our conceptualization of epistemic cognition is grounded in the AIR model of epistemic cognition (Chinn, Rinehart, & Buckland, 2014). In brief, this model describes epistemic cognition as comprised of: (a) Epistemic aims and value - the epistemic goals actors set and the perceived importance of these goals; (b) Epistemic ideals – standards or criteria that can be used to evaluate whether epistemic aims have been achieved and the quality of epistemic products; and (c) Reliable epistemic processes - procedures or strategies that can successfully achieve epistemic aims and create epistemic products.

Recently, Barzilai and Chinn (2018) argued that the goal of epistemic education should be to promote learners’ apt epistemic performance, defined as performance that achieves valuable epistemic aims through competence. They further identified five aspects of epistemic performance that are important to achieving this goal: (a) engaging in reliable cognitive processes that can lead to achievement of epistemic aims; (b) adapting epistemic performance to diverse situations; (c) metacognitively regulating and understanding epistemic performance; (d) caring about and enjoying epistemic performance; and (e) achieving epistemic aims together with others. Each of these aspects involves competent engagement with epistemic aims and value, ideals, and processes. In the present study, we use this framework, called the Apt-AIR framework, to conceptualize the goals of teachers’ epistemic growth. We focus on growth in two specific aspects of Apt-AIR—understanding epistemic performance and caring about epistemic performance. Briefly, growth in understanding of epistemic performance is defined as increase in metacognitive understanding of epistemic aims, ideals, and processes. Growth in caring about epistemic performance is defined as valuing epistemic aims, ideals, and processes and aspiring to achieve or apply them (Barzilai & Chinn, 2018).

The potential contribution of reflection in education has been emphasized and described by numerous researchers and theorists (e.g., Dewey, 1933; Schöen, 1983). For instance, Schöen (1983) argued that a “reflective practitioner” reflects on her aims, tacit norms, and performance as part of her practice, with the intention of putting into action what she realized or learned. In this study, we adopt Boud, Keogh, & Walker’s (1985, p. 19) definition of reflection as “those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations.” Yet, we specifically focus on experiences related to
achieving epistemic aims. Thus, our working definition for reflection on epistemic cognition is those intellectual and affective activities in which individuals engage to explore their epistemic aims, ideals, and processes in order to lead to new (or to change in) understandings, appreciations, and performance. Because epistemic aims, ideals, and processes are cognitive constructs, reflection on them is a metacognitive activity.

In this report, we focus on examining teachers’ reflections on epistemic ideals and processes because these were the main foci of their reflections. Thus, the questions we explore are: (1) How do teachers reflect on changes in understanding and caring about epistemic ideals and processes? (2) How do teachers perceive the contribution of the reflective activities in an academic course, and the manner in which they interplay with other course components, to changes in understanding and caring about epistemic ideals and processes?

Method

The context of the study was an intensive 7 week summer MA course on digital information literacy that was fully online. Participants were 17 teachers with diverse teaching experience in several age bands and subjects. The course included four components that were jointly intended to promote epistemic growth along the five aspects of the Apt-AIR framework. The first two components involved two different types of reflective activities:

(a) Reflective experience tasks – These tasks posed information problems that required engagement in cognitive epistemic performance. The tasks involved searching, evaluating, and integrating online information sources about various current topics (e.g., organic food, cellular radiation, and Brexit). These topics are appropriate for teaching digital literacy because they are richly and diversely represented online. Two tasks included questions from different domains to prompt adaptive epistemic performance. Participants were also asked to describe the criteria and strategies they used and to evaluate their effectiveness, in order to foster understanding and regulation of epistemic performance. One week later, participants met online in groups to create a shared list of epistemic criteria and strategies for addressing the challenge. This feature was designed to encourage participation in epistemic performance with others and to enhance caring about epistemic performance by developing a commitment to shared ideals and processes (Chinn, Duncan, & Rinehart, 2017).

(b) Reflective journals - Participants were asked to write four journal entries in which they considered their beliefs regarding issues such as what is valuable knowledge, what are good sources of knowledge, and how is knowledge justified. This activity fostered understanding and regulation of epistemic performance, albeit in a more open-ended way that encouraged participants to form connections between their learning experiences and their personal and professional experiences. The last journal entry invited participants to look back to their first entry and to consider if there were any differences in the entries and why. In the last entry, participants were also asked if there is anything that they would like to “take” from the course into their professional practice.

(c) Readings and discussions – Students read articles on digital literacy, which discussed strategies such as searching, evaluation, and integration. Following reading, students participated in weekly discussions. This activity fostered understanding of epistemic performance and engaged students in participation in epistemic performance through critical discussions that created opportunities for developing shared understandings.

(d) Design tasks – Participants also engaged in collaborative design of instructional units for fostering digital information literacy. These created additional opportunities for participating in epistemic performance.

The present findings are based on analysis of participants’ reflective journals and on retrospective interviews with four of the participants. These were analyzed using codes that were inductively inferred over several rounds of coding and refining. Interrater reliability by two independent judges was Kappa 0.79 to 1.00.

Results

Growth in understanding of epistemic ideals and processes

Participants described two interrelated planes of growth in understanding of epistemic ideals and processes:

Growth in understanding of epistemic ideals and processes for knowing online (70.6% of the participants)

– Participants reflected on gaining better understanding of valuable ideals and processes. For example, Bella described growth in understanding of epistemic criteria: “I understand that there are criteria that help evaluating information and how much these criteria are prioritized differently by different people.” When reflecting on their own ideals and processes, some participants (41.2%) were surprised to discover that their strategies and standards for knowing online fall short. For example, Monica discovered that she often relies on inadequate criteria: “I find myself often searching for information… in the same way that my students search for information and according to the same criteria – ease of use, website design, the order of the results, etc.”

Growth in pedagogical knowledge about teaching epistemic ideals and processes for knowing online (64.7%) - Increase in understanding of their own and others’ epistemic ideals and processes was a gateway to increase in pedagogical knowledge about teaching epistemic ideals and processes. Experiencing the challenges of
aptly employing epistemic ideals and processes gave participants new appreciation of the difficulties that students can experience. This led to growth in pedagogical understanding:

My personal experiences revealed the fact that although the Internet is an inseparable part of my life, I don’t really know how to use it effectively and even find it hard to analyze the actions that I make in order to evaluate or locate information sources. The difficulty that I describe also surfaced in the articles that we read in the course, and it helps me understand more deeply the pedagogical rationale and challenge that face us when we talk about digital literacy. (Monica)

Gaining better understanding of valuable ideals and processes led the participants to reconsider their instruction and to set new teaching goals. Carmen reflected: “Following the course… I think I can say that the principle of critique… is the focus of knowledge acquisition, especially good knowledge. The ability to select ideas according to criteria that are adapted to the content and situation will enable me to critically examine new ideas.” When reflecting about her teaching, Carmen described a change in her beliefs about what it means to teach digital literacy: “I understand now that throughout my work as a teacher, I did this partially and did not deepen the need for and the meaning of thinking critically during evaluation processes.”

Growth in caring about epistemic ideals and processes

Teachers described several aspects of growth in caring about epistemic ideals and processes:

*Growth in appreciation of the importance and value of using epistemic ideals and processes* (52.9% of the participants) - Participants described greater appreciation of the importance of using epistemic ideals and processes to achieve epistemic aims. For example, Dana reflected that she understood that “it is very important to check source trustworthiness and reliability in all stages because not all of the information in certain.”

*Growth in appreciation of the importance and value of teaching epistemic ideals and processes* (52.9%) - Participants also expressed greater appreciation of the importance of teaching epistemic ideals and processes for knowing online. For example, Rose described how: “My awareness of the process of integrating texts and the many difficulties during this process, after learning about it and experiencing it myself, strengthened in me the feeling of how important and critical it is to teach digital literacy today.”

*Expressions of explicit intent to teach epistemic ideals and processes* (94.1%) - Perhaps the strongest expressions of caring were participants’ expressions of intent to foster their students’ capacities to use epistemic ideals and processes. Nearly all of the participants made such statements, e.g., “I am certain that during the year I will teach the students various criteria for evaluating information sources” (Ginna).

Reflections on reasons for growth

The prompts in the last journal entry invited participants to consider possible reasons for change in their epistemic cognition. Participants most frequently attributed change to the course papers and reading discussions (58.8%), followed by the reflective experience tasks (41.2%), and to a lesser degree the reflective journals (11.8%). Only one student mentioned the design tasks as a reason for change. Participants’ explanations of how these elements contributed to change suggested five main mechanisms at play that jointly enabled growth:

(a) Practically engaging with epistemic ideals and processes. The reflective experience tasks contributed to growth by expanding participants’ practical experiences with ideals and processes. This was important for grasping these ideals and processes and refining understandings of them. For example, Bella wrote that she learned from the experiential tasks “that there can be different conditions and different approaches to the same strategy, depending on the specific information that we try to seek and evaluate.”

(b) Expanding knowledge of epistemic ideals and processes. In tandem with these tasks, the course readings helped participants gain new knowledge about valuable ideals and reliable processes for online problem solving and helped them understand why these are important and reliable. Noah wrote in his journal:

One of the most meaningful points of the course for me was the paper by Rouet (2006) and the study by Wineburg [(1991)] that was described in that paper. I discovered that my condition today is in between the novices and the experts [in Wineburg’s study], with a considerable leaning towards the novices… The ways in which the experts looked at the information, even information that seemed trustworthy, made me ask how much I activate my critical sense when I read information online.

(c) Critically reflecting on own epistemic ideals and processes. Noah’s quote demonstrates another mechanism at play. In the reflective writing tasks, participants used their growing knowledge of epistemic ideals and processes to reconsider their own ideals and processes. Thus, the theoretical and empirical readings enabled
the participants to gain a new perspective on their epistemic performance, as learners and as teachers. For example, Anna wrote that the readings led her to: “gradually start doubting myself and thinking before I act.”

(d) Collaboratively understanding and reflecting on epistemic ideals and processes. When participants pooled together the knowledge they gained from performing the reflective experience tasks and from the readings, they achieved a better grasp of ideals and processes. Ronna described the collaborative sessions: “We tried to clarify the concepts together. We often argued…. We talked about the issues in order to go deeper.”

(e) Making the connections between course experiences and epistemic performance. Although only two students referred to the reflective journals as instigators of growth, we believe that these journals had a subtle yet important contribution. The journals prompted participants to consider the connections between their course experiences and their epistemic performance, that is, they encouraged higher-order reflection on processes of epistemic change. For example, David wrote in his journal: “I think that one of the things that I learned about myself and about digital literacy is to metacognitively observe how I investigate and construct knowledge.”

Conclusions and implications
Promoting teachers’ epistemic growth, and their capacity to promote the epistemic growth of their students, is a critical educational challenge in the digital age. Current research emphasizes reflection on practice as a central mechanism of promoting teachers’ epistemic growth (e.g., Feucht et al., 2017). However, little is known about how to productively engage teachers in reflection on their epistemic performance. In this study, we used the Apt-Air framework (Barzilai & Chinn, 2018) to design activities that integrated reflection on epistemic performance in teachers’ learning experiences. Analysis of participants’ reflections indicated that they experienced growth in understanding and caring about epistemic performance and that this growth was enabled by the combined effects of engaging in epistemic performance, in adaptive and collaborative ways, along with an increase in metacognitive understanding of epistemic ideals and processes, and ongoing reflection.

The findings suggest that simply prompting teachers to reflect on their epistemic cognition might not be sufficient to foster meaningful epistemic growth. Expanding teachers’ awareness of appropriate epistemic ideals and process, how these can be employed, and conditions on their use, may be critical for helping teachers gain a new perspective on their epistemic cognition. In addition, gaining new practical experiences in applying epistemic ideals and processes may be an important foundation for growth. The reflective experience tasks, a new format of reflective activity designed for this course, enabled teachers to closely examine in situ how they engage in epistemic performance and to compare their epistemic performance to that of their peers and to that of the novices and experts described in the literature they read. The interconnections that participants formed between their personal and collaborative experiences and the literature enabled them to gain new insights into their own epistemic performance and into their students’ performance. The reflective experience tasks and, to a lesser degree, the reflective journals, also helped teachers learn to metacognitively reflect on their performance. In turn, growth in understanding of epistemic performance led teachers to appreciate the value of epistemic ideals and processes and to care more deeply about their instruction. However, teachers minimally engaged in reflection on epistemic aims and value. Thus, more work is needed to examine how to better foster reflection on these facets.

References


Dealing With Changes and Challenges: Grade 5 Students’ Experience With Knowledge Building Pedagogy in a Yearlong Science Inquiry

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Abstract: The goal of this study is to understand how grade 5 students as new knowledge builders adapt to the changes and address the challenges associated with Knowledge Building pedagogy to sustain their science inquiry over a school year. We observed the knowledge building process of a Grade 5 classroom that studied ecology, conducted in-depth semi-structured interview with nine students to gather detailed accounts of their personal experiences with science inquiry organized based on Knowledge Building pedagogy. Qualitative analysis of the interviews in relation to the classroom observations elaborates how the students experienced changes in their learning and their socio-emotional and cognitive responses to these changes. The findings show that the students addressed the challenges brought by the changes by exerting a series of cognitive efforts themselves and by gaining support from their knowledge building community.

Introduction

Education in the 21st century needs to prepare students for creative knowledge-intensive careers and collaborative practices. Various collaborative, inquiry-based learning programs have been developed to cultivate productive knowledge practices among students. Among the inquiry-based programs is the Knowledge Building pedagogy, which is aimed at restructuring classrooms as knowledge building communities in line with how creative knowledge practices operate in the real world (Scardamalia & Bereiter, 2014). Despite the advances made in understanding the socio-cultural and cognitive processes of collaborative inquiry and knowledge building (Bell & Linn, 2000; Hakkarainen, 2003; Hmelo-Silver, 2004; Roschelle, 1992; van Aalst, 2009), we, as a field, still have not found out how to bring sustained collaborative inquiry and knowledge building into broad classrooms to transform educational practices. The implementation of authentic inquiry and knowledge building requires teachers as well as their students to adapt to a new paradigm of learning that involves new learning goals, processes, social roles and norms, and environments. For example, students need to learn how to enact high-level agency and collective responsibility for co-managing the processes of inquiry (Scardamalia & Bereiter, 2014; Zhang et al., 2011). While existing research has investigated the progress made by various classrooms toward productive knowledge building practices (van Aalst & Truong, 2011; Zhang et al., 2007), it is unclear how students as new knowledge builders experience and respond to the dramatic changes to strive for effective knowledge building. The purpose of this study is to understand how students in a grade 5 classroom adapted to the changes and addressed the challenges associated with knowledge building to sustain their science inquiry over a school year.

Conducting science inquiry using Knowledge Building pedagogy represents a demanding challenge to teachers and students who are new to the pedagogy. Students are expected to take on new roles and handle learning differently to become effective knowledge builders who work together to develop collective understandings through sustained inquiry processes at both the individual and community level. Such transformation takes a gradual process through which students become more comfortable embracing changes and addressing challenges associated with Knowledge Building pedagogy. To better support the process of classroom change, we need to investigate the motivational and socioemotional aspects related to the ways students deal with the challenges and difficulties of knowledge building (cf. Miyake & Kirschner, 2014). When experiencing challenges, students have various emotions, which are associated with the ways they view themselves in relation to the nature and context of learning (Dweck, 2006). More positive responses to challenges involve seeing challenges as opportunities to learn and dealing with challenges through persistent efforts (Duckworth, Peterson, Matthews, & Kelly, 2007). Students need to make decisions at an individual level to adapt themselves to the new pedagogy that requires them to actively seek support and build knowledge as opposed to passively waiting to be guided and taught by their teacher.

What specific changes students experience, what these changes mean to students, and what efforts they pay to respond to the challenges when doing inquiry with Knowledge Building pedagogy are worth investigating. This study investigates the experience of a group of fifth-graders in their first year of knowledge building. We ask the following research questions: (a) How do students conceive of the new way of learning
through knowledge building? (b) What characterizes student experience as new knowledge builders? And (c) How do students deal with challenges to sustain and deepen their science inquiry over a school year?

Methodology

Classroom contexts
This study was conducted in a grade 5 classroom at a public school in Northeast US. This classroom had 24 students who were taught by a veteran teacher. The students studied ecology over a whole school year, with two science lessons each week. The ecology study was implemented based on Knowledge Building pedagogy supported by Knowledge Forum: an online collaborative environment (Scardamalia & Bereiter, 2014). The science inquiry began with focused research on crayfish and was then expanded to study different ecosystems. Students generated various interests and questions and formulated shared wondering areas as the focus of their inquiry. They generated ideas, conducted research using online and printed materials, and engaged in knowledge building conversations to share and build on one another’s ideas for deeper understanding. On an ongoing basis, students contributed ideas to Knowledge Forum for continual discussion online.

Data sources and analyses
The data sources included classroom observations and interviews. The first author observed each science lesson and took detailed notes. At the end of the inquiry, we conducted a semi-structured interview with nine students randomly selected from those who had consented to be interviewed. The interview included nine questions focusing on the processes and experiences of inquiry. Follow-up questions were asked in each interview to have students explain their response in detail. The interviews lasted between 10 and 19 minutes each. All the interviews were video-recorded and transcribed verbatim.

We used qualitative inductive data analysis (Hatch, 2002; Strauss & Corbin, 1998) to analyze the interview data supported by our classroom observations. The first author read and re-read the interview transcriptions. Focusing on each of the research questions, a set of raw codes was developed and applied to the interview data. The raw codes were further reviewed and linked to develop salient themes. The themes and codes were described in Findings.

Findings
To understand how the students experienced and conceived of the changes in their classroom caused by the adoption of Knowledge Building pedagogy, we asked students to reflect on their journey of inquiry and their experience with this new way of learning in the interview. Qualitative coding of the students’ responses resulted in five major codes that gave rise to two themes (Table 1). Students recognized that they were expected to take ownership over their science inquiry to generate inquiry directions and questions and plan and structure their inquiry processes. With this expectation, students noticed that they needed to take on new roles to find the information through research, to go beyond the information for deep understanding, and to build connections across the various ideas to understand how ecosystems work.

Table 1: New changes students experienced with Knowledge Building pedagogy

<table>
<thead>
<tr>
<th>Themes</th>
<th>Codes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning as student-driven</td>
<td>Defining inquiry topics and questions</td>
<td>“choose what you wanted to learn about, instead of teacher saying, this is what you gonna learn about”</td>
</tr>
<tr>
<td></td>
<td>Structuring inquiry processes</td>
<td>“there is a lot of resources I can work by”</td>
</tr>
<tr>
<td>Learning through deep inquiry</td>
<td>Conducting research</td>
<td>“having to find out all the answers for ourselves”</td>
</tr>
<tr>
<td></td>
<td>Going deep</td>
<td>“had to figure out why this was the answer and how it worked”</td>
</tr>
<tr>
<td></td>
<td>Building connections</td>
<td>“make… connections to many other things”</td>
</tr>
</tbody>
</table>

In the interview, the students were further asked to reflect on any exciting things or difficult moments they had experienced in the knowledge building process. Coding of their responses helped us to identify both their feelings/emotions as well as cognitive challenges (Table 2). As new knowledge builders, students
experienced different emotional reactions along their journey of science inquiry. On one hand, they showed enjoyment and excitement. On the other hand, they also experienced struggles to adapt to their new role as knowledge builders who needed to manage their inquiry interests and directions. Associated with the struggles are the specific cognitive challenges they encountered at different stages of their inquiry: to go deeper, to find helpful sources of information, and to deal with setbacks in thinking.

Table 2: Socio-emotional responses and cognitive challenges students experienced with Knowledge Building

<table>
<thead>
<tr>
<th>Themes</th>
<th>Codes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feelings about inquiry</td>
<td>Enjoyment</td>
<td>“It’s actually very fun!”</td>
</tr>
<tr>
<td></td>
<td>Struggle</td>
<td>“It would’ve helped if some of the questions I could have gotten answers to like easier, like if the teacher knew the answer to a question, she could tell us.”</td>
</tr>
<tr>
<td></td>
<td>Finding and changing interest</td>
<td>“I couldn’t find anything else about tundra and so I decided that I switched topic because I was stuck in the tundra.”</td>
</tr>
<tr>
<td>Cognitive challenges</td>
<td>“couldn’t go any further”</td>
<td>“Sometimes I felt like everything I read was kind of just over and over again, the same exact thing.”</td>
</tr>
<tr>
<td></td>
<td>“hard to find information”</td>
<td>“can’t find the information that we were trying to find.”</td>
</tr>
<tr>
<td>Setbacks in thinking</td>
<td></td>
<td>“my train of thought stopped”</td>
</tr>
</tbody>
</table>

In the interview, students further commented on what they did when they faced difficulties and challenges. Analysis of their comments revealed their active efforts and strategies along three themes: deep thinking, reflective monitoring and strategic focusing, and seeking collaborative support in their community to connect ideas and deepen inquiry. These comments aligned with our classroom observations, showing that the students exerted continual efforts both individually and as a community to solve problems, stretch their thinking, and achieve deeper understanding.

Table 3: Cognitive efforts students made to deepen inquiry with Knowledge Building

<table>
<thead>
<tr>
<th>Themes</th>
<th>Codes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep thinking</td>
<td>Keep thinking and researching</td>
<td>“to think in a different way, at a different angle”</td>
</tr>
<tr>
<td></td>
<td>“got more information”</td>
<td>“look at the websites, the extra information, the books, the videos”</td>
</tr>
<tr>
<td>Reflective monitoring and strategic focusing</td>
<td>Seeing the whole picture</td>
<td>“learn about other things about it to figure out how that affecting what you think is important”</td>
</tr>
<tr>
<td></td>
<td>Tracking thinking</td>
<td>“Think about what you know, and think about what you don’t know”</td>
</tr>
<tr>
<td></td>
<td>Refocusing</td>
<td>“After I switch topics, I found a lot about coral reefs, so I did not get stuck during the coral reefs”</td>
</tr>
<tr>
<td>Collaborating to connect and deepen inquiry</td>
<td>Reaching out to other people</td>
<td>“get ideas from my friends and Mrs. O”</td>
</tr>
<tr>
<td></td>
<td>“connecting ideas”</td>
<td>“connect your knowledge with other people and your thinking.”</td>
</tr>
<tr>
<td></td>
<td>Contributing to the community</td>
<td>“to take the most important things you kinda want to talk about what’s happening more than the facts about it.”</td>
</tr>
</tbody>
</table>

Discussion
Efforts to transform classroom practices using Knowledge Building pedagogy and other inquiry-based learning programs require deeper understandings of how students as new knowledge builders experience and respond to the dramatic changes. In this study, the participants understood that their learning was expected to be “student driven” for “deep inquiry,” which were two major changes they faced in their science learning. The participants
reported enjoyment of their yearlong science learning experience. Meanwhile, they reported struggles to play their new roles and manage their inquiry interests and directions when they reflected on the beginning phase of their inquiry. The contrast of students’ emotional responses between “struggle” and “enjoyment” indicates a sense of accomplishment after they adapted to the changes by dealing with the “cognitive challenges”, by engaging in “deep thinking” and “reflective monitoring and strategic focusing.” and by “collaborating” and reaching out to their KBC for inquiry support. To students, “reaching out to other people” and “connecting ideas” through face-to-face or online interactions were not the only ways they practiced to deepen inquiry. “Contributing to community” by generating and improving ideas in Knowledge Forum also fostered their cognitive effort and stretched their thinking. The community served as a supportive context to sustain the science inquiry of both individuals and the community as a whole.

Implications and next steps
The findings contribute to understanding how students experience and respond to the changes and challenges associated with Knowledge Building pedagogy. Transforming classroom practices using inquiry-based learning and knowledge building not only requires the efforts of researchers and teachers but also the persistent efforts of students to make sense of the changes, embrace challenges, and deploy proactive strategies to seek idea improvement despite difficulties. We are expanding this analysis to a larger group of students from several classrooms to understand the full range of changes and challenges students encounter. We will also do deeper analysis of students’ specific actions to address the challenges in relation to knowledge advances achieved.

References

Acknowledgments
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How Does Expansive Curricular Framing Support Productive Epistemological Framing of Computational Modeling Activities?

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Abstract: Computational modeling can be generative for sense making of scientific phenomena. However, because models are abstractions of real world phenomena, making connections beyond them may not be straightforward. In this paper, we argue that expansive curricular framing can support productive epistemological framing of modeling, and influence how learners see their model exploration as relevant to their ongoing investigations. We present an analysis of two groups of undergraduate students investigating relative fitness of low and high mutating bacterial strains in a computational model. We demonstrate that even though the groups are comparable in the quality of work within the model, expansive curricular framing impacts students’ epistemological framing of the activity and whether students see ideas from the model as relevant in a broader scope of their investigations.

Introduction
Computational modeling technologies provide generative contexts for sense making of scientific phenomena, enabling students to explore dynamics, and supporting reasoning about mechanisms underlying phenomena (e.g., White, 1984; Wilensky & Reisman, 2006). However, because computational models are abstractions, determining their relevance to other contexts may not be a straightforward task (Goldstone & Wilensky, 2008). This may especially be true when learners investigate pre-built models. Constructing models involves making decisions about abstracting aspects from real world phenomenon to represent (Wilkerson, Gravel, & Macrander, 2014). However, when investigating pre-built models students may be less familiar with underlying abstractions and need help making connections to other contexts. In this paper, we argue that expansive curricular framing (Engle, 2006) can influence whether and how learners see their modeling investigations as relevant to their ongoing inquiry. To make this claim, we present a contrasting case study (Yin, 1994) of two groups of undergraduate students. We argue that even though both groups engage with the model in productive ways, they frame the activity differently, and this difference in framing impacts whether and how they see ideas from the model as relevant to their larger inquiry.

Expansive framing and intercontextuality
Expansive framing involves framing the boundaries of a learning context “as being wide-ranging and permeable, increasing the number of contexts that can become intercontextually linked with them” (Engle, Nguyen, & Mendelson, 2011, p. 605). Engle and colleagues (2006; 2011) have argued that expansively framed learning environments help learners see ideas as applicable in a wider range of contexts – creating intercontextualities. We draw on the construct of intercontextuality to explain differences in how students saw a computational modeling activity as connected to a broader scientific investigation.

Epistemological framing
Framing is an individual’s sense of “what is it that’s going on here” (Tannen, 1993). Epistemological framing is a student’s interpretation of an activity with respect to knowledge and learning (Hutchison & Hammer, 2010). For instance, students may frame science class as for learning scientific terminology or for investigating how the world works. These different frames can impact what students do in science class, and ultimately, what they learn. Research has found that student behaviors can provide important cues about their epistemological framing (Scherr & Hammer, 2009). However, these frames are dynamically constructed and sensitive to contextual cues such as teacher moves (Hutchison & Hammer, 2010) and curricular design (Hayes, Wagh & Gouvea, In preparation).

Research goals
This work was done as part of a design-based research (Collins, Joseph, & Bielaczyc, 2004) project called Hybrid Labs. The project aims to integrate physical experimentation and computational modeling for student investigations of complex biological systems. In this paper, we examine factors that enable students to contextualize and connect their model investigations to their ongoing scientific investigation.
Methods

Data collection
The Hybrid Labs curriculum was designed for introductory undergraduate biology labs. Data comes from Years 1 and 2 of the first lab. Lab 1 consisted of 3 3-hour long lab sessions over which students conducted experiments and engaged in model explorations to investigate relative fitness of a low and high mutating bacterial strain. In each year, we collected data in two lab sections, each consisting of about 25 students. In each section, we recorded data from 3 groups: Video recordings of in-group work and Camtasia video data. We also collected students’ lab reports, in which they were asked to make a claim for the question, Is it better to be a high mutator or a low mutator?.

Data analysis
Initial analysis involved repeated viewing (Jordan & Henderson, 1995) of videos from Lab 1 of student groups from both years. We discussed initial themes for analysis with the larger research group. We also read through students’ lab reports to inspect how students referred to activities from the lab to make an argument. One theme that stood out from this initial work was that though students engaged productively with the modeling activity in both years, fewer students drew on ideas from their model exploration in Year 1 in other parts of the lab. This trend was also reflected in student interviews. This led us to want to explain why this happened.

We selected an exemplary group that engaged most productively in the computational modeling activity each year. We analyzed their Camtasia videos and identified three practices that were salient in students’ work: 1) Manipulating parameters to create conditions to produce a specific outcome or investigating how parameter changes would impact outcomes; 2) Attending to a specific outcome or trend in the populations; 3) Justifying or accounting for an observation or prediction. We coded the transcript synced with video to identify occurrences when student utterances reflected engagement in these practices. We also analyzed videos to investigate students’ framing - how they interpreted the purpose of the activity and where they located epistemic authority (Hammer, Elby, Scherr & Redish, 2005). Based on prior work (Scherr & Hammer, 2009), we identified 3 framing modes: 1) Sense making mode: Indicators included authentic engagement with the model such that students engaged in noticing and talking about the model, often accompanied by surprise, confusion, and persistence. Students positioned themselves as agentic in the work. Students’ gaze was largely focused on the model in this mode; 2) Worksheet mode: Indicators included gazing down at their worksheet for extended periods of time, enacting actions for the sake of filling out the worksheet, and positioning the instructor as being an authority of their investigation; and, 3) Hybrid mode: Indicators involved a combination of the two that made it hard to surmise student framing. We coded videos for engagement in these frames. Finally, we analyzed lab reports (N = 3 in G1, and 4 in G2) to inspect whether and how students drew on their model investigations in their discussion of results.

Findings
Our argument is that intercontextuality impacts students’ epistemological framing of the activity and whether students see ideas from the model as relevant in a broader scope of their investigations. We compare four aspects of the groups’ work: 1) Practices for engaging with the model; 2) Epistemological framing of the activity; 3) Connecting ideas within and across the lab; and, 4) Use of the model to make an argument in lab reports.

Groups’ practices of engaging with the model
Both groups engaged with the model in different ways. G1 tried to create specific trends in the model, and changed the parameters multiple times to generate them. They also frequently attended to trends in the model, and tried to explain and justify those trends. G2 asked questions about what would happen when the parameter settings were at particular points (e.g., what would happen when metabolic benefit is high and lethal is low), and they ran six runs for each of their six questions. They ran the model for much longer than G1, and closely attended to trends in the model. However, they did not engage in explaining trends or justifying their predictions as frequently as G1.

Table 1: Practices engaged with in the model (number of occurrences)

<table>
<thead>
<tr>
<th>Group</th>
<th>Manipulating parameters</th>
<th>Attending to</th>
<th>Justifying/ explaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>26</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ICLS 2018 Proceedings 1138 © ISLS
Group 2 (Year 2) | 6 | 20 | 5

How the groups epistemologically framed the modeling activity

Though both groups engaged productively with the model, we found differences in how they framed the activity. The groups framed their interactions with the model in different ways (See Tables 2 and 3). G1 went back and forth between a worksheet mode and a sense-making mode. During moments of sense-making, their conversations, gestures and affect reflected authentic engagement around their investigation. However, they repeatedly switched back to a worksheet mode, positioning the TA as an epistemic authority (e.g., when they noticed a trend in their model that seemed stable, they asked the instructor if it “counted as stable”). In contrast, G2 framed their work more consistently in a sense-making mode – using the model to understand their experimental results.

Table 2: Epistemological framing of the activity in Groups 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Worksheet mode</th>
<th>Sense making mode</th>
<th>Hybrid mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>25.87%</td>
<td>55.97%</td>
<td>1.15%</td>
</tr>
<tr>
<td>Group 2</td>
<td>0</td>
<td>98%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 3: How Groups 1 and 2 framed the task of recording data from their models

<table>
<thead>
<tr>
<th>Group 1’s Worksheet mode</th>
<th>Group 2’s Sense-making mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S1 asks as they fill out the worksheet)</td>
<td>(D &amp; W are asked to share data from their model)</td>
</tr>
<tr>
<td>S1: Do you guys write down the numbers for the past</td>
<td>D: Which one do you want me to put in of the three?</td>
</tr>
<tr>
<td>ones?</td>
<td>W: Um the first one, wait not that one, yeah that one.</td>
</tr>
<tr>
<td>S2: Uhh, I did but I don't really know why. I didn't</td>
<td>(Scrolling through captured screenshots of the model)</td>
</tr>
<tr>
<td>know what else to write down so. If we need them,</td>
<td>D: I can put in all 3</td>
</tr>
<tr>
<td>I'll, I have them if we need them.</td>
<td>A: Yeah because I think all 3 really say a lot</td>
</tr>
</tbody>
</table>

How the groups made connections between the modeling activity and the experiment

Our conjecture is that these epistemological frames were cued by an expansive framing of the modeling activity. Intercontextuality provides opportunities for connecting across contexts. This conjecture is based on our analysis of transcripts - we identified moments when students referred to their experiments or other ideas from class to help make sense of the model. G2 explicitly tied observations and sense-making in the model to their experiment more frequently than G1 (9 times v/s once). This was evidence of intercontextuality – students saw other components of lab as relevant and applicable to ideas they were exploring in the model.

In both years, the model was presented as a tool to make sense of their experimental data. However, in Y1, the connections were not framed explicitly. For instance, the TA introduced the model by simply listing parameters from the model as available features to try out. As a result, the students experienced the model as isolated from their ongoing investigation, and did not tie it back to their experiment. In contrast, in Y2, the TA positioned the model as a way to make sense of experimental data: “I want you to try to model something that is relatively close to the experiment ... set up a model that gets at the question that you asked .. [and] really watch those patterns for a while .. and think about how that might relate to some of the data that you actually saw in our experiments.” This orienting helped students view the model as a space to make sense of their experiment. Students in G2 repeatedly referenced the experiment during their model investigation, and made attempts to map their experiment and the model.

How students draw on ideas from the model in their lab reports

Of the three students in G1, only one student referenced the model in her lab report. She used her model observations to validate her experimental results, specifying conditions in the model that supported her experimental results. However, she did not provide reasoning to support this claim. All students in G2 used their model exploration in their discussion of the investigation. One reason for this was that in Y2, we explicitly asked students to discuss their model explorations in their lab reports. However, students went much further than simply mentioning the model exploration. In lab reports, we found students meaningfully mapping conditions in the simulation with experimental conditions, drawing out similarities and contrasts between the
two as mechanisms to explain their observations in each. We also found students in G2 comparing temporal aspects of the simulation and the experiment: Describing how the experiment had been conducted over only a few generations relative to the number of generations that had played out in the simulation. This makes sense given that G2 ran their model for much longer periods of time than G1, which made the temporal dynamics over time salient to them.

Discussion
This work calls attention to the importance of fostering intercontextuality between modeling activities and other components of student inquiry. In our data, both groups engaged in productive practices with the model - they manipulated parameters, attended to and explained how parameter changes impacted survival of the two strains. One might expect that engaging productively with the model itself would help students see the relevance of ideas beyond the model. However, these findings suggested that this was not the case. The model needed to be framed expansively more explicitly for students to be able to see relevance of ideas beyond the model. We tried to create intercontextuality in a few different ways: One, as previously mentioned, the TA explicitly framed the modeling activity as being intended for students to make sense of their experiments. Second, in Y2, we encouraged students to explore the model multiple times through the lab. Students also explored the model as a space for experimental design. The expansive framing created supported students in connecting their work outside the model into their model investigations as well as connect ideas from their model to the larger inquiry.

References
Missing the Brilliance of Scholars of Color: Mathematics Teacher Educator Discourse in a White Zone of Proximal Development

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Abstract: In this paper, we describe and critically examine how white mathematics educators participated in the perpetuation of mathematics education as a white institutional space and zone of proximal development. Following Martin (2008) and Leonardo and Manning (2017), whiteness is examined as a series of discursive moves that frame and guide activity among a group of mathematics teacher educators. The paper examines mechanisms through which white researchers, working with a racially diverse team on professional development (PD) for mathematics teachers, instantiated an institutional space of whiteness despite the expressed goal of all of the researchers and designers of the PD to interrupt sociopolitical injustice in mathematics education. The analysis uses empirical examples from a particular conversation about the PD design process that we argue discursively maintains whiteness as the overarching frame of the joint activity.

Keywords: equity, justice, mathematics education, whiteness

Mathematics education as a white institutional space

Equity has been an important, long-standing goal in mathematics education. Although efforts toward equity and justice in mathematics education through research and teacher education are making an impact on the field, this work remains situated within broader systems of privilege and oppression that support and constrain these efforts in various ways. In 2008, mathematics education researcher Danny Martin called on stakeholders in mathematics education research and policy to recognize the field as largely a white institutional space. Feagin and Moore (as cited in Martin, 2008) characterize white institutional space as ideologies and practices in a context, framed as “neutral” or “fair,” that serve to maintain white supremacy. In this characterization, white privilege is maintained through mundane, transparent practices that operate (often) beyond the conscious attention of the individual actors involved in the activity. This view of white institutional space couples well with racialized conceptualizations of Vygotsky’s (1978) zone of proximal development (Leonardo & Manning, 2017). As mathematics education scholars committed to equity and social justice, we take up this call to closely examine the ways in which our project space maintained white institutional space. We recognize that, as Leonardo (2004) argues, whiteness saturates everyday school life (and also our project work) and that one of the first steps to articulating its features is coming to terms with its specific modes of discourse. We must understand whether and how whiteness is operating in order to transgress existing boundaries and engage in explicit work to disrupt its function.

Discursive practices of whiteness

This paper focuses on work that is part of the Access, Agency, and Allies in Mathematical Systems (A³IMS) project, in which our project team set out to design and study a mathematics teacher professional development (PD) that explicitly attended to access, agency, and ally work as embedded components of equitable mathematical systems that support students’ and teachers’ opportunities to learn. This paper examines mechanisms through which some white researchers on our racially diverse project team instantiated and sustained an institutional space of whiteness through their discursive activity despite the expressed goal of all project team members to interrupt sociopolitical injustice in mathematics education. This paper, then, speaks to the question of how mathematics educators committed to equity and justice still perpetuate whiteness in their work and, thus, require additional, targeted efforts toward the continued dismantling of oppressive structures. Like Battey and Leyva (2016), we hope not just to name white privilege but to “document the institutional ways in which [white] supremacy in mathematics education acts to reproduce subordination and advantage” (p. 51). Specifically, this paper presents empirical examples, drawn from a particular conversation about the original
plans for part of the PD by the racially diverse research team, to illuminate how whiteness was instantiated and maintained as an overarching frame of the interactions taking place.

**Theoretical and methodological approach**

Here we draw on a range of literature from outside and within mathematics education to introduce and describe the key constructs that inform this study: race and racism, whiteness, white supremacy, white privilege, white institutional space, and white zones of proximal development.

Our project team has been comprised of 16 scholars at various times, in different stages of careers and with multiple areas of expertise. The five principal investigators on the research project were white. The scholars of color on the bigger project team were early in their careers and not yet tenured or were doctoral students. Yet, all of the project team had teaching experience and various expertise related to the PD design. The PD design team was made up of three white principal investigators, two white senior personnel, one African American and one white graduate student, and participation on this team was voluntary. It is important to note that although there is a danger in focusing solely on a single dimension of team members’ identities (see, for example, Bullock, 2017), we believe strongly that a focus on race helps to illuminate longstanding racial injustice in the U.S. and in mathematics education. We also acknowledge “choosing” a racialized term to signify one’s racial identity can be difficult, in part because this identity may not be consistent across contexts and the ways in which race intersects other socially-constructed concepts (e.g., ethnicity, nationality). Here we use race and professional status to illustrate the complexity of tensions present in white institutional spaces reified through white zones of proximal development.

Across several contributions, Martin has referred to mathematics education and research contexts as white institutional spaces (e.g. 2008; 2013). To define white institutional space, Martin tied his early work to Moore (as cited in Martin, 2008. p. 27) to characterize four foundational elements around exclusion, framing, historical construction, and the assertion of neutrality. Martin (2008) argues that even “well-intentioned individual whites” have benefitted from the historical constructions of race that have produced and reproduced boundaries between whiteness and non-whiteness to create racial hierarchies to reward those who are socially constructed as white. Martin continued by adding that structural and institutional perpetuations of whiteness and white privilege also help to maintain white institutional space (p. 390). Given the presence of whiteness and white privilege within mathematics education, there is motive to view mathematics education and research-based work related to mathematics education as white institutional spaces.

Martin (2013) adapted his earlier definition of white institutional spaces to apply it to the context of mathematics education, characterized by (a) numerical domination by whites and the exclusion of people of color from positions of power, (b) the development of a white frame, (c) the historical construction of curricular models based on white thought, and (d) the assertion of knowledge production as neutral and unconnected to power relations (p. 323). Martin’s characterization of mathematics education as white institutional space has influenced further investigation into areas mathematics education informed (e.g. Battey & Leyva, 2016; Stinson, 2017). Stinson (2017) argued that researching race in mathematics education without researching white supremacy in mathematics education is a strategic discursive practice and supports Martin’s (2013) use of white institutional space and the encouragement to question the type of project and the interests being served by the project of mathematics education. Battey and Leyva (2016) stressed the importance of naming white institutional spaces, including their mechanisms of oppression, to provide those in the field of mathematics education ideas for combatting racist structures (p. 49). We aim to shed light on one particular white institutional space in order to share specific encounters with whiteness to support growth toward resisting structures of racism within the field of mathematics education.

Within the instantiation of white institutional space one mechanism for maintaining whiteness is what Leonardo and Manning (2017) call a white zone of proximal development that works against learning to advance the actual development of white people and maintains a white zone of proximal underdevelopment (p. 24). This application of whiteness extends Vygotsky’s (1978) zone of proximal development, the space where the development of one person can be extended through the collaboration with a more capable peer via meditational tools. In this paper, speech, race, and professional status all are potential meditational tools. Therefore, we focus our analysis on discourse processes that mediated the goals of diverse team of PD designers and illustrate the complex interplay between racialized professional identities.

One transcript of a project team meeting was selected for the focus of this paper, since the topics discussed dealt explicitly with issues of whiteness. The interaction in this transcript took place at a whole group meeting in May 2016 during the second year of the project work, two months before the first week-long PD with the teachers occurred. This segment of the meeting was meant to allow team members of the research project who did not work directly on the design of the PD to give feedback to those who did.
We used Haviland’s (2008) analytic framework for identifying white educational discourse to analyze discourse moves within the transcript that maintained or disrupted whiteness. Drawing on literature from critical whiteness studies, Haviland identified discursive techniques involved in 1) power-evasion and 2) affirming whiteness. With this framework, we each independently reviewed the transcript, marking instances of power-evasion, whiteness affirmation, and efforts seemingly aimed at disrupting whiteness occurred. Following multiple discussions of the discursive moves in the transcript, we jointly identified six key events from within the longer transcript for further examination. The selection of key events follows the qualitative research practice of choosing excerpts to aid in conceptualization of ideas (Erickson, 1985). The selection of these key events was not based on its adequacy to support analysis, but rather to help illuminate and interrogate what we consider to be instances of whiteness in this particular space.

Discursive mechanisms in a white zone of proximal development

Three primary discursive mechanisms functioned to maintain the discursive (and design) space as largely a white zone of proximal development situated in a white institutional space. The first mechanism coincides with Martin’s (2008) first element of white institutional space: racial exclusion. In this episode of interaction, turns of talk, topic changes, and decision making were dominated by white members of the project team. The second mechanism is reflected in Martin’s assertion that much of mathematics education continues to be guided by curricular models created and sustained by white elites. In this episode, materials, activities, and ideas used to build the PD, and the expertise that was assigned in the construction process, were often located within a white zone of proximal development, which reifies the white institutional space. The third mechanism stemmed from a conceptualization of “trust” and “readiness” related to white norms (and subsequent practices). These conceptualizations emerged in relation to the topic of whiteness deemed “difficult” to discuss with teachers and reflect power-evasive moves that maintained and sustained the white institutional space. We illustrate these three mechanisms below through brief abbreviated vignettes from each episode.

The complex interplay between race and professional status was prevalent in how more capable peers were acknowledged in conversation. This was evident in two ways concerning how scholars of color were invited into discussions. First, scholars of color from the project were invited only when the conversation turned to issues of race, despite their expertise in other areas, such as the design and implementation of PD. One white principal investigator commented on the PD design saying, “I feel like there’s less of the focus on the self, and on whiteness and the history of whiteness in this community and the overlap between whiteness and mathematics. Maybe it is too much to do in a week, but I think it would be good to get other people’s feedback on that. What do people think?” (May 2016 Transcript, Turn 165). Since the conversation was dominated by white scholars up until this point, this discursive move to solicit the feedback of “people” and “other people” was coded language for wanting feedback from scholars of color. Second, when scholars of color were brought into the conversation, only those prominent in the field outside of the project were referenced as experts. A white principal investigator (turn 275) requested more concrete and detailed suggestions for future changes to the PD design. “(275) If the thought is, we are really not getting at interrogating whiteness enough, then it would also be helpful to have some suggestions. Move this here or do this instead or make sure…” “(276) Or bring in [outside consultant who is a person of color]. Because I don’t know the activities [they would do in their institutes focused on anti-racism]” (May 2016 Transcript, Turns 275-276). After the request, another white principal investigator (turn 276) quickly turned to the curricular materials and expertise from a scholar of color outside of the research group. References to outside experts and focus on limitations of project members tended to diminish the opportunity for the project team, especially the project members of color who brought varied expertise and experience to uncover and develop new sets of expertise. Another way whiteness emerged was in the dismissal of contributions of scholars of colors in favor of white normative conceptualizations. For example, one African American researcher, a graduate student, offered a counter-narrative to the conceptualization of trust and its relation to risk-taking among teachers engaging in topics around equity and social justice advocated by the white researchers stating, “I feel like in the ways in which we’re talking about these teachers in terms of not being ready for—I think it’s a little premature” (May 2016 Transcript, Turn 186). They highlighted participants’ identities as teachers who teach a particular racial group of students (predominantly African American children), which suggested that teachers (white or otherwise) could be ready for race-based conversations based on the context of their work and their connection to their students. This notion of being prepared for race-based conversation based on participants’ caring relationship to students was raised again by another scholar of color later in this conversation, but again was not taken up among other participants.

The tensions we faced in attempting to transgress whiteness in the design of this PD are prevalent in the field of mathematics education research, particularly among white researchers who take a social justice
orientation to their work. We argue that the discursive mechanisms taking place within and reifying white zones of proximal development are ubiquitous in the current conditions of mathematics teacher PD, and require close attention by mathematics teacher educators. As a result, we must critically examine the lines of research that inform research goals and materials. As Aguirre et al. (2017) argue, it is important to find and draw on research by scholars of color, and to expand our views on what counts as research that relates to mathematics education. The research of scholars from less-dominant backgrounds should not be “tokenized” as solely related to issues of equity, but rather inform how we conceive of “knowledge” and the relations between mathematics, community and broader social issues. This calls for the application of more expansive understanding and acknowledgement of expertise and meditational tools in the design and implementation of mathematical learning experiences. Furthermore, mathematics education researchers should look beyond the scope of our discipline to fields in which ideas around race, racism, whiteness and white supremacy are more deeply theorized.

Relevant scholarly references

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Co-Navigating Mobilized Student Inquiry Across Multiple Contexts

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Abstract: This study traces the learning trajectories of secondary students who conducted inquiry projects based on their personal interests. The study conceptualizes the activities, practices, and tools associated (and not associated) with the inquiry projects within the learning lives of the student participants. The university researchers and the classroom teachers were active participants who assisted the students; shared their own learning lives; and provided resources, tools, and opportunities that helped shape the students’ inquiry projects. The analysis features a co-navigation (with the researchers, the teachers, and the students) of learning trajectories across multiple contexts and social interactions. Findings reveal the agentive ways students took up and cast aside opportunities and artifacts in unexpected, yet fruitful, ways for the development of their inquiry projects. The paper concludes with implications for the design and facilitation of student inquiry across multiple contexts.

Major issues
The purpose of the study is to understand the divergent and agentive ways students co-navigated the learning trajectories related to an inquiry project. We use the term co-navigate rather than follow or trace in relationship to their learning trajectories because the university researchers and the teachers were both involved in the design of the learning opportunities; the facilitation of the inquiry projects across contexts, and the mapping of the learning trajectories across time and student-produced artifacts. The research study was conducted with and alongside the participants, and the data analysis serves as a partial reconstruction of the learning trajectories we co-navigated as a group. Our objective is to represent the participants’ learning in the ways they agentively wove together learning opportunities and resources across activity in the classroom, the library, the hallways in between, and various locales in the community, including their homes. This study intentionally disrupts classroom-as-container discourse and constructs (Leander et al., 2010) to consider how students weave different contexts together (and break them apart) to chart a learning trajectory within their learning lives (Erstad, 2012). We share with other researchers the goal of tracing learning across multiple contexts “as a means to generate new knowledge about the borders and edges of different practices and the boundary crossings these entail in the learning lives of young people” (Erstad, et al., 2016, p. 1).

Potential significance
Our approach to facilitating student inquiry projects based on their personal interests stems from two main arguments about designing and supporting learning opportunities for youth. The first argument is that learning opportunities can be designed to connect multiple places and spaces of learning (e.g., Ito, et al., 2013). We intentionally seek to disrupt the notion that learning is limited to the attainment of isolated skills within classrooms. From our perspective, youth are engaged in complex mobilities and trajectories that establish relationships between the different physical places and virtual spaces they navigate when learning and establishing/maintaining social relationships. We draw on Leander and his colleagues (2010) framing of mobility as encompassing: physical mobility, the embodied movement from place to place; virtual mobility, the use of technology and media to build social connections across time and space; and educational mobility, the distribution of learning opportunities across people, tools, and learning environments. Additionally, our aim is to understand how learning takes shape in different ways in distinct places (e.g., classroom, playground, corner store), but we are also interested in supporting learning across these places in terms of what adolescents bring along with them from place to place, as well as what learning is supported and brought about in those places.

The second argument is that learning opportunities should be oriented toward the lived experiences of people as they grapple with the social complexities that shape their lives (Bruce & Bishop, 2008). Our goal is to work with students on inquiry foci that they consider relevant to their lives. We argue that inquiry projects as learning opportunities should begin with an orientation toward issues that are relevant to youth and eventually build toward issues that impact others. Therefore, our approach to inquiry is conceptualized not only as a learning opportunity for an individual, but also as a learning opportunity that involves many people who share their lived experiences and collaboratively identify issues that are collectively considered to be relevant. To support learning opportunities such as these, we argue that youth should be conducting inquiry alongside people of a range of ages,
diverse lived experiences, and different life trajectories and mobilities. This argument further highlights the inherent limitations of learning opportunities that only involve youth of a certain age or school grade level.

Theoretical framework
The study is informed by a *learning lives* approach (Erstad, et al., 2009) that considers the longer (life-long) and broader (life-wide) learning trajectories that young people are involved with as they move within and across different social settings. This perspective eschews the conceptualizations of learning and the enactment of social and literacy practices as contained exclusively within imagined geographies such as classrooms (Leander, Phillips, & Taylor 2010). As a generative alternative, this study considers how learning and the enactment of social and literacy practices are both brought along with people and brought about in particular sites along trajectories that are most often only apparent in hindsight.

The *learning lives* approach to a broader conceptualization of learning is based on two interrelated sets of theories: socio-cultural learning theory and social practice theory (Erstad, 2012). Socio-cultural theory accounts for the relationship between the mental functions of people and the social, cultural, and historical situations in which, and tools with which, people take action. In particular, this approach identifies mediated action as the unit of analysis in consideration of how people exercise agency and take action with mediational means within and across contexts (Wertsch, 1998). However, these mediated actions aggregate over time into social practices that are shared among people within and across contexts (Scollon, 2001). Therefore, this approach considers mediated action on the micro level and social practice on the macro level (Scollon & Scollon, 2004). These constructs are particularly generative for conceptualizing what the social and learning significance of particular mediated actions within and across contexts and for how social practices are related to one another within a nexus of practice, unencumbered by assumed social, physical, virtual, geographic and spatial boundaries (Rish, 2015; 2017).

Methodology
We are referring to the hybrid methodology used in the site as *co-navigation*, as we attempt to reconstruct and represent the learning trajectories that we navigated alongside the students in the study. The metaphor and particular analytical methods of navigation are derived from nexus analysis (Scollon & Scollon, 2004) and the transliteracies framework proposed by Stornaiuolo and colleagues (2016). Nexus analysis is an ethnographic method that involves three recursive analytic activities: engaging the nexus, navigating the nexus, and changing the nexus in future iterative phases. Engaging the nexus of practice accounts for the roles of the researchers and the teachers in the design of the learning opportunities meant to bring about a nexus of practice that will support student inquiry. Within this phase of data analysis, the history of the participants is considered in terms of the practices they bring to bear on the design of and participation within the learning opportunities. The researchers had worked with students on inquiry projects before, the teacher had facilitated the inquiry projects in previous years, and the students had completed comparable tasks before. All of these prior experiences inform how the people involved with the student inquiry engaged the nexus of practices at work. The second phase of the analysis is navigating the nexus, or as we are calling it, *co-navigation*, which involves mapping the cycles of the people, places, discourse, objects, and concepts which circulated through this micro-semiotic ecosystem looking for anticipations and emanations, links and transformations, their inherent timescales, and to place a circumference of relevance around the nexus of practice. (Scollon & Scollon, 2004, p. xx)

We consider this phase of the data analysis to be *co-navigation*, because as researchers, we did not make these considerations and decisions absent from the participants. Rather, as a point of emphasis, we privileged the participants’ (both teachers’ and students’) understandings of what was relevant within the nexus of practice.

Within the *co-navigation* analytic phase, we have also found the transliteracies framework to be helpful in naming and following mediated actions and practices within and across contexts (Stornaiuolo, Smith, & Philips, 2016). In particular, we have found the concept of emergence to be helpful for accounting for (or not) the “indeterminacies of meaning making across interactions” and for allowing “the unprecedented, surprising, and meaningful to emerge in observations of human activity without predetermined and text-centric endpoints of explanation” (pp. 10-11). As the nexus is co-navigated, there is a risk of dismissing or misunderstanding ephemereral practices (Pahl, 2002) and proto-practices early in ontogenesis.

The third phase of changing the nexus accounts for the mediated actions and related social practices that are enacted to change the linkages within the nexus. Change is a constant process; therefore, this phase of the analysis is not considered to be tertiary, but rather an ongoing recursive and iterative phase of analysis.
The focal data of this paper include three students from each school and their learning trajectories, derived from video recordings, audio interviews, field notes, and teacher-provided and student-produced artifacts (digital and print). Student and teacher histories with inquiry were constructed with retrospective interviews. Data collection involved capturing activity with video and audio recorders while working alongside students as they conducted their inquiry in the classroom, the library, and the hallways in between.

**Research participants and multiple contexts**

The multi-sited study was conducted concurrently in two different high schools (one urban, one suburban) during an academic semester. The student inquiry projects in both high schools were initiated by English teachers and were designed to allow students to explore an issue they were interested in learning more about and/or an issue they felt passionate about in the world. The issues identified by the students within the inquiry projects varied vastly, changed frequently for some students, and gained complexity and nuance over time for most students.

Each English teacher planned the instructional unit separately. Though, they knew each other and had both taught in the same building in the past, they were not in contact during the inquiry projects (purely due to time constraints). The English teachers each had a different way of structuring and supporting the students’ learning that included drawing on previous iterations of the student inquiry project to adapt and orchestrate a series of learning opportunities with accompanying artifacts (e.g., handouts, graphic organizers, brainstorming documents) in consultations with the university researchers.

At the encouragement of the researchers, both English teachers incorporated options for students to collect their own data on their focal issue, in addition to the published research literature they were locating and reading. The researchers facilitated learning opportunities wherein students created online surveys and semi-structured interview protocols. The researchers and the teachers supported the students in the design of their survey instrument or interview protocol and the interpretation of the data they collected. The students were also provided guidance by the researchers on ways to use the data they collected in relationship to the published research they were gathering within their findings of their final papers and presentations.

In brief, the students’ learning trajectories variously and divergently wove together classroom and library learning opportunities; artifacts designed to organize the inquiry; online informational resources; collected data; and conversations with peers, family members and other people in the community.

**Findings**

Tentative findings for six focal student participants (three from each high school) demonstrate the divergent and unexpected learning trajectories related to the inquiry project. Each student wove together contexts of learning in ways that were shaped by their histories and social relationships, but also in ways that were informed by their needs in the moment for moving the inquiry project forward. Though each teacher carefully designed a sequence of learning opportunities, each meant to build on the one prior, the six focal students did not all demonstrate participation and uptake in those learning opportunities as designed. In fact, some of the learning opportunities were revisited when they were considered to be relevant by the students, and other learning opportunities were either not completed or the participation was attributed to “going through the motions” or “only for the grade.” For some of the students, the most salient learning opportunities were those afforded by the data collection and/or interviews, indicating that some of the student inquiry projects were bolstered by involving more aspects of the learning lives of students.

A full articulation of the findings demonstrates how moments of emergence that were initially overlooked by the researchers and the teachers as not directly related to the development of the student inquiry project were either some of the more salient moments that supported the students’ inquiry or held meaning for the student that transcended beyond the purposes of the inquiry project (e.g., interviewing a family member about an inquiry issue and gaining a better understanding of the family member as a result). The findings demonstrate how the inquiry project unfolded as a nexus of practice, but for some of the students this nexus was interrelated and linked with purposes and practices that extended beyond the project. This consideration allows for a fuller understanding of how an inquiry project based on personal interests works within the learning lives of students.

**Implications**

The focal students in this study demonstrate the agentive and unpredictable ways that young people weave together contexts of learning. The focal students wove together learning opportunities afforded by instructional time in the classroom, online resources and social interaction, conversations with peers in official and unofficial places and spaces, and social interactions that accompanied the online survey data collection and semi-structured...
interviews. These examples expand our imagined geographies of learning to include moments and conversations that otherwise may be overlooked or dismissed in the learning lives of youth.

The focal students in this study also demonstrate the participation and learning trajectories that are not wholly accounted for by the sanctioned learning opportunities they are presented with and often disrupt the intended timescale of instructional planning. Some but not all of the focal students completed project-related tasks within the suggested times. However, others navigated learning trajectories that leveraged learning opportunities at times other than when they were meant to fall in a sequence. These examples help us consider the assumed linearity in instructional design and value the examination of the actual learning trajectories that students create in relationship to the instructional design.

The focal students also demonstrated ways with which they negotiated among the practices at work within the inquiry project. Often, the practices that students brought along to learning opportunities were not the ones supported there, which required negotiation on behalf of the students, the teachers, and the researchers. How students negotiated among these practices within the nexus that linked together the inquiry project helps us understand how students shift practices across time and context, beyond simplistic notions of transfer.

References
Assessing Equity in Collaborative Learning Situations: A Comparison of Methods
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Abstract: We set out to apply methods for assessing equity in a collaborative learning situation of four college students. To do this, we utilized prior work assessing equity in programming pairs (Lewis & Shah, 2015; Shah, Lewis, & Caires, 2014) and coded for talking time, questions asked, and commands given. Using these methods to analyze two different groups we found the groups to be very similar. However, our sense was that the groups were not similar in regard to equity. We then used an adapted version of Duck’s (2000) group processing behaviors to code and analyze the two groups. This method indicated that one group engaged in far more equity-promoting behaviors than the other, suggesting a difference in the relative equity between them.

Keywords: equity, research methods, processing behaviors, collaborative learning

Introduction
Collaborative learning in small groups has been identified as an instructional practice that can support students’ conceptual understanding and create the potential for a more equitable learning environment (Esmonde, 2009; O’Donnell, & Hmelo-Silver, 2013). Though some also worry poorly designed collaborative work has the potential to exacerbate inequity rather than promote equity. Because there is reason to be both hopeful and cautious, understanding equity-dynamics in collaborative learning contexts is important work for our research community.

Developing that understanding will be complicated. As a beginning point, one must define and then operationalize equity in collaborative learning contexts; no small task. Like others in this community (Langer-Osuna, 2011, Shah, Lewis, & Caires, 2014, Lewis & Shah, 2015, Dietrick, Shapiro, & Gravel, 2016) we find Esmonde’s (2009) conceptualization of equity, from math education, useful when paying attention to equity in collaborative science learning contexts. Esmonde characterizes equity as “…the fair distribution of opportunities to learn…”, going on to identify two kinds of access to attend to, “…students’ access to mathematical content and discourse practices…” as well as “…their access to (positional) identities as knowers and doers of mathematics…” (p. 249). This characterization captures the potential we see for both the positive and negative equity-outcomes in collaborative learning situations. Equity is about fair access to opportunities. Compared with didactic learning situations, we expect learners have greater potential for access to content, discourse practices, and identities; but the social dynamics of collective problem solving may function to diminish such access for some group members.

Taking Esmonde’s characterization as a starting point, the next task is to operationalize it. In our case, we aim to do quantitative analysis that allows for comparisons like, for example, different activities done by the same group or different groups engaged in the same activity. Our interest in quantitative methods, as opposed to qualitative ones, is pragmatic. Both contribute to the development of a rich understanding. Quantitative methods make analysis across multiple groups over longer periods of time more practical, which is why we are investigating them. A common quantitative method is to identify behaviors that serve as an indicator of equity and code video data for those behaviors. (ie. Lewis & Shah, 2015; Dietrick, Shapiro, & Gravel, 2016) Commonly used equity indicators are the distribution of talking time or turns of talk, commands given, and questions asked. Typically researches track the quantity of the behavior for each individual learner and assume that a more equitable situation will yield a more equal distribution of the behaviors.

Notably, these studies acknowledge that the distribution of indicators is at best a rough proxy for equity. This is one of the trade-offs one makes when choosing quantitative over qualitative methods. We value the use of rough proxies; it makes our goal of analysis of larger sets of data possible. But we question whether equal distribution is a reasonable proxy for equity. While it is easy to imagine extreme cases where, say, one student dominates the activity of a group, it also seems likely that there are group contexts where some students bid to contribute to the intellectual or social discourse and are rebuffed by other group members. A student whose bid is unsuccessful may lose access to content, discourse practices, and identities. In those cases, measuring these behaviors may not give reasonable insight into equity.

We set out to investigate and compare a variety of methods for “measuring” equity in collaborative learning situations. In this paper, we report on a comparison of two different methodologies for assessing equity. We had access to an extensive data set of videos of collaborative learning situations in a pre-orientation program for students about to begin school at their undergraduate institution. In the course of comparing all five student
groups in a class when they were engaged in the same activity, we somewhat luckily stumbled across two groups engaged who (1) appeared markedly different to us in terms of Esmonde’s (2009) conceptualization of equity and (2) had remarkably similar distributions of talking times, questions asked, and commands. In what follows we first describe the comparison of the two groups using talking time and commands given analyses. Then, we describe how we adapted Duek’s (2000) group processing behaviors into a coding scheme and describe the two groups through that analysis. The first analysis suggests the two groups are very similar, while the group processing behavior analysis shows large differences.

**Methods**

The video data analyzed in this paper comes from the Integrating Metacognitive Practices and Research to Ensure Student Success (IMPRESS) program. This is a two-week pre-orientation program aimed at supporting science-interested deaf/hard-of-hearing students and first generation students about to start their first year at the Rochester Institute of Technology (RIT). (Franklin et al., in preparation) A large set of data, including videos from collaborative learning activities, has been accumulated by a research group that uses the program as a site for data collection.

The IMPRESS program’s content focuses is on climate change. We analyzed the activity of all five of groups in one session when they worked to construct a physical model of the atmosphere. As we note above two of the groups were remarkably similar in the typical equity indicators but intuitively appeared very different in terms of equity. “Group A” contained three female students, Brittany, Arya, and Pat, and one male student, Daniel (all names are pseudonyms). “Group B” was all male and contained Justin, Jakob, Herb, and Brock. The data for this paper comes from the second day of the program. Our analysis focuses on the same 20-minute time period for each group.

In the following analysis, we first use a system similar to Shah and Lewis’ (2015) scheme to quantify the distribution of talking time, questions, and commands by each individual in each group. We used BORIS software to record start and stop times of each utterance and mark questions and commands. Then we used an adapted version of Duek’s (2000) group processing behaviors to code the same data. A description of that coding scheme is provided below. As this is relatively new analysis for us we first created transcripts of each group to allow for easier comparison of different coders’ codes. We broke the 20-minute period into 5 minute segments and independently coded a few of the segments. We compared results and talked through instances of disagreement until we resolved each difference.

**Results and discussion**

The first quantitative measure analyzed was talking time, shown in Table 1. The groups are surprisingly similar in distribution of talking time among participants. The percentage of the total time that each student was responsible for is within 1 or 2 percent of the person from the other group in the same rank-ordered position. For example, Brittany and Justin talked the most in their groups, 38 and 40 percent of the total talking time respectively. Arya and Brock ranked third in their groups, 20 and 19 percent respectively. We compare the percentage distribution here because of the difference in the overall time spent talking by each group. The members of Group B had almost five more minutes of talking time in aggregate than Group A, 1112 seconds compared to 844 seconds, during the twenty-minute segment. This disparity is caused by the students of Group B engaging in a significant amount of overlapping talk, while the students of group A tended to take turns when talking.

<table>
<thead>
<tr>
<th>Group A</th>
<th>Time (s)</th>
<th>%</th>
<th>Commands</th>
<th>%</th>
<th>Group B</th>
<th>Time (s)</th>
<th>%</th>
<th>Commands</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brittany</td>
<td>321</td>
<td>38</td>
<td>25</td>
<td>71</td>
<td>Justin</td>
<td>445</td>
<td>40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Daniel</td>
<td>247</td>
<td>29</td>
<td>5</td>
<td>14</td>
<td>Jakob</td>
<td>329</td>
<td>30</td>
<td>19</td>
<td>76</td>
</tr>
<tr>
<td>Arya</td>
<td>172</td>
<td>20</td>
<td>5</td>
<td>14</td>
<td>Brock</td>
<td>195</td>
<td>18</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Pat</td>
<td>104</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>Herb</td>
<td>142</td>
<td>13</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>844</td>
<td>35</td>
<td></td>
<td></td>
<td>Total</td>
<td>1112</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second measure on which the groups were similar was commands issued, also shown in Table 1. In each group one student dominated the number of commands issued with the other three students having a few or
zero commands. An interesting difference that bears comment is Justin, in Group B. He is the student who speaks the most yet he gives no commands. Justin’s talk is largely arguing in support of his ideas when they disagree with the ideas of others. He is also the student who takes the group off task a couple of times. So, while Justin talks frequently he is not directing the on-task progress of the group.

Based on the assumption that equality is a rough proxy for equity, the similar distribution of talking times and commands in these two groups suggests they are relatively similar in terms of equity. Perhaps based on the fact that there is wide variance in how much different group members talk and how commands are distributed we should consider these groups relatively inequitable. However, when watching and analyzing the video of each group, the discourse in Group A appears to offer greater support for all students’ access to content, discourse practices, and identities than Group B. The members of Group A support each other’s access to such opportunities while the members of Group B engage in a significant amount of closing off access to opportunities.

Our sense of this difference was based on how members of each group interacted with one another, that is, the discourse that occurred between them. So, we looked for coding schemes of group interaction behaviors in the context of assessing for equity and found Duek’s (2000) work. We considered which of her behaviors were good candidate coding categories for our data. For example, several were not behaviors we could reliably code and we discarded them. We added an “Ignoring” code because we saw the behavior occasionally and it is a similar type to other behaviors Duek identified. We then considered whether each behavior we could reliably code promoted or demoted equity, using Esmonde’s (2009) characterization of equity to guide our choice. We considered whether each behavior could be identified as promoting or demoting access to content, discourse practices, and identities. In cases where the outcome was unclear or seemed ambiguous we removed the code from our analysis. We ended up with the eight codes listed in Table 2. The fact that there are four each that promote and demote equity was not planned, but we like that feature of what we are left with.

Table 2: Group Processing Behaviors with description and impact on equity

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Description</th>
<th>Equity Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraging/Energizing</td>
<td>Statements or actions that promote the ideas or statements of another student</td>
<td>Promotes</td>
</tr>
<tr>
<td>Orienting/Clarifying</td>
<td>Statements or questions that attempt to clarify/understand an idea or action in the group</td>
<td>Promotes</td>
</tr>
<tr>
<td>Gatekeeping</td>
<td>Attempts to get any/all members of the group to participate in the discussion or activity</td>
<td>Promotes</td>
</tr>
<tr>
<td>Forwarding</td>
<td>Taking a leadership role in moving the group towards completion of the task at hand</td>
<td>Promotes</td>
</tr>
<tr>
<td>Ignoring</td>
<td>Not verbally engaging or acknowledging the ideas or attempts to contribute of another member of the group.</td>
<td>Demotes</td>
</tr>
<tr>
<td>Overtalking/Aggressing</td>
<td>Talking louder while another student is talking, making harsh comments or tone of voice toward another student</td>
<td>Demotes</td>
</tr>
<tr>
<td>Individual Blocking</td>
<td>Any action or statement that prevents another student from contributing their ideas to the group</td>
<td>Demotes</td>
</tr>
<tr>
<td>Derailing/Group blocking</td>
<td>Statements or actions that cause the group to become off task or lose focus on the task</td>
<td>Demotes</td>
</tr>
</tbody>
</table>

We then coded the same data using our Duek-inspired coding scheme. Frequencies of each behavior category are shown in Table 3. There are a number of things to point out. The most notable is to look at the different percentages of equity-promoting and equity-demoting behaviors in each group. In group A, the one we perceived as being the more equitable of the two, there was a fairly equal split between equity-promoting and equity-demoting codes. In group B, the less equitable of the two, there were far more equity-demoting codes than equity-promoting ones. So overall this coding matches our intuitive sense of the relative difference between the two groups.

We also note that several codes are markedly different across the two groups. We are interested to see if these differences are a function of these two groups of if they will hold up with other groups. The complete or near absence of Encouraging/Energizing, Forwarding, Ignoring, and Individual Blocking in one but not the other group leads us to wonder if presence or absence of those behaviors are particularly salient markers of equity.

Other behavior codes are frequent in both groups. Overtalking, an equity-demoting code, is the most frequent code (or nearly so) in both groups, but a larger percentage of the total in Group B, the less equitable
group. Its frequent presence in both groups is unsurprising. The social dynamics of four students collaborating is simply going to involve overtalking. Orienting/Clarifying, an equity-promoting behavior, occurs equally in both groups, though it is a larger percentage in group A, the more equitable group. Again, this seems unsurprising, four students working together should involve instances of seeking clarification or explanation. But in both cases, the percentage supports our sense of more or less equity in the groups.

Table 3: Group Processing Behaviors exhibited by each group

<table>
<thead>
<tr>
<th>Behaviors</th>
<th>Group A</th>
<th>%</th>
<th>Behaviors</th>
<th>Group B</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraging/Energizing</td>
<td>7</td>
<td>13</td>
<td>Encouraging/Energizing</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Orienting/Clarifying</td>
<td>16</td>
<td>29</td>
<td>Orienting/Clarifying</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Gatekeeping</td>
<td>0</td>
<td>0</td>
<td>Gatekeeping</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forwarding</td>
<td>5</td>
<td>9</td>
<td>Forwarding</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ignoring</td>
<td>0</td>
<td>0</td>
<td>Ignoring</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Overtalking/Aggressing</td>
<td>14</td>
<td>26</td>
<td>Overtalking/Aggressing</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>Individual Blocking</td>
<td>0</td>
<td>0</td>
<td>Individual Blocking</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Derailing/Group blocking</td>
<td>13</td>
<td>24</td>
<td>Derailing/Group blocking</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Equity Promoting</td>
<td>28</td>
<td>51</td>
<td>Equity Promoting</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>Equity Demoting</td>
<td>27</td>
<td>49</td>
<td>Equity Demoting</td>
<td>69</td>
<td>79</td>
</tr>
<tr>
<td>total</td>
<td>55</td>
<td></td>
<td>total</td>
<td>87</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

As the above section hopefully communicates, we are excited that this processing behavior coding scheme produces a result that is robustly consistent with our sense of which group was more or less equitable compared to the other. That suggests there is potential for a useful rough proxy for equity. We are driven by many questions these analyses beg. We want better calibration for this coding instrument, which analysis of more and different data will provide. We wonder how the number of group members matters. Much of the work we look at for methodological guidance focuses on programming pairs in computer science. What systematic differences should we expect when groups get larger? We look forward to continuing to investigate and refine this coding scheme.

References


Open Discussions of Cultural-Historical Activity Inquiry Questions

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Abstract: This study presents initial analyses of a sample of historical activity inquiry questions formulated by presenters at the 2017 congress of the International Society for Cultural-historical Activity Research (ISCAR) participating in an activity entitled Open discussions of shared problems. Results point to the problems that generated most interest (e.g., participation) and a majority of problems of a practical nature (intervention and research). We propose reflection on implications as regards to theory advances.

Background
The International Society for Cultural-historical Activity Research (ISCAR), a society that holds its congress every three years, met in Quebec City in late August 2017. The theme of the congress was Taking a 360° view of the landscape of cultural-historical activity research: The state of our scholarship in practice. The three main subthemes were: Foundations, Practices and INsights (meaning future intervention and research). In an attempt to provide opportunities for participation similar to those many ISCAR members promote when moving away from “assembly-line instruction”, the Local Program Committee (LPC) introduced into the program the activity Open discussions of shared problems (OD-SPs). At first, the online platform prompted authors submitting an abstract to also send one or more question(s) they would like to discuss. Next, we analyzed the questions in an attempt to find similarities: three themes and 14 subthemes emerged. Participation stood out, and the LPC took it as validating its own emphasis on participation and dialogue in the congress’ program. Over 200 delegates who clearly manifested interest in OD-SPs, and all others, were invited to join one or another of the 25-30 groups that were to focus their discussions on a question or a cluster of questions. The discussions spread over three days, and each session lasted 50 minutes. No other congress activity was scheduled at the same time.

Conceptual framework
Participation being our organizing concept for the congress, it was natural to adapt it to the process for the OD-SP activity put forward in the ISCAR 2017 Congress. We found Rogoff’s perspective on participation and activity to be particularly suited, and we invited her to present an organizing framework. The framework built on Rogoff’s (1997, p. 266) concept of activity and the suggestion that levels of analysis ought to be integrated. Rogoff (1995) stressed that one “may consider a single person thinking or the functioning of a whole community in the foreground without assuming that they are actually separate elements”.

It also built on Rogoff’s (1995) definition of learning as transformation of participation, and her three lenses for participation analysis:

1. Participatory appropriation, which refers to the process by which individuals transform their understanding of and responsibility for activities through their own participation.
2. Guided participation, which refers to the processes and systems of involvement between people as they communicate and coordinate efforts while participating in culturally valued activity.
3. Apprenticeship, a term that applies not only to individuals but also to a small group in a community with specialization of roles oriented toward the accomplishment of goals that relate the group to others outside of the group.

The family of sociocultural theories, of which Rogoff is a prominent figure, does not distinguish boundaries between theory, methods and practice (Rogoff, 1997, p. 265). This paper reports on contents and process of the OD-SP activity at the ISCAR 2017 Congress. Its three objectives are as follows:

1. To document the participation process in OD-SP groups.
2. To identify the preoccupations of ISCAR 2017 participants.
3. To formulate promising ideas at the theoretical and methodological levels.
Methodology

The method of participation in the OD-SP was knowledge building, as defined by Scardamalia and Bereiter (2014) as “the production and continual improvement of ideas of value to a community” (p. 1370). Each group was to focus on a question/cluster of questions/problem, and six knowledge-building scaffolds were suggested: My theory, New information, A better theory, I need to understand, This theory cannot explain, and Putting our knowledge together. A collaborative online platform, Knowledge Forum, was made available for extended social interaction among participants within and between groups.

Participants

104 authors who submitted abstracts/proposals also submitted at least one question, writing a few lines to a few paragraphs. Most of them already had a doctorate. Doctoral students and others also submitted questions. Over half of all registered participants (512) engaged in at least one OD-SP.

Preliminary Analysis

The analysis of the questions was conducted by the authors of this paper. Qualitative analysis procedures were applied for clustering them, and several iterations conducted for themes and subthemes to be identified (Charmaz, 2005). Some of the questions were reformulated by the research team to reflect a broader level of preoccupations or for clarity purposes. Ahead of the congress, the formulation of problems adopted a distance-relation process with participants’ original submissions.

Onsite/online discussions/data collection

Barbara Rogoff kicked off the OD-SP activity. The subthemes resulting from the preliminary analysis were submitted to ISCAR 2017 delegates. A facilitator was attached to each group. Marlene Scardamalia joined in for the de-briefing session that took place toward the end of the congress. The artefacts resulting from the discussions at the congress provided further data (notes of cardboards or online, pictures) for 1) documentation of the participation process in OD-SP groups; 2) identification of the preoccupations of ISCAR 2017 participants; and 3) formulation of promising ideas at the theoretical and methodological levels. Some groups are continuing online their discussions.

Results

Table 1 presents the results. Themes and questions are supportive evidence of the preoccupations of participants:

Table 1: Themes and questions

<table>
<thead>
<tr>
<th>Foundational concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ZPD, learning and development</strong></td>
</tr>
<tr>
<td><strong>Agency</strong></td>
</tr>
<tr>
<td><strong>Perezhivanie</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td><strong>Davydov's genetic model of a learning activity</strong></td>
</tr>
<tr>
<td><strong>The abstract and the concrete</strong></td>
</tr>
<tr>
<td><strong>Participation in Communities</strong></td>
</tr>
<tr>
<td><strong>Learning through participation in school</strong></td>
</tr>
<tr>
<td><strong>Participation in online spaces of learning</strong></td>
</tr>
<tr>
<td><strong>Participation in the face of “superdiversity”</strong></td>
</tr>
</tbody>
</table>
**Socio-political and economic exclusions as impediments to participation**

What would a cultural activist practical stance look like that can work to alter (overcome)... the reproduction of inequities and injustice?

**Discussion**

The rich data base developed through this inquiry is an invitation for reflection, and we believe it will be useful to the learning sciences community to orient possible pathways for our future. The overarching themes of agency, moving from the abstract to the concrete, and the meaning of the ZPD (Foundational concepts and Methods) emerge from the first and third congress’ subthemes: Foundations and INSights. Participation in communities gives a clear direction to the second subtheme of the congress, Practices. Though the congress devoted a full day to Foundations and INSights (theory and method), questions discussed revealed intervention-oriented rather than research-oriented preoccupations or ideas. We found almost no discussion regarding online collaborative platforms’ affordances for reification and discourse analysis. This suggests that CSCL research results do not impact as much as they could the research and intervention practices of the ISCAR community.

**References**


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Teachers Collaboratively Creating Micro-Credentials for Professional Development

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Abstract: Micro-credentials are an effective means of providing teacher choice and evidence of achievement in professional development. Engaging teachers in a co-design process to create micro-credentials for professional development activities provides quality requirements and options that are valuable for improving teacher’s knowledge and skills, and impacting classroom practice, providing an opportunity to bridge the gap between research and practice. Through a research practice partnership between a suburban school district and a local university and using design-based implementation research, a co-design process for developing multiple micro-credentials was successfully implemented. Teachers with little to no previous experience with micro-credentials are capable of designing rigorous and relevant required tasks for professional development that targets improvements to classroom practices for improvements to student achievement.

Introduction
Micro-credentials, also called digital badges, are a mini form of a full, traditional credential and are valued by school administrators for professional development because of their ability to provide evidence of specific knowledge and skills gained during professional development (Keane, Otter, Oxley, & Lipscomb, 2016). Teachers appreciate relevant professional development choices provided by well-constructed micro-credentials (Gamrat & Zimmerman, 2015) and value professional development options that “respond to personal and professional schedules” (Gamrat, Zimmerman, Dudek, & Peck, 2014, p. 1146). Metadata from digital micro-credentials presents valuable research opportunities on teacher learning and development (Hickey, Ottow, Itow, Schenke, & Chow, 2014).

However, a major challenge in the development of a micro-credential program for professional development rests in aligning the micro-credential system to the organization culture and faculty interests (Goodrum, Abaci, & Morrone, 2016). Research shows that for professional development to be effective, meaningful, and lasting, it should contain relevant and current content, be ongoing, be collaborative, provide opportunity for practice, be connected to local context, and enact the pedagogy promoted by the professional development (Kennedy, 2016; Desimone, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). A co-design approach to creating transformative teacher professional development (Kyza & Nicolaïdou, 2016; Palinscar & Heerenkohl, 2002) shows promise for enhancing the benefits of micro-credentials and overcoming the challenges.

A district in the western United States partnered with researchers from a nearby private university to facilitate teacher co-design of micro-credentials for professional development. The university and school district have participated together in a public-school partnership for over thirty years and have recently formalized a research-practice partnership for this project (Penuel & Gallagher, 2017). This young research-practice partnership includes the school district professional development director, teachers, and coaches with a university education professor and graduate students. Together they identified a district need that aligned with researcher interests and committed to a long-term partnership to continuously improve knowledge and practice. The district student population of approximately 16,000 is 66% white, 24% Hispanic/Latino, 3% Pacific Islander, 3% multiple races, 2% Asian, 1% African American, and 1% American Indian, 46% low socio-economic status, and 10% limited English proficient. Almost one third of the 676 teachers in the district are in their first three years of teaching.

Background
The district professional development coordinator identified high impact pedagogical strategies shown to improve student learning around which to build professional development micro-credentials. The first micro-credential, titled Teacher Clarity, was created by the district professional development coordinator, in consultation with the district content specialists team, on the pedagogical strategy of consistently communicating learning targets and success criteria with students (Moss & Brookhart, 2012).
The micro-credential structure and requirements were based on research by Joyce and Showers (2002) and Knight (2014), indicating that collaboration and coaching are needed to improve teacher implementation of professional development strategies in the classroom. The requirements include reading articles and watching videos explaining the theory and research basis behind the use of the strategy, watching demonstration videos and attending a training about the topic, practicing several times using the strategy in the classroom, writing a lesson plan emphasizing the use of the strategy, videotaping and analyzing the videos of class sessions where the strategy was presented to students, collaborating with other teachers to discuss successes and struggles with implementing the strategy, and submitting evidences of improved classroom practice and its effect on student achievement.

A pilot group of 16 teachers worked through the micro-credential requirements during the last four months of the school year and then completed a survey about the experience. The professional development coordinator and content coaches revised the Teacher Clarity micro-credential based on the survey results and comments from participants in the pilot, and created a template for use in creating future micro-credentials.

Method
To examine the impact of co-design on teacher professional development using micro-credentials we adopted a design-based implementation research (Penuel, Fishman, Cheng, & Sabelli, 2011) methodology, where design, implementation, and research take place in cycles and inform one another. Researchers from the university worked with the district professional development coordinator, teachers, and content specialists to co-design more micro-credentials.

The summer after the Teacher Clarity micro-credential was introduced, small groups of teachers and content specialist participated in one of several three-hour introductory workshops which introduced micro-credentials and the co-design process, defined the product to be created, and built team cohesiveness. A survey was completed by participants at the beginning of the workshop which included questions about experience with micro-credentials and design-based implementation research, as well as asking about the importance of choice in professional development. Following the workshop, co-design teams met at their convenience over the summer, divided the workload, and worked together to design a new micro-credential following the template. Support was available to teams by request, and some teams invited a researcher to participate in team meetings, while others submitted digital documents to other teams, researchers, and the district professional development coordinator for review. Completed micro-credential documents were submitted for review and subsequent revisions were made based on feedback received.

By the end of the summer, five micro-credentials were accepted as complete by the district professional development coordinator. Two micro-credentials, Questioning and Classroom Discussion, and Proactive Classroom Management, were chosen to pilot as an option for district educators for professional development. For the pilot, courses taught by members of the co-design team were offered to assist teachers in completing the micro-credential requirements. These courses were held during scheduled professional development days and involved 30-70 teachers in each course. Two specific-use micro-credentials, New Teacher and Special Education, were approved for limited use and the Elementary Science, Technology, Engineering, and Mathematics (STEM) micro-credential was deemed complete, but not selected for the pilot.

Results
The introductory workshops involved 32 teachers and district content specialists, creating 10 co-design teams based on the results of an interest survey completed by the workshop participants. This paper presents results from a survey on teachers’ perceptions about professional development, micro-credentials, and the co-design process, as well as data gathered during the co-design process for the Questioning and Classroom Discussion micro-credential.

Survey results suggest that all participants believed choice in professional development was important or extremely important, with an average score of 9.0 on a scale of 1 (not at all) to 10 (extremely important). Most were comfortable working with peers on assessment design (7.8 of 10, where 10 means extremely comfortable), while experience using micro-credentials in teaching (2.4 of 10, where 1 is none and 10 is I’m an expert!), creating micro-credentials (2.1 of 10), and earning micro-credentials (2.5 of 10) were all very low.

During the second introductory summer workshop, four participants had expressed interest in designing the Questioning and Classroom Discussion micro-credential and became a co-design team. The team members created a collaborative online folder and began work filling out the template. The team decided on meeting dates and invited the researcher to collaborate with them. At the fourth introductory workshop, two more participants chose to help design the Questioning and Classroom Discussion micro-credential. They were introduced to the original team by the researcher, at which time researchers were informed that two of the
original team members were no longer able to participate in the summer co-design work. Team members 1 and 2 were part of the original team while members 3 and 4 joined the team after a later workshop, but before the first team meeting. Member 1 is a district content specialist, member 2 is a middle school teacher, member 3 is an elementary teacher, and member 4 is a high school teacher.

At the first team meeting after the workshop, the team collaborated on necessary steps to complete the micro-credential design, divided the tasks, and continued populating the template. The researcher provided guidance and clarified expectations. During the remainder of the summer, the team met online one more time, and collaborated by email and in the collaborative online folder. In that time, 29 revisions were made to the template on 16 separate days and 59 edits or additions were made to supporting documents. Team member contributions to the design process are shown in Figure 1.

![Team Member Contributions](image)

**Figure 1. Co-design team member contributions.**

While the team members did not participate equally in ways that were easily measurable, the group worked well together, communicated with each other and the researcher, and completed the design to the given specifications. The completed and approved micro-credential includes a theory section containing links to 12 quality articles (participants choose 1 from each of 3 sections and select quotes from the reading to answer questions) and requirements to attend a training, putting into practice one strategy learned then reflecting on the results, and to present the concept formally to another teacher. The demonstration portion of the micro-credential includes a video reflection form and links to 10 videos, from which participants are to watch two from each of two sections, and complete and submit the reflection form, and a live observation form to be used during each of three classroom observations. The practice section includes a document to plan for questioning and discussion, a requirement for participants to film 20 minutes of three of their own lessons and reflect on the use of questioning strategies, and an assessment of the impact of questioning strategies on students through the use of exit slips. The collaboration and peer coaching section requires the use of questioning and classroom discussion strategies in at least 3 lessons followed by completion of a reflection form, and inviting three teachers to observe in the participant’s classroom and fill out the form provided. On completion of the requirements, participants are to meet with a badge facilitator to review learning and determine if the micro-credential has been earned. For clarity, a completion checklist outlines the requirements to earn the micro-credential.

When the pilot for the Questioning and Classroom Discussion micro-credential is complete, participants will complete a survey. Survey data and co-design team feedback will be used to revise and strengthen the micro-credential completion requirements prior to future use.

**Conclusions**

Through this research-practice partnership, a co-design process for developing multiple micro-credentials was successfully implemented. Teachers with very little experience creating, using, or earning micro-credentials are capable of creating quality requirements for earning professional development micro-credentials in a co-design
process. Teachers were empowered by the process of co-design for their own learning, but also for the future learning of peer teachers as some teachers assumed the responsibility to participate in piloting the micro-credentials as professional development activities. Micro-credentials provided an opportunity to differentiate professional development as well as provide a vehicle for tracking implementation in the classroom and the content learned in a professional development program. They are a way to record progress and learning on a small scale and are used to document learning of specific skills, knowledge and abilities. Additionally, micro-credentials provided transparency into teachers’ professional development activities and supported the classroom implementation practices. Providing background theory and understanding of micro-credentials, an example micro-credential, a template, and assistance as needed allows teams of teachers to effectively design rigorous and relevant badges informed by Learning Sciences methodologies.

The school district administration will have access to the micro-credential metadata to better understand teacher professional development. District teachers have more options of micro-credentials to choose from for personal professional development, which can be earned at times that are convenient for them and in teams that can support their learning. Researchers will have access to the metadata for future studies. The research practice partnership between the district and the university has provided multiple benefits for all involved.

References


Infrastructuring for Participatory Design of School Technology Practices: How Students Refined Design Practices

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Abstract: This paper analyzes the ways in which student partners in a school-based participatory design project (Le Dantec & DiSalvo, 2013) constructed and refined the design practices. Two researchers collaborated with a group of high school students with a shared goal of designing school technology practices that were meaningful to the students. Informed by theories of infrastructuring in participatory design (Le Dantec & DiSalvo, 2013), the collaboration explicitly sought to re-mediate the social relations in the design of school technology practices. Four themes emerged in relation to the ways students sought to construct and refine the design space: Relevance to Student Interests; Opportunities for Responsibility and Growth; Expansion and Refinement of Activity; and Ensuring Use. Implications of the findings are discussed.

Purpose of the study
This paper analyzes the ways in which student partners in a school-based participatory design project (Le Dantec & DiSalvo, 2013) constructed and refined design practices. Informed by participatory design literature that argues for the need for infrastructuring, the continuous refinement of the collaborative activity among stakeholders of participatory design partnerships (Le Dantec & DiSalvo, 2013), the author partnered with a small group of students and teachers through two academic years between 2014-2016 to design technology practices that were responsive to the needs of local school stakeholders. In the context of this partnership, participants were both explicitly and implicitly encouraged to refine the practices of the partnership. The paper offers a thematic analysis of the ways in which the student participants recommended shifts to the design activity over time in order to better understand student perspectives on how participation in collaborative research and design endeavors may be better supported.

Challenges in school technology integration
The drive to introduce up-to-date technology resources in K-12 settings has been met with considerable obstacles, exemplified, for example, by Los Angeles Unified School District’s (LAUSD) well-publicized challenges in rolling out its 1-to-1 iPad program. An evaluation of the iPad rollout by Margolin and his colleagues (2014) found that most schools that received the hardware along with instructional software did not have the adequate infrastructure, organization, and training to shift teaching practices through the newly acquired tools. This was particularly unfortunate, considering the many affordances of educational technologies such as the iPads and related software, which allow students and teachers to interact across physical learning ecologies, pursue self-driven learning, and experience learning in multimodal texts (e.g. Peppler & Kafai, 2007; Barron, Gomez, Pinkard & Martin, 2014). More concerning is the fact that in spite of evident systemic constraints to shifting school technology practices, the discourse surrounding these challenges often placed the blame on LAUSD students, majority of whom come from traditionally marginalized backgrounds, as deviant “hackers” that were unprepared to utilize these tools (LA Times, 2015).

The episode highlights two concerns pertaining to integrating technology in schools. First, the episode echoes arguments made by a number of researchers that the way technologies are introduced to schools must pay attention to the sociocultural contexts in which they are being introduced to, and conceptualize practices that respond to unique needs across those contexts (e.g. Barron et al., 2014). This necessitates processes of technology integration in schools that can make aspects of the local context visible. Second, related to the first point, but needing particular emphasis, is that like most schooling practices, school technology use is valued, and mediated by broader social power structures (Selwyn, 2016; Delpit, 2006). The fact that LAUSD students were thought of as “deviant”, echoing broader deficit views of this very student body, suggests that technology use at schools have the potential to reproduce problematic social discourses and power relations. Therefore, as researchers such as Selwyn (2016) argue, echoing earlier researchers across educational contexts (e.g. Delpit, 2006), who is represented, and how they are represented in the process of technology integration design are greatly consequential for educational equity. How students, especially those from nondominant communities, are represented in this process holds particular weight because of their traditional non-representation in educational design processes (Delpit, 2006).
Participatory design and infrastructuring for student participation

Infrastructuring in participatory design (Le Dantec & DiSalvo, 2013), the iterative refinement of the social activity to support democratic stakeholder participation in the design process, provides a useful methodological framework towards addressing the issues identified above. In particular, developing knowledge around how student participation in the design of school technology practices can be facilitated, and how that in turn mediates various outcomes relating to use and social structures in schools, can guide how school technology integration processes can be made more equitable for students. Participatory design as an approach to educational design focuses on the redesign of social relations between stakeholders to develop more equitable educational practices. While a number of researchers have partnered with students and children in educational technology design, such as Schwartz’s (2015) study of how the Funds of Knowledge of immigrant Latino/a students informed the design of a technology-mediated literacy curriculum (Schwartz, 2015), using infrastructuring as a design framework offers a unique perspective on how these partnerships may be built and modified while simultaneously facilitating the development of concrete design outcomes that are situated in the context of use.

With the need to better understand how student participation in school technology design might mediate shifts in a school’s design and technology practices, this paper asks the research question: In what ways did student participants in a school-based participatory design project (Le Dantec & DiSalvo, 2013) seeking to develop localized technology-mediated learning practices change the design infrastructure? By examining this research question, the paper hopes to provide insights into the characteristics to the design activity that are sought by students, and help encourage students to engage in the design of school technology practices.

Methods

Study background

The site, a public university-partnership school in a large urban school district in California with 80% Latino and 14% Asian students, and 55% of students classified as “Limited English Proficient”, reflected broader challenges of technology integration across urban schools. It had recently acquired a learning software named Schoology, an online Learning Management System (LMS) as well as hardware such as Chromebooks and Apple computers, gradually transitioning to a 1-to-1 laptop to student ratio. Such investments were met with inconsistent practices and uncreative use due to the lack of training, buy-in, and coordination across the school stakeholders. Students had indicated that these new tools were mostly used for submitting assignments, receiving grades, and taking quizzes.

Responding to the school site’s needs, the author of this manuscript partnered with a small group of high-school students and teachers to carry out a participatory design research project (Bang & Vossoughi, 2016) to design school technology practices. Participatory design as a research method was chosen due to the assumption that a method aimed at collaboratively re-mediate educational practices by addressing the sociocultural aspects of a problem space, including the political and institutional dimensions of the design work (Bang & Vossoughi, 2016) would allow for theoretical insights into how school technology practices responsive to local context. During the 2014-2015 school year, an advisory class of 15 high-school students and their advisory teacher, along with the author formed the initial design group. In its second year (2015-2016), responding to feedback from the initial group of students, the collaboration moved to an after school space with an added emphasis on students to engage with their own personal interests. The students gradually transitioned to a new group of 12 students who continued the collaborative design work. Meetings generally consisted of checking in with students to generate feedback on the structure of collaboration, design goals, and design outcomes, as well as work-shopping prototypes of student designs including an ePortfolio system to facilitate more holistic evaluation of students, an archive of “college-going interviews” of seniors to make college-going knowledge more visible, and a video gaming tournament centered on the development of safe spaces for students. Most importantly, all aspects of participation by students were voluntary.

Data collection and analysis: Design infrastructure as an activity system

This analysis examined field notes and design artifacts form design meetings, as well as participant interview responses from the two-year study. Data points where students either made recommendations to shift the infrastructure of design, or took actions that concretely shifted the infrastructure of design were isolated, and descriptive coding was utilized to summarize the nature of the recommended or acted upon shift. These descriptions were then grouped into larger themes that generalized the refinements students made regarding the design practices of the partnership. To identify instances of students making recommendations to, or actively
shifting the design practices of the partnership, the collaborative endeavor was viewed during analysis as its own unique activity system that had its own set of design goals, tools and symbols, participant roles, community, and expectations (Engeström & Sannino, 2010). Instances of students refining this activity system was identified when students referred to any these aspects of the design activity system and recommended changes or directly acted to change an aspect of the activity system. Both explicit recommendations and direct action were captured for this analysis because the analysis is primarily interested in the design infrastructures students wanted to see.

Findings
The findings from the study will be presented in two parts. First, a representative vignette that encompasses the themes that were identified across the general data set will be shared. After the vignette is shared, the five themes that were identified, Relevance to Student Interests, Opportunities for Responsibility and Growth, Expansion of Activity, Refining Infrastructure, and Ensuring Use will be described using the vignette.

Vignette: Transitioning to an after school program
At the beginning of the second year of the participatory design work (2015), four students from the original design group met with the first author to discuss potential improvements in the way students engaged with the partnership. The first year had concluded with a professional development (PD) session organized by the students with administrators, teachers, and university researchers as an audience. This reflected an earlier session where students articulated a desire to share their designs with teachers because they “needed to learn how to use some of these tools” and they “were able to decide what happened in classrooms”. The design goal of the first year was to develop practices that were meaningful to students using Schoology, a learning management system (LMS) that the school had recently purchased, but in the view of teachers and students still in its infancy of use at the school. Consequently, at the PD session, students presented their designs which all utilized the new LMS, such as an ePortfolio system to facilitate more holistic evaluation of students, an archive of “college-going interviews” of seniors to make college-going knowledge more visible, and an introduction to the “calendar” feature on the LMS. However, about five students had lost interest in the design work through the first year, and did not present at the PD session.

At the onset of the second year of the partnership, five students from the original group who had volunteered to offer feedback on the first year’s collaboration met with the author with the goal of articulating ways to improve the design methods. Asked why some students seemed to become disengaged from the previous year’s work, the students unanimously agreed that the design goal, to develop “school practices” was too limiting, and that students needed to do work that they felt “passionate” about. As a result, the group decided to ask future participants to initiate their involvement by engaging with an issue or activity they felt passionate about, and use digital tools to more deeply engage with their passions with an eye towards using the outcomes of this work to inform teachers of technology practices that are meaningful to students. With engaging in “passion-driven work” through digital technology as a central thrust of the design group, the collaboration moved to an after school space with a mostly new group of twelve students who each initiated various technology-mediated, passion-driven projects, such as creating an e-sports (gaming) community, continuing the development of an ePortfolio system, and building a financial literacy website.

Themes from student recommendations to refine design infrastructure

Relevance to student interests
The student recommendation to foreground student “passions” in the design process described in the vignette is representative of how students consistently sought to center their interests as they designed school technology practices. Many of the student recommendations referred to the need to make the design process enjoyable and engaging by ensuring opportunities for students to connect the design work with interests developed in and out of school, such as fictional writing, gaming, photography, and financial literacy.

Opportunities for responsibility and growth
Students in this vignette are beginning to view themselves as authority figures within the design partnership. For example, the students who gathered to reflect on the previous year’s partnership took on an additional responsibility to improve the quality of the partnership, while earlier in the year, students constructed an opportunity to position themselves as experts in relation to teachers by organizing a professional development session. Once again, students frequently sought, or created opportunities for themselves to develop skills necessary to, and take on greater responsibilities in the design process.
Expansion and refinement of design activity

Another observation made throughout the design partnership, and observed in the vignette is that students played an active role in constructing the ways in which infrastructuring occurred. In other words, students sought to develop ways in which they can participate in the refinement of the design process. While this is an a priori aspect of participatory design processes like this, it is noteworthy that students actively sought out, and created opportunities to participate in this process.

Ensuring use

Finally, students sought to participate in design processes that would ensure the use of their designs in school. For example, the professional development session that the students planned at the end of the first year was partly due to the recognition that teachers hold significant authority within the school to utilize the designs that were developed by students. Students modified the design process through a rationale of ensuring use of the designs.

Conclusions and implications: Promises and complications of infrastructuring

The findings in this paper suggest that student participation in this design partnership echoed existing research on participatory design, learning, and human-computer interaction. Existing research has found that students seek out learning opportunities that speak to their interest across ecologies (Barron, 2006), that students engaging in participatory inquiry and design seek out learning and greater responsibility in the context of the work (Kirshner, 2007), and that participatory design work often leads to designs that are rooted in the local context (Bang & Vossoughi, 2016), as well as providing opportunities for activity systems to expand beyond their original boundaries (Engeström & Sannino, 2010). What is noteworthy about this study is that students seem to have endorsed the value of these concepts in the context of participatory design. Therefore, in future participatory design endeavors with students, some of the themes identified in the findings can support the development of frameworks to support the formation of student participatory design spaces.

The findings also serve to complicate the notion of “equity” and “democracy” in design processes. As is evident in some of the findings, and particularly in the vignette, the themes identified in this analysis interacted in complex ways that prevents any observer from making definitive judgments on the quality of participation and equity in the design process. There were times, as seen in the vignette for example, when students would sacrifice a level of agency over their designs with the desire to make the designs accessible to a greater number of students. On the other hand, some of the modifications to the design practices that were recommended by students and subsequently taken up, such as facilitating the design activities to include work related to their personal interests, suggests that involving students in the construction of collaborative practices positions them in a position of relative authority. These complications suggest the value of continuously reflecting on and refining the characteristics of participatory design processes as they unfold.

References


Selwyn, N. (2016). Minding our language: why education and technology is full of bullshit… and what might be done about it.

Design Math: Middle-School Youth Making Math by Building Yurts

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Abstract: While Project-Based Learning (PBL) has been shown to be an effective approach to learning, teaching math through PBL has long been challenging for practitioners. To explore new ways to engage youth and complement math learning in the classroom, researchers and middle school teachers collaborated to implement a year-long PBL course, “Design Math.” This course supported math learning through design and textile-based crafting projects by leveraging embodiment and tangible manipulatives. Students built life-size and scale-model yurts (i.e., tents) while adhering to a set of design constraints. Preliminary findings suggest that project-based approaches in math learning have the potential to promote and sustain student engagement, broaden participation in mathematical thinking, and afford deeper conceptual understanding of the mathematical concepts of measurement and geometry.

Keywords: Project-based math learning, geometry, middle-school math, Constructionism

Introduction
In 2016, the U.S. Bureau of Labor Statistics projected that the strongest job growth in the next decade will be in the areas of “operations research analysts, statisticians, actuaries, and other mathematics-oriented jobs,” which are projected to grow by 28% (compared with just 12.5% for computer and information technology) (DeSilver, 2016). Giving the growing employment trends for math-oriented jobs, it is startling to see that only 33% of eighth-grade students are at or above their math proficient level (U.S. Department of Education, 2015). That is, while math is increasingly important for job-seekers in the United States, those who are educated in the U.S. are less qualified to fill these positions. But more than exclusively making a “market economy” argument of supply versus demand, the poor math performance trend of these students is an indicator of insufficient preparation in prior grades and for future academic years, especially if they will be pursuing STEM careers.

For more than two decades, Project-Based Learning (PBL; Blumenfeld et al., 1991; Krajcik & Shin, 2014) has been an effective pedagogical approach to developing problem solving skills, deeper conceptual understanding, and increasing engagement. However, studies of project-based math initiatives are outnumbered by studies of project-based learning in science and social studies (Condliffe et al., 2017). In order to contribute to the understanding of the effectiveness of project-based learning for math content and practices, we partnered with a public charter school. This unique setting has integrated PBL across its entire educational ecosystem (i.e., teachers, students, curriculum, culture) for over eight years, but not as consistently every year for mathematics. To address this need, we developed a Research-Practice Partnership with teachers and administrators for grades 7-8 for the co-creation and implementation of a new PBL math curriculum, Design Math (DM).

DM is a set of collaborative PBL activities for the learning of middle-school geometry through designing, modeling, and sewing in two projects: a scale model and a full-size fabric yurt (i.e., tent). DM is designed to address a number of Indiana State’s middle-school geometry math standards, including (1) 2D-3D nets, (2) protractor use, (3) area and volume calculation, (4) angle types (e.g., acute, obtuse), (5) congruence, and (6) transformations. In our research, we sought to discover whether students in grades 7-8 demonstrate mathematical proficiency as defined by the National Research Council (NRC) through their involvement in DM, as well as to uncover the extent to which this project-based math learning initiative affords conceptual understanding of geometry and measurement, increases and sustain student engagement, and promotes problem solving skills.

Background
Since the 1990s, major reforms in mathematics education have resulted in periodic Math Standards (e.g., National Council of Teachers of Mathematics, 2000) which guide all state educational systems with one common understanding of mathematical proficiency. The National Research Council (2002, 2005) defined mathematical
proficiency as five interdependent strands: conceptual understanding, procedural fluency (computing), strategic competence (applying), adaptive reasoning, and productive disposition (engaging).

When math is believed to be just rules and procedures, one is putting a lot of emphasis on the computing strand that produces a weak level of math proficiency. But if pedagogical approaches include all strands, then they will produce strong sense making necessary for successful problem solving (NRC, 2005). Research shows that PBL usually involves real-world contexts, supporting and promoting deeper understanding, and sustained engagement (Epstein et al., 2010). PBL is also collaborative and cognitively engaging, with multiple sources of support as students apply their knowledge and understanding of concepts (Blumenfeld et al., 1991). Thus, we believe that PBL aligns with the goals of mathematical proficiency.

However, project-based math can be challenging. Working outside of “traditional” textbooks and curriculum can be seen as risky for teachers given the high-stakes nature of math performance in today’s public school context. Thus, teachers are rightly concerned about students performing adequately on both state and district standardized tests (Huberman et al., 2014). Other challenges are that PBL takes more time to prepare and implement than more traditional approaches; it needs careful preparation to provide scaffolds and to be able to implement during limited class periods. PBL activities also introduce classroom management skills different from those of the traditional classroom, such as providing constant feedback, giving more time for reflection, and facilitating small-group collaboration, among others (Darling-Hammond et al., 2008).

Though PBL has not traditionally focused on including the creation of tangible manipulatives in the projects, the production of personally meaningful artifacts (i.e., “objects-to-think-with”) can support the learning of underlying concepts that are inherent in the materials used during construction (Papert, 1980). According to constructionist theory, learning happens best when learners build knowledge structures in context through designing publicly shareable artifacts and also ongoing reflection (Papert & Harel, 1991). We take this as the theoretical basis for the hands-on, tangible design of DM.

Methods

Design Math took place in a public not-for-profit charter school with about 270 students; about 36% were eligible for free or reduced lunch. DM took place 1-2 times per week in one-hour sessions for one school year. The participants were 72 students (25 girls and 47 boys), mostly from grades 7 and 8, and a few math-advanced students from grades 5 and 6. The three teachers in this classroom were the primary drivers of the curriculum development, receiving occasional suggestions from researchers.

Though we administered a variety of assessments throughout the year, including a final survey to learn about student perceptions of the benefits of DM and final semi-structured interviews with focal students, in this short paper we focus on the video recordings of the construction of the life-size yurt. In the first half of the school year, the project was to create a full-size yurt large enough to fit eight students and be able to withstand outdoor conditions of a cold fall night (see Figure 1). They were provided with a prompt (i.e., build a 5-side yurt using wood, canvas, and other provided materials and tools) and worked in groups to accomplish the goal.

Figure 1. “Yurt Day” at the farm. Middle school students building their yurts from their blueprints.

After two 1-hour planning sessions in the classroom, the class took a one-night camping trip to a farm where the life-size yurts were put to the test in a real-world context. The time to complete their project was unconstrained, except they had to have a final structure to spend the night in. We video recorded the building process of three groups, for eight hours each. In the second half of the school year for the second project, students were instructed to build a scaled-down model of a yurt of their choice with a short concept statement, scaled floor plan, orthographic drawings (top, front, back, and sides), 3D perspective images, and optional, scaled furniture.
Findings
The data we present here (see Table 1) comes from Sam (8th grade), Rob (6th), Todd (8th), Peter (7th), and Gabe (7th). This piece comes from a video recorded, semi-structured interview inside the yurt they built during the experience on the farm. This group talked about their understanding of specific geometric concepts when one of the authors asked them to imagine they were substitute math instructors of 6th grade students. Then he asked: “Do you think this [DM] project would teach them [6th graders] geometry? Yes or no? And how would it teach them better?... Is it helpful? Not helpful?”

Table 1: Excerpt of one interview transcription with one of the focal groups during the trip to the farm

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>Sam:</th>
<th>Rob:</th>
<th>Peter:</th>
<th>Todd:</th>
<th>Gabe:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I think it will definitely help them with geometry. Because, like, for each side we had to measure like the angles and get the right shapes and why not...like figuring out like building architecture...</td>
<td>Yeah I think 'cause the main thing I learned was the surface area. I've never heard that like um</td>
<td>Where's the surface area here (pointing inside the yurt)?</td>
<td>Anywhere. Anywhere there's stuff.</td>
<td>Outside. Everywhere.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interviewer:</td>
<td>Rob: (looking at Todd as if expecting an answer). It was like 140 square feet.</td>
<td>Peter:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gabe: It was 110 square feet. Well, it was supposed to be (boys chuckle).</td>
<td>Todd:</td>
</tr>
</tbody>
</table>
|             |                                                                     |                                           |                                                                     | Gabe:                                                                 | Todd: (we got it pretty exact...)
|             |                                                                     |                                           |                                                                     | Peter:                                                                                                               |
|             |                                                                     |                                           |                                                                     | Gabe: Um, yeah I also think this is like a really good thing, 'cause a lot of stuff I kind of already knew already...there's no reason for me to know it...it was just kind of another thing of math that I...learned from my teacher that I would never use but...you have to use stuff like...finding how to make a pentagon, like finding the angles, measuring all the stuff, like finding the hypotenuses, Pythagorean Theorem, all that stuff, we really have to actually use it, 'cause we have to sleep in these. Like we have to build this and then if we, like if we hadn't finished it we would still have to sleep here. So it really gives us like good incentive and, like, like, real world, I don't know, connections, to like all that math that you learn in school that you don't think you need. | Todd: I have to, like, add on to that, like I don't think I, I personally, I don't think I learned a new, entirely new like, a concept, but putting them into real life, other than, um, just knowing them it is an entirely different level of learning math. |

This exchange demonstrates examples of understanding, applying, reasoning, and engaging (i.e., math proficiency). Rob expresses understanding when he says, “the main thing I learned was the surface area.” Peter alludes to easier future recall due to deeper understanding when he says, “I think that [the challenge] it would just kind of burn it into your brain like...I'll remember this.” Gabe demonstrates application of the math when he says, “you have to use stuff like...finding how to make a pentagon, like finding the angles...” Peter shows reasoning when he says “it’s better to...look at it [hands-on project] from different perspectives.” Gabe also shows an example of application and engagement when he says, “[the project] really gives us like good incentive and, like, like, real world, I don't know, connections, to like all that math that you learn in school that you don't think you need.”

Discussion and implications
This short interview extract provides evidence of math proficiency we are uncovering through the analysis of our data corpus. DM, as a project-based math learning initiative afforded conceptual understanding of geometry, increased and sustained student engagement, and promoted problem solving skills. Anecdotal data from parents and graduation speeches from 8th grade students also shared how the “yurt project” (DM) was a favorite project.

Standardized tests may need to be adapted to place greater emphasis on other forms of math proficiency beyond conceptual understanding and procedural fluency (computing) (NRC, 2005; Darling-Hammond, et al., 2008). For instance, math education researchers Boaler and Staples (2008) found that “unfamiliar terms and
culturally biased contexts” of a state standardized test may have contributed to its “inability...to capture the mathematical understanding” of their research participants involved in a project-based math curriculum (625). When in fact, their participants successfully demonstrated mathematical understanding in different assessments administered by the researchers. If more schools continue to adopt PBL in math classrooms, high-stake State assessments may need to be optimized to adequately measure mathematical proficiency for all five interdependent strands (i.e., understanding, computing, applying, reasoning, and engaging).

In an upcoming paper, we expect to share our findings that could contribute to design principles of these types of PBL math initiatives for math proficiency, particularly with the infusion of hands-on projects involving textile-based materials to help students create their personal manipulatives (“objects-to-think-with”). We would also pinpoint design and implementation challenges of DM to identify areas of research to spread the benefits of PBL for math to help students be prepared in an increasingly technical and math-based world.

References
DeSilver, D. (2016) Jobs requiring preparation, social skills or both expected to grow most. Pew Research Center, October 13, 2016

Acknowledgements
This project was possible by the support of the National Science Foundation (NSF) under Re-Crafting Mathematics Education: Designing Tangible Manipulatives Rooted in Traditional Female Crafts (grant 1420303) awarded to Dr. Kylie Peppler. The views expressed herein are those of the authors and not of the NSF. We thank our students and their parents, Ms. Cathy, Ms. Sandy, Ms. Karla, Ms. Sara, Sophia, Naomi, Anna, Kate, Tony, Ed, Lori, and Janis.
Cultivating Formative Intervention Research Partnerships in Mathematics

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Abstract: This paper describes an approach to cultivating formative intervention research partnerships in mathematics with school districts in the U.S. state of Missouri by researching the diagnosis and specification of problems as framed and experienced by those grappling daily with challenges related to learning and teaching mathematics. Through a mixed methods approach, we engage various stakeholders in identifying and describing important problems of practice, work to specify the inherent contradictions that often exist in those challenges, and, by confronting those contradictions, initiate a process of innovation rooted in the contexts in which students, teachers, leaders, and parents learn and work.

Introduction
Changing the nature of mathematics teaching in the U.S. at any significant scale has proven to be extremely difficult (Hiebert, 2013). The predominant approach continues to be some variant of what Freire (1970/2000) criticized as the “banking” method, with teachers narrating largely procedurally-focused demonstrations and asking students to repeat it themselves. A common story in research in mathematics education has been the introduction of some conjectured driver of change (e.g., a professional development program, a new curriculum, different approaches to assessment, etc.), for which researchers work to find schools or districts willing to provide test-sites and subjects for their research, with the idea that an “effective” idea will eventually get “scaled up.” While innovations in education are certainly needed (and worthy of support) and while there are potential benefits for the students, teachers, parents, principals, and district leaders who act as research participants, the problems and designs for solutions are typically identified at the outset by researchers, rarely originating in the communities with whom those researchers briefly partner. Consequently, the innovations that are put in place are often not sustained after the research effort has concluded (Resnick & Hall, 1998), and typically fail to change the “instructional core” of what happens between teachers and students around disciplinary ideas (Elmore, 2004; Hiebert, 2013).

Innovation through partnership
To address this shortcoming, different models for collaborating and conducting research in/with entities such as school districts have emerged in recent years, often captured under the umbrella term “improvement science” (Lewis, 2015). There are variations across different models, but all share a commitment to taking up “problems of practice.” For example, one of the more prominent models in recent years—and one that has been well received in mathematics education—has been design-based implementation research (DBIR). As described by Penuel, Fishman, Cheng, and Sabelli (2011), DBIR focuses on persistent problems of practice from multiple stakeholders’ perspectives through iterative, collaborative design work. Consistent with the tradition of design research in education (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003), the aim of DBIR is to develop theory related to both classroom learning and implementation through systematic inquiry, but it is also concerned with developing capacity for sustaining change in systems. Thus, DBIR holds potential for research partnerships that lead to more authentic, lasting change.

Of course, improvement science approaches such as DBIR implicitly require something to be implemented, and often that design quickly becomes the predominant focus as collaborators pursue potential solutions. Less attention—particularly in scholarly writing about such partnerships—has been devoted to first understanding and defining the problem(s). As Lewis (2015) noted, “there is relatively little education research in the improvement science tradition, which emphasizes building organization members’ understanding of the problem and its causes” (p. 2015). One approach that holds promise for treating such problem specification as an object of interest (and not merely prerequisite work) is the cultural-historical activity theory tradition of formative intervention research. Drawing on Engeström (2011), Penuel (2014) suggested that the methodology includes three key commitments: (a) focusing on a problem of practice—a contradiction encountered by participants in their life or work activities (the “germ cell”); (b) stimulating participants to produce innovations—by first calling attention to a challenging situation or set of obstacles, and then triggering a process for overcoming those obstacles through design work; and (c) taking as the primary goal the expansion of
participants' agency—to "enable new forms of collective activity to emerge through direct engagement with the contradictions embedded in practice" (p. 100). These contradictions are, at first, abstract. Through attempts to understand and model their relationship, they are made concrete, through which "learners learn something that is not yet there" (Engeström & Sannino, 2010, p. 2).

As an example in mathematics education, for teachers who strive to provide students with culturally relevant and responsive opportunities to engage in meaningful mathematical practice and to become proficient in standard ideas and skills, a contradiction in practice (or "germ cell") might be the inherent challenge of affording learning opportunities that are emergent in order to achieve learning goals that are, to a large extent, prescribed (Munter, Stein, & Smith, 2015). Neither emergent nor prescribed learning goals and processes can be eliminated; the transcendence of the contradiction is fundamental to the work (and agency expansion) of teachers and students. But, as the first commitment of formative intervention research above suggests, such "germ cells" cannot be identified a priori, but only as the result of investigating a problem of practice. Instead of pursuing a predetermined agenda or implementing a particular program, "the researcher aims at provoking and sustaining an expansive transformation process led and owned by the practitioners" (Engeström, 2011, p. 606).

It is exactly there that our project is attempting to initiate partnerships with school districts—in the investigatory work of understanding problems that students, teachers, principals, parents, and leaders face, and identifying germ cells for expansion through partnership. We do so with the expectation that what we are embarking on will be a long, slow process (in fact, internally, we describe the project as a 20-year pursuit). Ultimately, our aim is to revolutionize the learning and teaching of mathematics in the state of Missouri. Our starting point, however, is to enlist practitioner partners in co-investigating their current problems of practice.

**Methods**

Our work is guided by the three commitments of formative intervention research listed above. Our first step—which is the focus of this paper—is to diagnose the problem(s) of practice that Missouri school districts are facing, and how various stakeholders frame those problems. To accomplish this, we employ a mixed methods approach—primarily through interviews, and supported by applicable quantitative analyses of district data.

**Setting and sample**

This ongoing study is taking place in K-12 school districts across the state of Missouri. To date, we are collaborating with 9 districts, ranging in size from large urban districts to very small rural districts. Our sample includes 37 (and counting) district leaders, principals, teachers, and parents/community stakeholders.

**Data sources and analysis**

Beginning with an initial, relevant contact in each district (e.g., curriculum director), we have conducted and audio-recorded semi-structured interviews, snowballing out to others from there (Talbert & McLaughlin, 1999), including district leaders, principals, teachers, and other partners (e.g., parents). In each case, we write a summary of the interview, share it with the participant and invite their feedback with respect to the summary’s accuracy. Additionally, we make use of publically available quantitative data for each participating district.

After interviewing all of the additional individuals suggested by interviewees and similarly summarizing those interviews, we analyze the summaries using qualitative analysis software to identify the (a) problems, (b) underlying causes of those problems, and (c) responses to those problems described across all interviews in the district. Our interest is in understanding how individuals frame the problems that they identify, for which two of the framing tasks described by Benford and Snow (2000) are applicable. The first, diagnostic framing, concerns the source and attribution (or underlying causes) of a problem. The second, prognostic framing, pertains to the proposed solutions for (or responses to) a problem. We also conduct quantitative analyses of publically available data for the district that are relevant to the problems described by interviewees.

We then write a synthesis report for participants to review and to initiate a follow-up discussion, in which we call attention to similarities and differences between participants with respect to not only what problems, causes, and responses were identified but also how those problems, etc. were framed—with the intention of sparking subsequent investigations of those problems and possible responses, which, in some cases, we might take up in continued partnership. We audio-record those follow-up discussions as well and then write a summary of the discussion, which we share with participants.

To further prepare for facilitating those follow-up discussions, we create two artifacts—one to share with participants and one for internal purposes. The first acts as an accompaniment to the narrative report. It is a single-page representation of the district’s problems, underlying causes, and responses, which we distribute at the meeting and use to structure the discussion (Figure 1 below). The second is our own agenda for the meeting, in which we list the participant reactions we anticipate and how we might respond. These are organized into 5
types, as we anticipate participants might: (a) think to express elaborations or new realizations after reading the report and seeing the diagram; (b) provide updates to the report since the interviews concluded; (c) invite our own ideas for solutions or professional development; (d) question the purpose or implications of the report (i.e., “so what?”); and/or (e) express disagreements (with us or among each other).

**Results**

Thus far, a number of patterns have emerged across multiple districts with respect to the problems that are identified and the variations in participants’ framing of those problems. Our focus here, however, is to describe the results of our efforts to date in terms of cultivating partnerships rooted in the co-investigation of current problems of practice. At this early stage, we consider it a success if the work described above sparks continued interest and conversation between our team and a school district. Below we describe initial success by this standard in District K, a public school district in an urban center.

Included below as Figure 1 is the representation we provided to district K leaders. As it indicates, the problems that emerged in interviews were related to student achievement outcomes, instructional quality, meeting students’ (not strictly academic) needs, and teacher recruitment and retention (with the second and fourth of those framed by some as an underlying cause of the first and third). Items drawn outside the ellipse represent elements of the broader contexts in which the district is situated. Overall, district leaders’ reactions to our summary report were positive with respect to its accuracy in capturing what they had expressed to us in interviews. This representation of “challenges and initiatives” was especially well received and acted as an important referent in our follow-up discussion in a variety of ways, including (district leaders’) updates and changes to district plans and (researchers’) questions about relations between components in the diagram, particularly between some that were not connected based on the interviews.

![Figure 1. District K challenges and initiatives.](image)

For example, a consistent emphasis in the new “strategic plan” that the district had recently released—which interviewees described as a key response to the challenge of meeting students emotional, relational, academic, and other needs—was the importance of cultural responsiveness. However, few details were included with respect to what that means in practice—particularly in any terms specific to mathematics learning and teaching. Using the diagram in Figure 1, we were able to raise questions about whether and how ideas in the strategic plan are (or should be) connected to other challenges (e.g., poor quality instruction) or initiatives (e.g., curriculum updates) that, up to that point, had not been explicitly connected. This led to a conversation about the possibility of considering all components of the strategic plan in terms of mathematics learning and teaching.

Allowing our (researchers’) questions to emerge from ideas and goals that had already been established as important in the district oriented us to identifying inherent contradictions that might be fruitful to address and around which we might build a partnership. For example, with respect to culturally responsive learning and
teaching, the district’s strategic plan stressed student-centeredness and tailoring to students’ needs and strengths. But it also committed to a “rigorous” curriculum based on “high standards” supported by “reliable assessments.” In response, we raised the question of whether those commitments might act as “competing forces” that are all likely necessary and helpful in their own way, but could potentially attract disproportionate attention, to the detriment of the overall plan. District leaders expressed interest in engaging with us in co-design efforts aimed at empowering students through mathematics by building from the district’s strategic plan and confronting the contradictions that we uncover through our partnership.

Discussion and conclusion

Our efforts our dual in nature. First, by investing in understanding the problems of practice that district leaders (perceive that they) face, including identifying the variation in how individuals within the same community might frame those problems, we hope to initiate partnerships at the ground level—a co-investigation and co-specification of problems before anything is “implemented.” Second, through such a process, we hope to find inherent tensions on which we can focus sustained attention as a means for inducing innovation. In this paper we have described an approach to investigating the problems that practitioners identify and how they frame those problems, and our process for planning for and facilitating follow-up discussions about what we find. In those presentations of our findings to potential partnering school districts, we have used representations like Figure 1 to invite participants’ reflection on whether tensions exist within their current challenges and initiatives (and broader contexts) that could be especially difficult to resolve, with the idea that continued co-examination of such contradictions could lead to the identification of “germ cells” that could manifest at multiple levels. As noted above, these are the very initial stages of what we hope will be prolonged partnerships. By starting a few “steps back” from where work typically has begun, we hope to make progress in confronting the stubborn challenge of changing mathematics teaching.

References


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Developing Theory-Practice Understanding Through Online Discourse Among Pre-Service Teachers

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Abstract: This study examined how pre-service teachers developed an integrated theory-practice understanding through online discourses in the context of a teacher education course. Twenty pre-service teachers from a university-based course “Educational Inquiry” that included a component of school experience participated in the study. It included students engaging in online discussion to help them reflect on their school experience and to collaborate with their peers in linking theory and practice. Through an analysis of their online discourses, we identified a range of reflective and collaborative strategies that the participants used to deepen their understanding and extend their learning space. We also examined the students’ discourse through the lens of theory-practice dialectics to show how pre-service teachers practicalize theories and theorize practical experience. We also discussed the implications of designing online discussion and the use of strategies to scaffold pre-service teacher learning in theory-practice integration.

Keywords: CSCL, online discussion, theory-practice dialectics, pre-service teacher education

Introduction
It is important to conceptualize, integrate, and examine the relationship between theory and practice in designing learning in teacher education (Korthagan & Kessels, 1999; Zeichner, 2010). Traditionally, the weak links between university courses and field experience may have discouraged a closer examination of this relationship. An important notion of merging theor and practice considers learning as developing reflective thinking and practice. From this perspective, pre-service teachers need to reflect on their own experience, and their observations in the field, in light of principles of why one does what (Loughran, 2002). Different approaches have been developed to make meaningful connections between university and classroom experience, and to engage pre-service teachers to examine their personal theories of teaching and learning (Orland-Barak & Yinnon, 2007). The relationship between theory and practice has also been examined in terms of practicalizing theoretical knowledge and theorizing practical experience (Cheng, Tang & Cheng, 2012; Tsui, 2009). This postulation focuses on the dialectics of adapting strategies to contexts in relation to theories, and the development of deeper meanings and personal theories based on practical experience.

Contemporary theories from the learning sciences highlight how learning emerges through social interaction (Sawyer, 2014). Groups of learners can come together to articulate, reflect, and grapple with ideas to develop new understanding. Research in the learning sciences and teacher learning has emphasized communities of practice (Fishman, Davis & Chan, 2014) for practice-based teaching and how technology-enhanced learning can support teacher education. Studies in knowledge building using Knowledge Forum have shown how collective online discourse can help pre-service teachers develop more sophisticated conceptions of teaching (Hong, 2011). There is now increased interest in online discussion in higher education and teacher education (Szabo & Schwartz, 2011). However, relatively little attention has been given to how it can support pre-service teachers making salient observations and reasoned interpretation of their observations by linking to the theory and principles of teaching and learning (van Es & Sherin, 2002). This reflection is central in teacher education (Orland-Barak, 2007) and can be enhanced by shifting from individual reflection to collective reflection. In this sense, online reflective discourse can help illuminate students’ learning experience, which is not easily captured when they work in different field settings. Accordingly, this study examined teacher learning in the context of a Postgraduate Diploma of Education (PGDE) program, which includes a School Experience component. Specifically, we explored how pre-service teachers engage in theory-practice connections and how online discussions could support their co-construction of ideas and enhance theory-practice understanding.

Results and analyses
Data were drawn from 20 pre-service teachers’ online writing and discussion in a required course “Educational Inquiry” with a component called School Experience conducted over the year. Students in Group A and B wrote
an average of 18.3 notes and 15.5 notes, and viewed the discussions 121.2 and 41.3 times respectively. Both groups went beyond the required number of notes in the assignments. The students’ writings were analyzed in terms of how they connected theory and practice as they worked collaboratively in making sense of their experience during their time at the schools.

Reflective and collaborative strategies for theory-practice connections
We identified different kinds of responses that illustrated how pre-service teachers reflected on their experience and connected theory with practice in university and school settings (Table 1).

Table 1: Reflective strategies linking theory and practice

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe observation with no reference to principles</td>
<td>The school set a strict rule about sleeping in class. When a teacher found that a student fell asleep, other students reminded the student… [WT]</td>
</tr>
<tr>
<td>Name teaching incidents in relation to principles</td>
<td>In my class, formative assessment was carried out in classroom exercises, such as ‘write your answers on the whiteboard and share with the class.’ [KA]</td>
</tr>
<tr>
<td>Interpret teaching incidents linking to principles</td>
<td>From observing Mr. C’s class, I noticed he asked very close-ended questions. In comparison, Ms. C asked open-ended questions. Mr. C’s students seemed less motivated and others more motivated. This seems to be same as.. readings [RH].</td>
</tr>
<tr>
<td>Consider principles in different contexts</td>
<td>I observed two classes and I saw the same teacher using intrinsic motivation strategies in different ways. The two classes had different reactions. [WT]</td>
</tr>
<tr>
<td>Note the gaps and tensions between expectation and reality</td>
<td>My mentor said that her class loved the traditional didactic way, rather than the constructivist approach. What should we do as student teachers… try out the constructivist approach or use the didactic approach to satisfy our students? [KW]</td>
</tr>
<tr>
<td>Connect and interpret observations with theoretical notions</td>
<td>One of the lessons that fascinates me is the school’s ‘Editorial Reading,’ which makes use of newspaper articles… Ss need to pose two questions on current news events to develop their analytic skills. I think these activities illustrate qualitative learning. They had to construct their own understanding of the world, formulate their own opinion. The teachers were there to facilitate and to scaffold students’ learning. [NW]</td>
</tr>
<tr>
<td>Restructure/deepen understanding emerging from theory-practice tensions and informing future actions</td>
<td>I think the biggest theory-practice gap was that we are encouraged to use students’ prior knowledge. However, in this case, their prior knowledge was misused… They should use evidence from the lab not from their pre-conceptions of what a plant looks like… I see that constructivism’s prior knowledge can be good and bad… I encouraged students to draw/write what they saw. If possible, I would talk to them about collecting evidence and how to utilize evidence… Scientists cannot rely on preconceptions, but on evidence. [TC]</td>
</tr>
</tbody>
</table>

These identified strategies ranged from just describing what they saw, to making interpretations, to working on the dialectics for restructuring knowledge; and they reflect students’ attempts to practicalize theory and theorize practice. Some were using just naming, and others linking and interpreting the experience in relation to principles as they try to make sense of what they learnt. In the last example, the responses suggested how the student’s reflection helped him to develop a richer understanding of the role of prior knowledge in constructivism, as he theorized his practice, showing how theory-practice gaps provide new meanings to enrich knowledge and practice. In the following, students writing were analyzed to identify collaborative strategies in online discussion that support them to make meanings (Table 2).

Table 2: Collaborative discourse strategies in online discussion

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build on and elaborate</td>
<td>I agree with you about setting criteria… Besides, I have 2 more examples to add [TV].</td>
</tr>
<tr>
<td>Enrichment of experience and identification of strategy</td>
<td>Thanks for sharing your experience in your school and it really benefits us reading your note. I particularly like two points… one is the strategy… the teacher used… [HW]</td>
</tr>
<tr>
<td>Share similar experience</td>
<td>Something very similar happened in my class. When you talked about this, I thought of the experience before. [NW]</td>
</tr>
<tr>
<td>Coordinate and synthesize</td>
<td>What I am thinking is in line with what I read from NW and FA. Like the two of you, I also think that. [BH]</td>
</tr>
<tr>
<td>Asking questions and brainstorming responses</td>
<td>What do you think? Do you think the school’s approach was the best choice? Or do you think there could be a better approach? [NW]</td>
</tr>
<tr>
<td>Springboard for questions</td>
<td>NW, I think your mentor did a great job using some already understood concepts for students to address their misconceptions. But I am curious how your teacher found out the misconception or whether he just assumed that [CH]</td>
</tr>
</tbody>
</table>
Providing explanation and elaboration

I think it’s very important that students (and everyone for that matter) understands the differences between ad hominem and ad rem arguments. Ad Hominem is...Ad Rem means... If students are making valid arguments (ad rem) let them continue. [RS]

Diversity, contrasts, and different contexts

To contrast the discipline in WT’s school and mine, my school does not focus on discipline, but teaching is still highly effective. I think this is a question of school culture. Maybe firm discipline is appropriate for some, but not others. This is a big factor that we as student-teachers need to consider [RS]...

We identified different patterns of collaborative strategies that included elaborating and building on others’ responses, asking questions, providing explanations, and extending the space of learning through considering others’ experience and examples. Reflection on their school experience put in a collaborative space is now enhanced with students supporting others using collaborative discourse strategies.

Productive discourse and theory-practice dialectics

We also examined how students developed deeper ideas through building on others’ posts. We emphasized co-construction of ideas for idea improvement and also from the lens of theory-practice dialectics (Tsui, 2009).

Excerpt 1: Practicalize theoretical ideas

HW: My mentor said that her class likes the traditional didactic way, rather than the constructivist approach. What should we do, try out the constructivist approach or keep the didactic approach?

HY: I think students like the didactic approach because they are used to it. Another possible reason is that the didactic approach allows them to be withdrawn, but a constructivist approach asks them to be engaged in learning. I think the teacher has to find out more about what students like and use their interests to design the lessons. If they find constructivist learning fun, they may start to enjoy it.

The exchange suggests a common tension between the theories and demands of a practice situation. HY’s response did not just provide the answers, but analyzed the problems and provided alternatives and her attention was shifting to student learning. As the discourse continues later, another student raised another problem related to student ability (“my mentor said constructivism cannot work for low achievers?”) HY responded by elaborating her understanding and providing practical strategies of how constructivism may work in school contexts (“weaker ones may be able to do that…perhaps it is the teacher’s questioning that influences how constructivist learning is practical or not?”) In dealing with these issues, they were working together to practicalize theories learnt in university classes.

Excerpt 2: Theorizing practical experience

WT: When the teacher tried to use formative assessment asking Ss questions to check their understanding, often she could not ask all students... But answers by the individual students may not show the picture of the whole class. Sometimes Ms. C gave the answers soon when students did the worksheets? Students knew she would give them the answers.

NW: Hi WT, I agree with your point that questioning may not be very effective formatively to assess all students. *Something similar happened to classes I have observed…*there were either no responses or always the same ones who answered the questions... Another way to get a better chance of the whole class’ learning is to use other forms of formative assessment, such as in-class quizzes or worksheets, which require all students to participate.

TC: *That is a great question about formative assessment. I think your concern is why we need to use different types of formative assessment not just questioning/worksheets. Asking students to work on the board, voting, traffic light, and mini-whiteboard may provide a clearer picture of what the class thinks. I would also like to put scaffolding into practice. My mentor encouraged me to use guiding questions to find out why*
students have questions/problems in the first place…I think it’s a great way to engage students in meaningful learning, rather than just giving answers for rote learning.

This discussion started with a practical problem where the teacher did not use questioning effectively to assess students. NW shared her similar experience and suggested other practical solutions. TC deepened this discourse by turning the practical problem of classroom questioning into an exploration of the nature of formative assessment by asking ‘why’ different types of formative assessment were used. They were not just discussing what to do, but why to do certain thing. TC continued to conceptualize by linking to theories he learnt on ‘scaffolding’ and examining the crux of the problem of assessment relating to meaningful and rote learning. The practical question on classroom questioning was deepened through collaborative discussion using experience to elucidate theory as they explained the nature of formative assessment for meaningful learning.

Implications
This paper reports on the findings of an ongoing study that examined how pre-service teachers attempted to make theory-practice connections for professional learning through an analysis of their online discourse. The analysis not only illuminated different patterns of reflective and collaborative strategies, but examined productive discussion from the perspective of theory-practice dialectics. For instance, they sought different ways to practicalize principles, used theory to inform observation, and adapted theory to particular contexts. They also theorized their experience, used their experience to elucidate, and enriched theory to inform their action. The online learning environment made it possible for the pre-service teachers to make their questions and ideas explicit. It also facilitated student peers to provide support and resources to scaffold thinking by asking questions, providing explanations, allowing tensions to surface, and collaboratively grappling with issues. Theoretically, the study extends current work on the reflection of theory-practice integration in teacher education by shifting from individual to collective reflection. It also enriches research on CSCL/online discourse by examining theory-practice dialectics and developing professional learning for pre-service teachers. From a design perspective, it is important to investigate how to design such environments to provide opportunities for novice teachers to interpret and test theories, which allow for the surfacing and revision of errors collectively. The identified reflective and collaborative strategies could provide useful scaffolds and pointers for the development of a scheme to help pre-service teachers reflect on and discuss the theory-practice connection. Issues including the developmental trajectory of productive discourse and how pre-service teachers change over time through their participation in online discourse need to be further investigated.

References
Examining Primary Teacher Expertise and Agency in the Collaborative Design of Project-Based Learning Innovations

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Abstract: Developing curriculum innovations aligned to research-based design principles and education reforms poses a daunting design challenge requiring substantial expertise. This study examines how prioritizing the agency of primary school teachers, engaged with researchers in the collaborative design of curriculum innovations, may allow for teachers to develop and productively leverage expertise. Using data from teacher surveys, interviews, and artifacts, our analysis has centered on what expertise teachers may develop around project-based learning and national science education reforms and what agency teachers have to influence the design of curriculum. We found evidence (1) teachers increased their understanding of project-based learning but showed fewer gains in understanding key ideas in science education reforms and (2) teachers significantly influenced the design of curriculum innovations. This study has implications for teacher learning and the design of curriculum innovations aligned to research-based design principles and national education reforms.

Major issues addressed
Successfully implementing innovative education reforms will require equally innovative materials. In science education, novel science curricula should embody the vision of reform (National Research Council, 2012). Developing science curriculum innovations, however, that faithfully reflect reforms and draw on research-based design principles has proven a daunting design challenge (Roseman, Fortus, Krajcik, & Reiser, 2015). Efforts to develop more innovative solutions to complex challenges may benefit from the presence of multiple or varied forms of expertise (Engeström, Engeström, & Kärkkäinen, 1995). Traditionally, researchers have dominated the process of developing innovations like curriculum to support reforms, often relegating teachers to merely the enactors of others’ designs (Ormel, Pareja Roblin, McKenney, Voogt, & Pieters, 2012). Such approaches to the design of innovations fail to adequately develop or leverage teachers’ expertise to support reforms.

We posit that positioning teachers to have the agency to develop and leverage expertise during curriculum design could serve to develop not only teachers’ expertise in research-based design approaches, like project-based learning (PBL; Krajcik & Shin, 2014), and science education reforms but also support the development of needed curriculum. Working within a large-scale curriculum development effort at the primary school level where we instituted a collaborative design framework, we explore the following research questions:

1. What expertise did primary teachers develop or leverage during the collaborative design process?
2. What agency did primary teachers have to productively shape the design of curricular innovations within the collaborative design process?

Significance
This study coheres with established precedents in the learning sciences and design-based research, particularly in using design to explore learning in real-world settings and in leveraging multiple forms of expertise to develop education innovations (Collins, Joseph, & Bielaczyc, 2004). In addition, this study reflects design research efforts that promote more equitable arrangements of expertise through the use of collaborative design (co-design; see Penuel, Roschelle, & Shechtman, 2007). While some recent co-design work has focused on developing curriculum, these efforts have occurred exclusively at the secondary level (see Severance, Penuel, Sumner, & Leary, 2016). This study is unique in its focus on the co-design of curriculum innovations and the role of agency at the primary level. Moreover, few studies posit, as this study does, that co-design alone can promote deep teacher learning (see Voogt et al., 2015). Relatedly, few studies have examined using co-design to develop teacher expertise in the Next Generation Science Standards (NGSS) or other national science reforms (see Severance et al., 2016), and no study has used co-design to promote teachers’ learning of key ideas in PBL.

Theoretical framework
Given this study’s emphasis on examining transformations in activity (i.e., developing new curriculum to achieve reforms), learning within social and collective settings (i.e., co-design activity), as well as agency (i.e., opportunities to leverage expertise to affect a design), we utilize a theoretical framework informed by
sociocultural and cultural-historical activity theory (CHAT; Cole & Engeström, 2007). We subscribe to the idea of “learning by expanding” wherein individuals work in collective activity systems to develop new forms of desired activity leading to desired outcomes (Engeström & Sannino, 2010). When designers achieve new forms of activity (e.g. artifacts, practices etc.) during a design process we take this as potential evidence of learning.

In sociocultural theory and CHAT, *agency*, defined as the capacity to produce an effect or a desired change in the world (Engeström & Sannino, 2010), proves essential for how people transform their activity and achieve new learning or expertise. In design work, individuals ideally share a common desired object (i.e., the goal of designing curriculum innovations), and must exercise agency to pursue and achieve the object and bring about desired outcomes. Achieving lasting transformative changes in activity requires a shared transformative agency (Virkkunen, 2006), as well as attending to historical contradictions—such as teachers having little say in curriculum—that can manifest as tensions (Engeström & Sannino, 2010). We posit unresolved tensions may serve as evidence of a lack of agency in collaborative design, whereas observing desired changes in activity and shared artifacts (i.e., shape of curriculum) serves as evidence of designers exercising agency.

**Methodology**

**Design methodology**

This study takes place within a large-scale, multi-year curriculum design effort. Charged with developing 8-week PBL science units at the primary school level, this effort recently adopted a co-design approach for two units. The co-design team under study includes three researchers, and three primary school teachers: Frank, Jill, and Michelle. Co-design activity took place across in-person and online settings over the course of six months (see Figure 1). After an initial two-hour researcher-led session introducing key features of PBL and the NGSS, teachers, on average, participated in 30 hours of synchronous in-person design collaborations and 12 hours of synchronous online videoconferences. Our approach sought to position teachers in agentic design roles, from seeking teachers’ expertise to negotiate initial unit storylines to having teachers lead the writing of actual lessons. Through mini-presentations and as-needed discussions, researchers sought to support teachers’ understanding and application of key ideas in the NGSS, chiefly that students should use knowledge in the context of science and engineering practices, a knowledge-in-use approach. Researchers also sought to support teachers in internalizing and leveraging certain PBL design principles: students (1) “figure out” (are not told the science of) phenomena, (2) build ideas coherently following a storyline over time, (3) continually engage with driving questions, (4) have choice in meeting learning goals (no one right way to build understanding).

**Research methodology**

Data collection and analysis for this case study occurred over six months. Sources of data for all teachers included pre-, mid-, and post-design process surveys assessing teachers’ understanding of PBL and key ideas from the NGSS; semi-structured exit interviews examining teachers design expertise and beliefs about teaching; and artifacts created by teachers during the design process, primarily snapshots of lesson development. Data underwent deductive, theoretically-driven coding and inductive, bottom-up coding. Code co-occurrence highlighted data for finer-grained interpretive analysis to identify patterns of evidence for defensible claims.

**Findings**
We make two claims based on patterns of evidence observed that respond to our research questions: (1) teachers increased their understanding of PBL but showed fewer gains in understanding key science education reform concepts (i.e., *knowledge-in-use*) and (2) teachers significantly influenced the design of curriculum innovations.

**Claim 1: Increased understanding of PBL (but not key tenets of reform)**

Data for the three primary teachers indicates internalization of several PBL ideas. For example, Frank’s survey responses show evidence he strongly internalized the idea, among others, of *driving questions* (see Table 1), a notion supported by his unprompted insertion of driving question discussions into his lessons. Patterns across Jill’s interview and survey data indicates she connected most strongly with the idea of student *choice*, whereas Michelle showed she came to understand how PBL lessons move towards “a purpose” or have *coherence*.

**Table 1: Teachers’ responses describing PBL (Key PBL tenets in bold)**

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Pre-Design Process Survey</th>
<th>Post-Design Process Survey</th>
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<tbody>
<tr>
<td>Frank</td>
<td>I would start by explaining the idea of teacher as facilitator, and how they will need to guide the students through the activities, and allow the students to take risks, even when you may feel that they will fail, it is often through that failure that success can be found.</td>
<td>Kids looking at phenomena, asking questions, experiencing and performing trials dealing with possible explanations, discussing and analyzing results, retesting and modifying when necessary, making a claim supported by evidence, and finally providing scientific reasoning to explain or answer the original question/s.</td>
</tr>
<tr>
<td>Jill</td>
<td>Materials! Prep time! Inquiry! Organization! Loosening of control!</td>
<td>I would describe it as giving the students powerful learning experiences where they have to <em>discover for themselves</em> the principles behind the phenomena. There is room for questioning, discussion, errors and all kinds of formative student ideas as they <em>figure it out</em></td>
</tr>
<tr>
<td>Michelle</td>
<td>...[A]llows for students to “discover” scientific ideas and theories without being told outright by their educator. The teachers role is that of mindful observer and travel guide. The educator may point out little clues by asking mindful questions but never spoons feeds students the answers...</td>
<td>PBL is an approach that puts students in the drivers seat. It allows students to take control of their learning and feel that their learning has a purpose. PBL allows the educator to play the role of a coach, one that fosters learning through guidance and mindful questioning.</td>
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Teachers showed fewer gains in understanding the *knowledge-in-use* approach called for in the NGSS. When prompted at the end of the design process to describe instruction embodying the NGSS, only Frank discussed students integrating science and engineering practices with science knowledge: “Kids…asking questions...making a claim supported by evidence and finally providing scientific reasoning to explain or answer the original question/s.” Conversely, Jill offered a practice-only approach where students “do various challenging tasks, like modeling principles” and Michelle noted only that students should have “control of their own learning and the educator plays the role of coach.” Notably, all teachers could not write integrated learning performance statements for their lessons without researcher support, even at the end of the design process.

**Claim 2: Teachers significantly influenced the design of curriculum innovations**

Teachers had agency in the design process to make lasting contributions to the units that persisted even after external reviews and editing. For example, Frank and Jill proposed early on in the design process an idea for a final community-based artifact to end a unit. Though details surrounding the artifact shifted during months of development, the kernel of the teachers’ idea remained focal in the unit. More tangibly, teachers’ contributions to lessons they developed, in terms of scope and substance, remained intact (See Table 2). Of note, teachers developed the first set of lessons in each unit, which subsequent sets of lessons had to follow and cohere with.

**Table 2: Teachers’ lesson contributions by unit**

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
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</thead>
<tbody>
<tr>
<td>Teacher</td>
<td>Lessons</td>
</tr>
<tr>
<td>Frank</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Jill</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
</tr>
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<td></td>
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</tbody>
</table>

While teachers did make significant contributions, survey and interview data revealed tensions when teachers felt researchers impinged upon their agency. On a pre-post survey item asking how much she felt valued in the design project, Jill decreased her 4-point Likert rating from (4) *extremely valued* to (2) *less valued*,...
and remarked disappointment at the lack of adoption of her ideas: “I feel a key idea of the two-column lesson plan that I was told had been adopted has needlessly not been implemented.” Although Frank did not change how much he felt valued ((3) more valued), he expressed similar dissatisfaction during his interview with the lack of adoption of certain ideas, citing “too many cooks in the kitchen” as a possible cause. Michelle did not express dissatisfaction, saying in her post-survey she felt her “ideas are taken seriously.”

Conclusions and implications

This study illustrates how prioritizing the agency of primary school teachers, engaged in the co-design of curriculum innovations with researchers, can allow for teachers to develop and productively leverage expertise. Moreover, this study shows how co-design approaches can potentially disrupt traditional design approaches to enacting reform—where reform has been done to teachers rather than with teachers. As seen in this study, purposefully supporting and leveraging the expertise of teachers through deeply inclusive co-design can support not only teachers’ individual agency regarding reforms but supports a broader shared collective agency to enact reforms: teachers can develop expertise for innovative design (see Voogt et al. 2015), as well as bring about needed curriculum innovations. Notably, this study provides a strategy for science education reformers to consider when attempting to build capacity for the implementation of science reforms at the primary school level, the critical foundation for all students’ future science education pursuits.

This study also highlights novel challenges in collaborative design work. While seeking to show how co-design can help address tensions stemming from the historical contradiction of teachers not having significant agency in reforms and curriculum, this study showed how new tensions can also arise. Primarily, this study demonstrates the potential double-edged nature of agency in design: promoting teacher agency allows the leveraging of needed expertise, but subsequently circumventing this newfound agency can create new tensions researchers must attend to or risk alienating design participants. Additionally, this study showed underwhelming learning gains for teachers in terms of their understanding of the idea of knowledge-in-use present in recent science education reforms. This points to the difficulty of developing teachers’ understanding of key shifts called for in reforms while engaging in design. We encourage design researchers to engage with our process and results and to further explore the interplay of design, learning, agency, and reforms.

References


Acknowledgments

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Towards a Radical Healing Praxis for Black Girls: Imagining Learning Environments That Foster the Sociopolitical Learning of Adolescent Black Girls

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Abstract: In education research and practice, there is a lack of attention paid to the unique racialized gendered needs and experiences of Black girls. This conceptual paper, a work in progress, utilizes the radical healing model (Ginwright, 2010) to (re)frame (Hand, Penual, Gutiérrez, 2012) and reimagine learning environments that not only eradicate but also redress the harm that stems from the structural and symbolic violence imbedded in the formal educational experience many US Black girls endure. A tailored Radical Healing Praxis provides an ecologically responsive pedagogical framework from which researchers and practitioners can begin the work of developing learning environments that lead to the healing and healthy sociopolitical development of Black girl learners.

Keywords: Black girls, Radical Healing Model, (Re)frame, Race

Introduction
With approximately eight million Black students participating in the U.S. educational system (Aud, 2013), 52% of them are girls, however, the scholarly trends regarding Black education continue to focus extensively on Black males. Statistics about the state of Black education largely ignore the unique experiences, performance, and outcomes of Black girls (Morris, 2015; Cooper 2015; Rollock, 2007 as cited in Ricks, 2014). Although attention to Black boys is warranted given their lower attendance and graduation rates, higher representation in segregated special education classrooms, lower levels of gainful employment, and high involvement in the criminal justice system (Ferguson, 2001; Greene & Winters, 2006; Holzman, 2004; Polite & Davis, 1999), this scholarly attention should not be undertaken at the expense of a critical look at the challenges confronting Black girls who are educated in the same woefully inadequate contexts as their male counterparts.

Although Black girls, like Black boys, are experiencing similar marginalization, structural oppression, and unfriendly learning environments, with few exceptions (Cooper, 2015; Crenshaw 2015; Evans-Winters, 2005; Evans-Winters & Esposito, 2010; Fordham, 1993; Morris 2016; Richardson, 2013; Ricks, 2014) there is widespread neglect on the part of education researchers to examine and conceptualize the integrated issues of race and gender that impact the learning experience of Black girls (Boston & Baxley, 2007; Mirza, 2009; Pinder, 2008 as cited in Ricks, 2014). “Instead, when researchers examine marginalized groups in education, the focus is almost exclusively on Black males and White females, with little attention devoted to the unique experiences and needs of Black females” (Ricks, 2014). Furthermore, the challenges that Black girls face in schools, for example, regarding suspensions, expulsions, and other disciplinary practices often go underreported therefore “leading to the incorrect inference that their futures are not also at risk. This assumption obscures the fact that all too often [Black] girls are struggling in the shadows of public concern” (Crenshaw, 2015, p.17). In the absence of specific attention on the unique educational needs and experiences of Black girls, they continue to fall through the cracks of our attention and our praxis.

I enter this work as a Black woman researcher, who as an adolescent, personally experienced chilly and untailored formal learning environments. After university, I entered the field as a practitioner, where I worked in a variety of capacities, from teacher to school leader. Despite my institutional position, I observed schools inflicting harm on Black girls through culturally isolating pedagogies, harsher discipline practices, and regular assaults against their personhood. The results of this structural and symbolic violence, are that Black girls are suspended at greater rates to white girls and at greater proportional rates than Black boys when compared to white boys (Crenshaw, 2015). Black girls fall victim to the school-to-prison pipeline and compose the fastest growing segment of America’s juvenile justice system (Black Woman’s Roundtable, 2014). Black women outnumber any other racial group of women in federal or state prisons (The Sentencing Project, 2015). Black girls continue to be on the losing end of the achievement and opportunity gap (Carter & Welner, 2013; Ladson-Billings, 2006; Darling-Hammond, 2007). Furthermore, they experience disturbing rates of poverty, confront higher health risks, experience adequate reproductive rights policies, and are isolated when subjected to violence (Romany, 2000). For those Black girls and women who can overcome the interlocking gendered racism of their primary and secondary school experiences, and are able to enter the academy as undergraduate or graduate...
students, they too continue to experience the violence associated with harmful educational praxis at the university level (Fordham, 1993), sometimes resulting in alarming rates of depression, anxiety, low self-esteem, thoughts of suicide, bulimia, and/or drug addiction (Croom, 2012; hooks, 2005). Although Black girls have deftly created and/or adopted a toolbox of skillful coping and defense mechanisms (such as gender passing, getting loud, or bringing “wreck”) to deal with the gendered racism they experience in schools (Richardson, 2013; Fordham, 1993; Pough, 2004; Williams, 1988), these coping defense mechanisms obscure the dire condition of their educational experiences and are often misinterpreted by teachers and school personnel as personality and/or cultural characteristics instead of responses to living with daily microaggressions (Ricks, 2014). Black girls are negotiating the significant gaps in their educational experience, largely by themselves, because the gaps are not being adequately attended to by practitioners and researchers. It is incumbent upon practitioners and researchers to assume responsibility for addressing the gaps created by inadequate design, harmful practice, and under theorizing of the Black girl educational experience.

Researchers and practitioners must begin thinking critically about how to better design learning environments that not only minimize the harm that Black girls experience in schools but also leads to the healing and healthy sociopolitical development of Black girl learners. This paper outlines research (in process) on utilizing a Radical Healing Praxis (Ginwright, 2010) framework to (re)frame traditionally oppressive learning environments (Hand, Penual, Gutiérrez, 2012) in ways that mitigate harm and maximize the educational experience and life trajectory of this neglected demographic.

Significance
One hallmark of the learning sciences field, is our commitment to researching and designing educational environments that work for learners. However, only approximately 15% of learning scientist conduct research on learning related to race, approximately 13% focus on learning impacted by gender, and an uncounted smaller fraction focuses on the intersections of learning, race, and gender (Yoon, 2017). Although learning scientists aim to understand and theorize learning in a diversity of contexts, not enough learning scientist are taking up research on learning that happens at the intersection of race, gender, and oppression (Yoon, 2017b), thereby producing dire outcomes for some learners. There is an increasing racialized opportunity gap, resulting in greater incarceration rates, diminished life chances, and less positive sociopolitical outcomes for minoritized learners, including Black girls. The need to create learning environments that disrupt the educational violence that Black girls experience in schools is urgent.

This work is consistent with a growing subset of learning scientists who are directly addressing issues of race, power, and privilege (Esmond, 2017; Hand et. al, 2012; & Politics of Learning Writing Collective, 2017). Within that subset of scholars, there are learning scientist who are “working to envision our field’s collective responsibility toward decolonial justice” by calling the field to develop theories of learning that are situated in this historical political moment (Politics of Learning Writing Collective, 2017). By moving towards a learning theory that is grounded in the lived experiences of Black girls, this work, responds to the call for developing critically aware learning theories that recognize and address how issues of race, identity, and power mediate the experiences of learners (Yoon, 2017).

Theoretical approach
Shawn Ginwright’s (2010) Radical Healing Model (RHM) prioritizes the healing of Black youth to happen simultaneous with their learning. RHM is an ecologically responsive strategy that 1) highlights the socially toxic conditions in communities 2) to build the capacity for youth to respond to their conditions 3) in ways that support social justice, agency and resistance thereby contributing to individual, community, and broader social wellness. Ginwright’s model prioritizes the acknowledgment of “toxic conditions” or the oppressive circumstances in which Black youth are currently and have historically lived and learned. By beginning with an explicit acknowledgment of the inequitable and toxic context in which most Black girls learn, we can imagine new learning environments that not only eradicate but also redress the harm that stem from the structural and symbolic violence connected with their educational experience. Envisioning new learning environments allows us to imagine contexts that attend to school related harm through an educational praxis of healing. The RHM provides a framework from which to think of healing not solely as a psychological endeavor but as an ecologically responsive pedogeological framework.

This work couples RHM with Hand, Penual, and Gutiérrez’s (2012) concept of (re)framing to establish the theoretical framework for which designers and practitioners can think differently about creating new more equitable learning environments. Hand, Penual, and Gutiérrez claim that “power plays out in everyday social interaction... through the stories, narratives and ideologies that serve as resources for interpreting and organizing ongoing activity” (p. 250). The way participants (usually teachers and students) organize and
interpret ongoing educational activities or interactions creates the frame. Frames are often invisible forces that position actors in ways that reify power and oppression. Furthermore, frames “shape the interaction that takes place within them and, hence, shape both access within learning opportunities and access to them” (Hand et al., 2012, pg. 251). Since frames operate as invisible shapers and interpretive filters of interactions, it is important to make frames visible to recognize their role in either advancing or diminishing the educational trajectory of the youth involved. Hand, Penual, and Gutiérrez point to an example from Nasir’s (2011) work, wherein teachers and school administrators orchestrate an invisible frame that was “inherently inequitable to African American students” (pg. 255). The frame was invisible to the students, consequently they participated without question or awareness. Although Black students in this example were actors in the frame, they were not creators, nor did they have the power to reframe. Therefore, students were effectively forced to accept and participate in the invisible frame, governing their educational experience, while also being victimized by it. Examples such as this, where students of color, who are operating under and within oppressive invisible frames, illustrate the need for (re)framing learning environments so that they can support student learning and development in non-oppressive, decolonial, and equitable ways (Hand et al., 2012).

This work uses Engle & Conant (2002) productive disciplinary engagement frame (as cited in Hand et al., 2012) to organize the learning environment in a way that positions Black girls to have more real and interpretive power of the organizational frame governing their learning environments. A productive disciplinary engagement (PDE) frame, moves minoritized students out of the role of passive learner/adopter of traditionally oppressive frames, into a position where they have the authority and obligation to make sense of domain ideas and procedures. The PDE frame allows learners to 1) problematize aspects of the domain, 2) exercise authority in approaching domain problems in a variety of ways, and 3) be held accountable for reasoning in ways that make sense to the learning goals and norms of the discipline (p. 256-7). Hand, Penual, and Gutiérrez (2012) provide an example of the PDE frame in use, when they highlight an example of a math teacher, using a PDE frame to organize a learning experience for a Latina learner, who otherwise has a weak math identity. In their example, this teacher utilizes several discursive moves to position the student as the ‘provider of knowledge,’ as ‘author of mathematical process,’ and skillful ‘navigator of the complex mathematical landscape’ (p. 258-9). This example illustrates how a PDE frame can reorganize the learning environment to remediate dynamics of power and race by redistributing authority and creating greater relational equity between teacher and learner, particularly when the learner is entering from a less than equitable position (p. 259).

This work contends that a PDE frame within the context of a broader Radical Healing Praxis has the potential to not only (re)frame Black girl’s learning environments in ways that are more immediately equitable, but also build Black girl’s capacity to advocate for greater educational equity for themselves and others. (Re)frame the learning environment allows educators to operate in ways that empower Black girls to heal while giving them the authority to question, solve problems, and be held accountable to high content domain standards. The coupling of an empowering frame with a healing model allows us to work toward a radical healing praxis that supports the sociopolitical learning of Black girls.

**Implications**

Those attending to the state of Black girls and their education are saying that “we must develop gender and race-conscious prisms that capture the vulnerabilities they experience today” (Crenshaw, 2015, p.47). The Radical Healing Praxis for Black Girls not only provides a race and gender conscious prism, it also encourages practitioners and researchers to more critically explore learning environment design, enhance educational practices, and reimagine theoretical frames in ways to more equitably serve all children.

**References**


Hand, V., Penuel, W. R., & Gutiérrez, K. D. (2013;2012;). (re)framing educational possibility: Attending to power and equity in shaping access to and within learning opportunities. *Human Development, 55*(5-6), 250-268. doi:10.1159/000345313


Symposia
Abstract: Learning environments based on axiological innovations (Bang, et al., 2016) recognize the resources learners of all ages bring and value learning based in commitments to expand relationships of collaboration. We take up lines of design-based research focused on the expansive engagement of families, where our goal was to create STEM-based intergenerational learning environments that center family collaboration to transform the process of partnering and increase collective capacity to make sense of the natural world, engage in practices, and reimagine participants’ relationships to technologies (Bang, et al., 2012). The four studies that comprise the symposium shed light on the kinds of axiological innovations that guided the design of learning environments that created equitable and transformative STEM-based learning opportunities for families from nondominant communities. Through the symposium we will explore the implications of family-centered axiological innovation for learning theory and design knowledge related to the articulation of extended, cross-setting learning pathways.

Rationale and contribution: Reframing family learning
Recognizing that learning occurs across space and time, learning scientists have thought deeply about how to design learning environments were both children and their adult family members can learn (Barron & Bell, 2015). This approach is often rooted in a commitment to seeing learning as dynamic cultural processes, recognizing that people make sense of and shape their world in ways that are connected to the practices, values, and worldviews of their communities (Bang, et al., 2012; Bang, et al., 2016; Bell et al., 2012; Gutiérrez and Rogoff, 2003). This perspective is important not only because it opens new avenues of learning and participating for learners of all ages, but also because it can create opportunities for all learners to make sense of the world through leveraging meaningful cultural practices, identities, and places as they interact with those whom they have a deep connection with (Nasir, et al., 2014; Rosebery et al., 2005). However, we argue that educational contexts have not adequately explored how to leverage the shared history and intergenerational learning processes of families in support of their own STEM education. In this symposium, then, we pursue the question: how can we design STEM-based learning environments founded on a set of values and ethics that create equitable and transformative learning opportunities for families?

Intergenerational designs have been particularly popular with STEM-based learning environments, particularly MakerSpaces that have sprouted all over the US and bring children and adults together to design artifacts, solve problems, and learn about the natural world through engaging in science and engineering practices (Roque, 2016). However, the STEM-based intergenerational learning environments we design need to systematically work to push against boundaries of normative practices and tap into the repertoires of practice of nondominant learners and non-traditional configurations of learners (Bang, et al., 2012). Otherwise, the programs we design will reify the same systems of oppression that have shut the door of STEM learning for students from nondominant communities and their families, and interrupted productive identity-work that would allow learners to see themselves as being able to make sense of the natural world (Bell, et al., 2009; Calabrese Barton &
Brickhouse, 2006; Calabrese Barton, et al., 2013; Tzou, et al., 2017). A very common example of how STEM-based learning environments recreate these oppressive dynamics is the out-of-school learning program that positions families as consumers or users of technology, rather than creating opportunities for families to reimagine their relationships to technology and how it can be used as part of the cultural practices of their communities (Tzou, et al., 2017; Vossoughi, Hooper & Escudé, 2016). Consumer-framed programs, often inadvertently, are founded on a set of values and ethics that embody deficit perspectives of families, their experience, their expertise, and their relation to technology. If left unchecked, learning scientists can continue to design learning environments in which these oppressive dynamics are reified and reproduced, narrowing and limiting the kinds of meaningful learning that families can experience, rather than building upon the heterogeneous sense-making practices and knowledge that families bring to learning environments.

To overturn these kinds of oppressive and colonial dynamics within STEM-based programs, it is paramount that our designs for learning environments are based on axiological innovations (Bang, et al., 2016) that transform relational positionings and value the resources learners of all ages bring to the learning environment. We draw from the construct proposed by Bang and her collaborators, who define axiological innovations as “the theories, practices, and structures of values, ethics, and aesthetics (...) that shape current and possible meaning, meaning-making, positioning, and relations in cultural ecologies” (Bang, et al., 2016, p. 28-29). We argue it is key for learning scientists that engage in design-based research to attend to how the axiological commitments that undergird their designs create opportunities for all learners to experience transformative agency and disrupt historical inequities. Here, we call for creating STEM-based intergenerational learning environments that desettle normative expectations about what it means to make sense of the natural world, engage in practices, and reimagine participants’ relationships to technologies (Bang, et al., 2012). We propose that family-centered, STEM-based learning environments provide a powerful context for exploring this perspective. Family-centered learning environments disrupt age segregation and the colonialist consequences of creating separate learning spaces for adults and children, which can be particularly disruptive for participants from nondominant communities. Nevertheless, much remains to be studied in terms of examining the axiological and ideological foundations of equity-oriented design and research in such environments, and we need to start by transparently communicating what those underpinnings are and how they inform our designs (Bang & Vossoughi, 2016). This is our plan for this symposium.

The four studies that comprise the symposium, all of which took place in the US, shed light on the kinds of axiological innovations that guided the design of learning environments to create equitable and transformative STEM-based learning opportunities for families from nondominant communities. The first study describes how youth and their families reframed their relations to technology, leveraging programming and robotics as tools for storytelling, memory-making, and STEAM learning, resisting being dominated by those technologies. The second study focuses on how engaging in computing practices supported children and their parents reframe how they saw themselves in relation to programming, and even each other. The third study highlights the importance of parent learning networks in the development of interest and experience with creative digital projects, and the importance of differentiating roles that parents can play as learning partners. The fourth study describes how families interacted and problematized natural phenomena together, in a learning environment designed to support intergenerational learning and recognize families’ funds of knowledge as productive resources. Taken together, these studies make the contribution that family-centered learning environments that support axiological innovations can ground STEM learning in families’ cultural knowledge and practices, promote role re-mediation through shifted social positioning, and support extended cultural learning pathways for youth and adults alike. Through the symposium we will explore the implications of family-centered axiological innovations for learning theory and design knowledge related to the articulation of extended, cross-setting learning pathways.

Paper 1: Technologies of remembering and learning with Indigenous Families: Storymaking, robotics, and computer science
Megan Bang, Meixi*, Philip Bell, University of Washington Seattle
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Framing and study design
The roles of science, engineering and technology in learning and learning environments are increasingly a focus and hope for more equitable and transformative learning, particularly for students from nondominant communities. However, these fields have not historically been attuned to culturally heterogeneous ways of knowing. Scholars are exploring how the cultivation of consequential learning environments (Gutiérrez & Jurow, 2016) are intimately intertwined with historicity, knowledge systems, and the agentic positioning of learners to
be the designers of new technologies (e.g. Prins, 2002). This paper presents findings from a Participatory Design Research (PDR) (Bang & Vossoughi, 2016) project that brought together learning scientists into collaboration with public librarians, informal science education staff, and staff from Native American-serving community organizations who were jointly focused on designing family-centered and culturally expansive STEAM (science-technology-engineering-art-math) learning experiences working with nondominant communities. We designed TechTales, a five session, 3-hour weekly workshop series that centered nondominant families’ stories and storymaking (Archibald, 2008) processes as a means of re-positioning families’ relationships to technology and more specifically robotics. Families made a diorama of an important family story using Scratch (programming language) and a Hummingbird (microcontroller) to animate the artifact using outputs such as LED lights, sounds, and motors, and inputs, such as sensors of various kinds.

Data sources and analysis
In this paper, we examine the forms of learning and engagement of two Indigenous families across the five TechTales workshops. Data were collected utilizing multiple video streams and audio to capture the discursive as well as the embodied forms of activity that unfolded over the course of the workshop (Goodwin, 2000, 2007). The videos were content logged and key moments of project development were identified for interaction analysis (Jordan & Henderson, 1995). Key moments in this analysis were conceptualized as interactions in which the families’ storyline and design development were dynamically intertwined. Further, we analyzed moments of refinement driven by interactions between design intentions and materiality. Finally, we explored the ways in which family identities were reinforced and expanded throughout the workshops.

Findings
We find that using story and storymaking as the focus of diorama building created learning environments where computer programming and robotics became dynamic tools towards family-making, collaboration, and learning simultaneously. Families’ attention to aesthetics during the design reflected both family identity and memory and opened important disciplinary epistemic opportunities in order to produce affective responses to their stories. For example, one family wanted to capture a family memory of an annual trip traveling to their homeland and their daughter’s first lightning storm. The family engaged in deeply agentic building to capture the aesthetic effects of both the lightning in a cloud and their hair standing on end when the lighting struck. In a post-interview with this family, the father indicated the important role this experience played in solidifying that memory for the family and especially for the daughter.

Father: I don't remember much when I was 7 years old. By doing this whole TechTales story, we all have a shared memory... I'm curious to see if, you know when she (daughter) turns 12, when she turns 20, will she remember that whole lightning storm? Which if we hadn't talked about it, hadn't done the TechTales, it would be just totally lost.

In this way, we are interested in both the work that stories do as both tools for memory making and as drivers of innovation with the technology to capture aesthetic and affective dimensions of place. Family-making, collaboration, and storytelling in this case seemed to open up deeper re-mediations against domination by technology, as well as opportunities for re-mediating agency as families appropriated these tools towards their own ends.

Implications and contributions
In a digital age, assimilative technology is often blamed for mediating away from and severing familial connections. Through shared memory-making within families, we explore the possibilities with digital technologies to build intergenerational connections rather than divides. The interweaving of storytelling, computer programming, and epistemic practices brought families stories to life, and worked towards re-making relations both within family units and to technology. In this way, learning environments based in a commitment to family-centered and culturally expansive design projects is an axiological innovation that provided multiple entry points for family member participation and spaces for ongoing cultural contribution, collaboration, and STEAM learning.

Paper 2: Making projects, making identities: Families constructing their own computing identities
Framing and study design
We will describe a study of families developing their identities as computational creators in a family learning program designed to support families to create and learn together with creative technologies. Through a series of workshops, Family Creative Learning (FCL) engages families, particularly from underrepresented groups in computing, and aims to support children and parents in developing roles and practices to support one another in a changing and increasingly important context in our digital society (Roque, 2016).

The design of FCL was inspired by constructionist approaches, which engage people in learning experiences where they can create personally and socially meaningful projects (Papert, 1980). Building on constructivist theory, as people build projects, they build ideas (Kafai & Resnick, 1996). To be personally meaningful, the design of FCL invites families to build on their diverse “repertoires of practices” and “funds of knowledge” (Gutiérrez & Rogoff, 2003; Moll, Amanti, Nef & Gonzalez, 1992). To be socially meaningful, the design of FCL has also leveraged learning theories that emphasize the social aspects of learning (Brown, Duguid, & Collins, 1989; Lave & Wenger, 1991). Families are encouraged to work together as well as interact with other families participating in FCL.

We argue that as people engage in building personally and socially meaningful projects, they have opportunities to build identities as creators with computing. We use sociocultural and practice-based views of learning and identity development to examine children’s and their parents’ developing a sense of self in computing in relation to their participation in FCL (Lave & Wenger, 1991; Nasir & Hand, 2008).

Data sources and analysis
We took an ethnographic approach to understand individual perspectives as well as to examine the social and cultural practices that emerge within the learning environment. The design and development of Family Creative Learning was inspired by design-based and participatory approaches, which emphasize being embedded in the local context, engaging people as collaborators rather than research subjects, and experimenting with multiple iterations (Stringer, 2013; Barab, et al., 2004).

We recorded observations and collected photos, videos, and project artifacts during the workshops. After the workshops, we conducted reflections with the facilitation team and 30-90 minute interviews with individual family members. We focused data collection on eight program implementations of FCL from 2012-2015, which engaged more than 60 families primarily from underrepresented groups in computing.

Findings
We describe the ways that children and parents’ participation in this program influenced their identity development in the context of computing. For example, parents and children had opportunities to see themselves and each other in new ways. Initially, parents shared how uncertain they felt about their abilities with technology. Often their children echoed these perceptions of their parents. Through first-hand experience with the creative technologies, parents saw how they could “create something out of nothing” with computing. Similarly, as they worked with their children on family projects, parents shared the ways their children saw them. As one child said when asked about what surprised him about his mom, he said: “When she invented things.” Additionally, we discuss the design of learning environment and its different aspects (tools, activities, facilitation, and space) in influencing their development as computational creators.

Implications and contributions
Often learning environments focus on developing skills and content knowledge and how these outcomes transfer in other settings. However, the shifting perspectives and identity development within these activities can have profound implications in how youth and their families decide to persist or pursue future opportunities (Beach, 1999; Nasir & Hand, 2008). Perspectives from parents and other adult caretakers can influence how they provide resources and broker new opportunities. We have an opportunity to design these learning environments and to engage children and their families to support children’s identity work in the context of computing.

Paper 3: Parents collaborating to learn: Insights from family co-design workshops about reframing expert roles
Nichole Pinkard, Northwestern University
Brigid Barron, Caitlin K. Martin, Stanford University
Framing and study design
Networked technologies and digital tools provide young people and their families with new forms of creative agency to pursue questions and activities of interest to them. They also provide rich opportunities for novel and varied forms of intergenerational learning with family members dynamically taking on roles as teachers, learners, collaborators and brokers (Barron, Martin, Takeuchi, & Fithian, 2009). The notion of families as a unique type of creative ensemble (John-Steiner, 2000) invites researchers and designers to expand our units of analyses to conceptualize parents, grandparents, and children as potential members of extended digital learning teams (Katz, 2014). In this framing, parents and children have unique and complementary funds of knowledge and repertoires of practice and are able to share them depending on what learning opportunities they have been provided at school, at work, and informally with friends or community-based organizations. How parents and children take up roles as more expert guides is also influenced by their cultural repertoires of practice around teaching and learning (Gutiérrez & Rogoff, 2003) as well as opportunities and needs that may present themselves because of rapidly changing technologies. In this paper, we share findings from a design experiment that created a novel learning experience for parents to connect with other parents about how they share and co-develop expertise with their children. The design of the workshop built on ethnographic studies of families in both Silicon Valley (Barron, et al., 2009) and in Chicago (Pinkard & Austin, 2014) that showed the varied ways that families learn to design and create together and how new roles as guides and learners emerged with changing expertise levels. A specific goal of the multi-sited ethnographic research was to support and make visible informal learning experiences that might contribute to future pathways as designers, digital artists and activists, and social advocates for one’s own community.

Data sources and analysis
Workshops were designed to support a community of parents and other caring adults (grandparents, aunts, adult cousins) to develop agency and confidence in the roles they play in their children’s technological learning, especially for those without perceived expertise. Workshops were developed for the families of middle school girls in an out-of-school computational making program. The majority of girls in the program were from non-dominant communities (59% African American; 18% Latina) underrepresented in STEM learning pathways. Sessions included an introduction to parent support roles, brokering STEM learning opportunities in Chicago, collaborating through co-design of an LED-embedded greeting card, and non-technical consulting through visibility of and discussion around their children’s STEM projects. Each session included presentation, activities, and reflection/discussion with the community. Data collection (N = 113) includes surveys of roles played and reflections on workshop participation, attendance records, online participation traces in community groups, and observations from in-person sessions captured in field notes, photographs, and created artifacts.

Findings
Results fall into three clusters: (1) Existing intentionality alongside perceived need for more support: Parents were deeply engaged in their children’s learning and hungry for opportunities to support STEM education. They were especially eager for ways to find quality STEM opportunities that could extend their child’s learning beyond the focal program. (2) Workshops sparked collective creativity and broadened networks: Adults brought individual interests and knowledge to the workshops and engaged deeply in collaborative design work, learning from, sharing with, and helping each other during the sessions. Enhancing adult community connections can widen opportunities for youth through expanded parent brokering as individuals combined knowledge and ideas. (3) Opportunities for reframing expert roles and for bi-directional technology content learning and teaching: While half of parents reported regularly encouraging their daughter and playing the role of a learning broker and a quarter reported learning from or teaching their child regularly, only 11% reported collaborating on projects involving technology.

Implications and contributions
Generating expansive designs for intergenerational learning is a critical need in the learning sciences. In this paper, we highlight the importance of parent learning networks in the development of interest and experience with creative digital projects and the importance of differentiating roles that parents can play as learning partners. Our ultimate goal is to advance possible pathways for all young people and their families as everyday and professional designers of digital tools, and to generate new methods to document their evolution. To the extent that we have a more homogenous group of professionals imagining and building future tools we fail to capitalize on a diversity of perspectives, ultimately limiting potential solutions. It is generally agreed that this is a multidimensional
problem that includes early gaps in experience, gender and racial stereotyping of technical work, and workplaces that create climates that suppress rather than invite contributions from all. Parent co-learning networks may be one resource that can foster resilience and boost collective creativity.

**Paper 4: Eliciting family sense-making resources in scientific inquiry during multilingual family science nights**

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**Framing and study design**

“Yo decía que la ciencia era algo extraordinario, que no se podía entender. Pero es algo que... se puede ver, se puede hacer. Para mi era algo... ahh... que no entendía. Pero la semana pasada que vine dije, “¡Wow!” Entonces la ciencia es algo que se puede hacer fácil y sencillo y sin estudio.” – Florencia

“I used to say that science was something extraordinary, that could not be understood. But it is something that... you can see, you can do. For me it used to be something... ahh... that I did not understand. But when I came last week I said, “Wow!” Then science is something you can do easily and simply and without studying.”

The above statement was made by a Spanish-speaking mother, Florencia, on the second night of our multilingual family science workshop, where children and adults collaboratively explored everyday materials and were invited to make sense of phenomena together. We had hypothesized that such experiences could shift families’ perceptions of what counts as science, who can participate successfully, and the role families play in children’s science learning. Florencia’s reported shift in thought was not uncommon in our workshops. Such shifts served as an existence proof that our approach could be successful. We conducted a more in-depth analysis to understand what led to such shifts in perspective, and their effects on family sensemaking dynamics. How did we help Florencia see that she is capable of understanding science without having to “study” science? How did this shift in perspective influence her approach to learning science with her daughter? Did other families have similar experiences?

We see this effort as exploring the intersection of two axiological innovations (Bang, et al., 2016): 1) Intergenerational learning: We asked families to make sense of phenomena together instead of asking parents to “help” their children with the science activities; 2) Resources as strengths: The primary modes of inquiry and exploration came from families’ own questions, their rich knowledge of the physical world, and their thoughtful engagement with scientific phenomena.

In designing and conducting the workshops we took a resources view of learning (Hammer, et al., 2005; Warren, et al., 2001) in which families use their linguistic and cognitive resources to construct their own understandings, in contrast with the dominant “deficit” view in which learners have robust scientific misconceptions that must be confronted and replaced. We used everyday materials (e.g., ice and water, flash lights, Slinky toys) and tied inquiry discussions to local contexts (e.g. a strange looking tree at their school), supporting families to draw upon their funds of knowledge (González, et al., 2005). For this ICLS session, we present the results of an in-depth analysis of moments of activity in which the design of our workshop supported intergenerational learning.

**Data sources and analysis**

We engaged families in an inquiry-based evening science program at four ethnically and linguistically diverse K-8 schools. Each school had four weekly two-hour sessions. Between eight and fifteen families attended each night. Sessions were conducted bilingually, with translation in real-time. In this paper, we present findings from an interaction analysis (Derry, et al., 2010; Jordan & Henderson, 1995) of video records of families’ activities during the workshop, focusing on how our design choices supported collaborative intergenerational learning. In the first part of the analysis, we identified moments when intergenerational learning occurred, i.e., moments where parents and children were making sense of phenomena together. Then we analyzed what led up to these moments, and what sustained them, to identify factors that supported intergenerational learning.

**Findings**
We will present analysis of three moments of activity from three different families. For example, on the third evening of the workshop Florencia and her daughter discovered that a blue LED light connected to a battery would suddenly go out when a red LED was added. They disagreed about whether the blue light was completely extinguished and, rather than Florencia asserting her explanation to her daughter, they investigated together by going into a dark closet to examine the light levels more closely and puzzled about what could be happening to the electricity flow when the red light was added.

In-depth analysis of such moments reveals several factors that supported intergenerational learning: 1) utilizing familiar, inexpensive materials encouraged families to playfully discover and co-investigate novel phenomena, 2) a resources-based perspective encouraged parents and children to draw upon their own ideas and lived experiences, 3) bilingual translation afforded English-primary and Spanish-primary families to be able to engage together, and 4) in-the-moment marking of their reasoning as “scientific” helped parents and children to associate their funds of knowledge with doing science.

Implications and contributions
The analyses provide accounts of how a design focus on families’ cognitive, linguistic, cultural resources can support intergenerational science learning and challenge dominant conceptions of what counts as science and who can participate. These findings provide additional support for the promise of design that encourages families’ playful scientific sensemaking in informal environments (Luce, et al., 2017). One question for future research is how to design supports for families to learn together in relatively unstructured environments or during family time at home. We have incorporated these design innovations in developing a bilingual app to support families exploring science together, on their own time and in their own terms.

References


Video Data and the Learning Event: Four Case Studies

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Abstract: Video data is now used throughout the learning sciences as a common form of documenting learning events. Wearable cameras and real-time video feed-back have changed the research terrain. And yet scholars often use such data without examining the ways that video – as digital technology - structures and shapes the research findings, while enabling new insights into the event-nature of learning. This international symposium addresses this topic by (1) showcasing and analyzing innovative uses of video technologies in the study of learning, and (2) historically situating such video experiments within traditions of scientific cinema. The term ‘scientific cinema’ is used in media studies to describe all uses of the moving image in scientific study, beginning with the pioneering work of the Lumière brothers in the 1890s. This symposium presents four contemporary case studies in which video is used innovatively to investigate mathematics learning experiences in three different countries (US, UK, Italy).

Symposium themes

The mass dissemination of recording technologies has always been pivotal for the emergence of innovative research methodologies in the social sciences (de Freitas, 2015, 2016; Schneider & Pasqualino, 2014). Over the last 15 years new facets of digital video have spread in society, not only through the availability of novel recording devices but through the pervasive growth of technical ecologies which made complex streams of digital video easily editable and communicable. These socio-technical innovations include action cameras (e.g. GoPro), streaming and generation of videos-of-videos (e.g. Skype), real-time diagramming (e.g. GPS drawing), eye-tracking and movement-tracking, and the assemblage of multiple video/audio sources (e.g. Multicam Editing). Scholars have begun to grapple with innovations in research methodologies as enabled and constrained by these digital recording devices (van Nes & Doorman, 2010). Derry et al. (2010) published a thorough review of video research, identifying principles for systematic selection from an extensive video corpus, analysis protocols, as well as discussing ethical issues with this kind of data. Software protocols for analyzing vast video archives are now deployed regularly, allowing researchers to annotate, code and sort images (Derry et al., 2010; O’Halloran 2013). But many of these software packages “mold” the data and reconfigure it, sorting and chunking it even before human eyes have seen it (van Nes & Doorman, 2010, p.6). The use of video analytic software without adequate attention to how such software is structuring the data becomes increasingly problematic as we begin to rely more and more on findings based on this data.

The question of what constitutes an event – as a unit of analysis - is brought to the forefront in video research, as scholars are able to examine activity at micro-scales of interaction, and trace micro-gestures or affective dispersal across a group. Derry et al. (2010) cited Lemke (2000), who claimed that “events are time-analogs of objects. Like objects, they have underlying structures reflecting multiple parts and timescales” (p.7), but the pragmatics of this comment need to be investigated and opened up for further exploration. This symposium will present four case studies exploring the use of video data in studying learning events. All four papers focus on mathematics education, as a way of sustaining focus on a particular kind of content, although each delves into very different kinds of learning.

Powell et al. (2003) reviewed a large spectrum of video research in mathematics education, but most of this was tacitly realist in its use of video, without adequate consideration for the specific ways that video structures the visibility of the event. The range of approaches to video collection and analysis includes Jacobs et al. (1999), who propose methods to “transform the video images into objective and verifiable information” (Jacobs et al., 1999, p. 718), and Hall, Nemirovsky, and Ma (2015) who see video creation and analysis as...
means to generate new images of teaching and learning. This symposium examines technical affordances and limitations of digital video technologies, such as action cameras, streaming, diagramming, and multicam editing, insofar as these become part of a learning event. Papers explore initiatives that interrogate social, educational, and methodological aspects of video-based research in the learning sciences, questioning previously unexamined ‘realist’ assumptions about the moving image (Schneider & Pasqualino, 2014).

Like any other technical apparatus, video technology brings with it a particular way of producing subjects. The danger is that we are all too likely to treat the video image as a recording of “raw data”, indexical of a given time-space relationship, as though it were a transparent realist representation of an event. Symposium presenters situate their work within the history of scientific cinema, a term from media studies that describes any use of the moving image in scientific study. Cartwright (1995) shows how scientific cinema has been part of the history of the moving image since its invention in the 1890s by the Lumière brothers. The early film makers, like Lumière, were experimental physiologists who were interested in recording the movements of the human body. Indeed, many of Lumière’s contemporaries regarded his invention of the cinematographe as a key contribution to physiology. The Lumière laboratories manufactured film stock and equipment for science - hundreds of films in the Lumière’s catalogues cover a vast array of different studies of bodily movement. During the early 20th century, scientists interested in the movement of the human body in various contexts – including formal and informal learning contexts – relied on moving image data to theorize about learning. By historically situating the ongoing work of the symposium members within this tradition, we hope to better understand the potential innovation (and limitations) that the digital nature of video allows today.

Symposium papers share a focus on the movement of bodies during learning events, exploring how the body is reconfigured in video data. This focus is pursued differently in each paper, studying the way the human body is both produced and recruited in different kinds of learning events. The challenge these papers explore is how to develop methods of inquiry that mobilize digital video innovatively, and with awareness of its power to structure what we see. Each set of authors explores: How does video help us plug into the heterogeneous duration of an event? What can we do – as researchers – that might allow us to study video data for the crystalline structure of a learning event? The symposium aims to address the conference theme by closely examining the specificity of the digital. We take inspiration from Wanono (2014) who describes how her work in anthropology has taken up new aesthetic-political perspectives that reflect the digital technology she is using. She uses programming as a creative language to re-assemble the pixels in her documentary video, using particular tactics that reflect her theoretical and political concerns. The aim of this symposium is to take on this challenge of thinking more innovatively about digital video research, while focusing on the complex temporal individuation of bodies during learning events.

The symposium will open with a 5 minute introduction to questions and themes, and set the stage for the four papers (each 15 minutes, including video data), followed by 25 minutes for the discussant and audience discussion.

**Paper 1: Graphing, measuring, and feeling force: Using multiple video feeds in complex learning events**
Ricardo Nemirovsky, Elizabeth de Freitas, and Kate O’Brien

This paper focuses on a teaching experiment in the UK with a group of 12 students, aged 11 years. The group participated in four 1.5 hour sessions where they worked with a variety of force sensors connected to computers generating real-time numerical and graphical displays. The goal of this study was to investigate student learning about physical force as an intensive (rather than extensive) quantity. Forces are typically learned through their effects, and tend to be associated with action. Research suggests that many students associate force with speed rather than acceleration. We revisit some of this previous research, but direct attention to how the differential intensity of force is an embodied experience. We used computer webcams and screen capture software, as well as wearable GoPro cameras and wall-mounted cameras to build a video-rich environment. As part of the sessions, real-time and slow-time video data were folded into the experiments, allowing students to investigate the otherwise invisible concept of force. This paper presents data from this research experiment, and shows how video was used to open up multiple temporalities in the learning event.

Our data analysis is microethnographic: a collection of techniques and approaches tracing the moment-by-moment bodily and situated activity, encompassing talk, gesture, facial expression, body posture, drawing of symbols, manipulation of tools, pointing, pace, and gaze (Erickson 1996, Goodwin 2003, Erickson 2004, Stivers & Sidnell 2005, Streeck & Mehus 2005). Our data sources include: four GoPro cameras head-held by children, two electronic bracelets recording temperature, skin electric conductivity, and heart pulse, one hand-held
camcorder, three wall-mounted GoPro cameras, one for each team, screen capture videos of force vs. time graphs generated by using force sensors.

Building on Henri Bergson’s (1889, 1996) distinctions between time and duration, and between extensity and intensity, and later reworkings of these ideas by the philosopher Gilles Deleuze, this paper explores the work that video does in learning about invisible forces. We propose that three kinds of temporalities were woven together through the use of video. Our use of video opens up the learning event to reveal: 1) Parallel temporalities in the synchronous depiction of the same events recorded from different perspectives, 2) Graphical temporalities in the juxtaposed screen capture alongside the wearable GoPro, and 3) Recursive temporalities in that students watched and reflected on these videos as they were replayed to them at various speeds. We weave these three temporalities together as part of the rich differential fabric of the event. For instance, in session 4 a group of children travelled in an elevator moving up and down while one child stood still on a force platform or scale. As the force measured by the scale was recorded on a graph of force vs. time, the elevator’s glass doors were videotaped with a webcam to keep track of its movement and stops. Later, in the classroom, the whole group watched and discussed the video of the graph and of the glass elevator’s doors. At times these videos were played in slow motion. As children and instructors watched and discussed these videos, additional videos with the whole group where recorded for subsequent study. These other dimensions are not spatial in the typical sense, in that they follow Bergson’s attempts to create a “new empiricism” that might study duration without representing it in terms of sensory-motor action.

Based on the case study, this paper elaborates on how the video data furnishes parallel, graphical, and recursive temporalities which together create a productive medium to learn about the intensive nature of force and its relation to movement. The use of video allowed students and researchers to investigate the conjunction of heterogeneous temporalities in the working sessions, unpacking learning events in terms of their temporal complexity.

Paper 2: Reflections on video-based techniques for studying bodies on-the-move in an immersive mathematics exhibition

Molly L. Kelton and Jasmine Y. Ma

We present video-based methods developed to study visitor learning in Taping Shape, a large, immersive geometry exhibition installed in a US science center, with the objective of investigating a technical ecology for recording, analyzing, and representing collective sense-making on-the-move in immersive-scale mathematics environments. We critically reflect on our own methods of viewing and mapping complex multi-video assemblages of mobile mathematics learners.

Extending scholarship on family learning in museums (Ellenbogen, Luke, & Dierking, 2004), our theoretical framework drew on theories for understanding walking and movement as forms of place- and sense-making (Hackett, 2015; Lee & Ingold, 2006), as well as scholarship that views sensual experience and material exchange as genuine constituents of mathematical thinking and learning (Nemirovsky, Kelton, & Rhodehamel, 2013).

Data come from a video-based field study (vom Lehn, Heath, & Hindmarsh, 2002) of visitors to Taping Shape. The unusual geometries of the 3000-square-foot immersive mathematics exhibition presented numerous data collection challenges, including the inexistence of any single panoptic vantage and visitors’ mobility as they explored the space. Our records come from multiple video technologies, including stationary 3rd-person cameras and wearable 1st-person cameras.

While methods of analysis included multimodal microanalysis (e.g., Erickson, 2006; Jordan & Henderson, 1995) we critically departed from its more orthodox articulations. Specifically, our theoretical framing pushed us to resist viewing events as having official boundaries or representing (a)typical phenomena. Instead, we treated video-recorded events as pointing backward and forward along experiential trajectories. To understand collective family-group activity, we repurposed video-editing software for multi-camera synchronization and viewing (see Figure 1).
Analysis was conducted through online collaborative viewing sessions during which we focused on one or two 1st-person camera angles at a time. Extending interactionist methodologies for studying learning on-the-move (Hall & Stevens, 2015), we crafted techniques for spatial transcriptions that coordinate representations of verbal and nonverbal interactions with spatio-temporal maps of members’ pathways through the exhibition (see Figure 2).

Results, in the form of methodological reflections, address the increasing use, and under-theorization, of wearable cameras in studies of learning on-the-move. While it is tempting to assume wearable cameras provide a more intimate vantage, our analysis leads us to question a simplistic mapping of 1st- and 3rd-person camera angles respectively onto ‘intrinsic’ and ‘extrinsic’ perspectives on experience. Additionally, in developing spatial transcriptions, we encountered a tension between (a) representing trajectories of multiple moving bodies in interaction and (b) representing the multiplicity of the body in terms of multi-modal expressions of hands, eyes, feet, etc. Finally, our attempts to stay with continuous flows of time and movement were imbricated with a countervailing desire to discretize participants’ pathways (evidenced by the dots in

Figure 1. Screen capture from multi-camera software environment. 1st-person camera views are shown for four members of a multi-generation family group inside a region of the exhibition shaped like a double torus.

Figure 2. Excerpt of spatial transcript representing a family’s coordinated talking and walking in the exhibition.
Figure 2, placed at 5-second intervals), echoing the slicing up of movement in early scientific cinema (de Freitas, 2016).

This paper’s significance lies in advances to understandings of emergent video-based methodologies for studying immersive mathematics learning environments. While these spaces afford opportunities for encountering mathematics in unprecedented ways, they also raise important methodological questions with respect to research on learning about mathematical objects by moving through them.

**Paper 3: Collecting and capturing movement in the mathematics classroom:**

**Assembling the researcher and the digital**

Giulia Ferrari and Francesca Ferrara

This paper discusses a case study in Italy with a class of grade 7 students aged 12 years. The study is part of a medium-term classroom intervention concerning mathematical activities with graphing motion technology. The class worked on the creation of couples of real time graphs, which capture spatio-temporal relationships associated to movements. These movements occur with pairs of students who move two controllers simultaneously in front of a sensor, in a wide interaction space. The main aim of the intervention was to learn function by means of a graphical approach. Classroom interactions were filmed using two mobile cameras to capture activity from different points of view. Additional data comes from recordings of the graphical window. Therefore, the combined videos capture two students creating motion graphs, the classmates seated all around watching them, and the computer screen displaying real-time graphs (e.g. Figure 3).

![Figure 3. Combined videos with two data sources](image)

Our analysis is devoted to capturing and tracing the moving bodies and choreographies of collective movement in order to better grasp the potentiality of the individual and collective body as a center of indeterminacy and understand dynamic aspects of temporality as duration (in line with the vision of Bergson, 1896/1988). In the style of early scientific cinema, the assemblage of the data helps us examine the event and the entanglement of mathematics and the learning bodies, as numerous unanticipated contingencies get incorporated (de Freitas, 2016). In so doing, we hope to offer a vision of the body primarily as an expressive body. The actions of such a body are not mere communicational and cognitive representations of rational thinking, but are an actualization of the qualitative kinaesthetic dynamics and “gradient information” (Sheets-Johnstone, 2011) experienced by students through change.

This perspective calls for the development of experimental methodologies to enrich research practices based on video recording and the subsequent use of professional video editing software (Derry et. al, 2010). For example, Multicam Editing Software (e.g. Final Cut Pro) allows for automatic pairing of video sources that have been recorded simultaneously from different angles. The software works through audio synchronization, which uses audio waveforms to compare and match different sources over time. Therefore, it creates video displays that—through the audible—embrace multiplicity of points of view around a learning event, assembling the researcher and the digital in new ways.

In this paper, we present these new ways of assembling with the data by discussing how synchronized multiple video streams help us: (1) make apparent distributed and unexpected dimensions of the classroom event; and (2) re-assemble complex learning events which involve a multiplicity of bodies simultaneously active in the classroom. We also delineate how the integration of videos from multiple sources may question the very act of seeing, interpreting, and learning of students, educators, and researchers. In addition, it addresses current issues emerging from theories that portray bodies as dispersed across auditory, visual, digital, kinaesthetic, and material dimensions (e.g. de Freitas and Sinclair, 2014).
Paper 4: How did they do that? Using video-elicited re-enactments to invite ensemble learning in mathematical activity
Rogers Hall and Lauren Vogelstein

Video recordings are commonly used as data for analyses of learning and teaching mathematics and a wide variety of other conceptual practices (Derry et al., 2010; Hall & Stevens, 2015). We report on research that uses video records both as the object of mathematical exploration and as data for understanding how learning and teaching are organized in that exploration. We focus in particular on using video-elicited re-enactments both to create and to analyze ensemble mathematical activity (Ma & Hall, in press).

As object, we used video records found in wide media circulation to create environments for exploring and learning mathematics. The “found object” in this paper is an episode selected from the television coverage of dance performances in opening ceremonies of the 2016 Rio Olympic Games (Figure 4, left). As data, we captured and analyzed video records of four-person ensembles (called “quartets”), who used their bodies and physical props (e.g., 7’ x 7’ square Mylar™ sheets) to re-enact what Rio performers were doing in the found video object (Figure 4, right). The quartets we studied used re-enactments to pose and answer basic questions concerning “How did they do that?” in found video from the Rio performance. We also used video-elicited re-enactments of our own to analyze what quartets were doing as they explored the original video object (Vogelstein, Hall & Brady, 2017).

Figure 4. (left) Video stills from television coverage of the opening ceremony for the Rio 2016 Olympic Games. Quartets in the “found” video used square, reflective sheets to create a dynamic array visual forms. (right) Video still images (toon sequence) from above and to the side as a quartet (PhD scientists, now middle school STEM educators) enacted a double reflection of their Mylar™ square prop.

Video-elicited re-enactments, both by study participants and analysts, involved forms of doing that led to explanations and new discoveries beyond what was possible by only viewing the found (or recorded, for research purposes) video. The first part of our paper shares findings from close analyses of video-elicited re-enactments of mathematical activity by ensemble quartets. The second part of our paper argues for re-enactment as a powerful addition to methods of interaction and multi-modal analyses of learning and teaching.

We captured video recordings of talk and activity in an ensemble performance space, treated as a clinical interview in which research participants were asked to make things together. Cameras and microphones
were positioned to capture different perspectives on re-enactment, as quartets alternated between closely inspecting the Rio video (viewing) and enacting their own efforts to create dynamic visual elements they found in the recordings (doing through re-enactment). We asked quartets also to explore expressive possibilities with props to create movement sequences with interesting visual and mathematical qualities. Our approach theorizes learning as consequential shifts in how people participate in conceptual practices that also change during their participation (Hall & Jurow, 2015; Lave, 2012). Our design based research seeks to create new forms of mathematical activity that combine cultural activities from everyday life with formal schooling (Hall, Ma & Nemirovsky, 2015; Ma, 2016, 2017).

We report several findings. First, participants found video records rich in detail, but recognized these offered a limited perspective and only partial access to techniques involved in ensemble performance. What could not be seen (or heard) while viewing became a deeply engaging problem for quartets to work out while doing (i.e., during re-enactments). Second, quartets with different backgrounds (i.e., middle school students, STEM educators, and professional dancers) explained “how did they do that” in ways that drew from familiar cultural practices (e.g., how task formats signal mathematical concepts in school textbooks). Third, discoveries made while doing (re-enactment) went well beyond what was possible while viewing found (or recorded) video alone. For example, while using Mylar™ sheets as a 1:1 scale model of props in the found Rio video, reenactments allowed participants to explain not only what Rio performers (or study quartets) were doing, but also to make discoveries about with might be done with the set up consisting of ensemble-plus-props. This included necessary aspects of technique (e.g., that thumb and index finger grips on corners of the Mylar™ sheet cycled between “up” and “down” positions during complex performance routines) and discoveries about new, expressive possibilities that had interesting mathematical meanings (e.g., “gathering” the Mylar™ sheet as a handy transition point during geometric transformations, or “billowing” the sheet in ways that made novel, extra-planar shapes and opened up new ways of operating together in the ensemble).

Finally, analysts’ bodies are rarely used in systematic analysis of the interactive organization of learning and teaching (e.g., Erickson, 2004, proposes choral readings of transcripts, augmented with scored rhythm or beat). We argue that ensemble re-enactment is a powerful but underutilized method for interaction analysis in learning sciences research. Much as archeologists re-enact tool use or hypothesized cultural practices in relation to the built environment (e.g., using sun, moon, star and building alignment as an agricultural calendar), we and our research participants made discoveries about the expressive possibilities of ensemble-plus-prop set ups that went well beyond a typical, seated viewing of found video recordings. As a matter of method, we recommend closer attention to reenactments that place analysts’ bodies into the very cultural activities of interest in their analysis. Linked to the organizing theme of this symposium on the history of film and in scientific visualization and discovery, viewing and doing (re-enactment) together are more powerful than viewing alone.

References


Exploring the Adoption, Spread, and Sustainability of an Informal STEAM Learning Innovation in Schools

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Abstract: This symposium brings together different studies on the adoption and sustainability of FUSE Studios, an alternative STEAM learning infrastructure. Since its launch, FUSE has been adapted successfully in 136 different school-based implementations operating across 18 different states and two countries (USA and Finland). Yet, despite being tailored to each context by local actors, FUSE has largely managed to preserve the integrity of implementation as educational innovation. Each contribution explores a point in the lifecycle of a FUSE adoption and describes local adaptations of the approach in the US and in Finland. In addition to addressing the critical question of how new educational innovations are adopted and sustained, this symposium provides perspectives on how to balance adaptability to local contexts and the integrity (rather than fidelity) of implementation.

Keywords: STEAM; scale-up; organizational learning; Actor-Network Theory

Session summary
A common goal in the learning sciences is the conceptualization and design of learning environments that improve learners’ opportunities and contexts for learning. It is also a goal to implement more broadly those carefully tended pilot innovations that achieve these objectives. While the diffusion of innovations has been studied and conceptualized in other fields (e.g., Greenhalgh, et al., 2004; Rogers, 2003), far less is known about how educational innovations travel between contexts and what factors aid or hamper wider implementation. The existing literature makes two key points. First, while initial adoptions of an innovation can be made with significant support by an implementation team or partnership, moving and ‘scaling’, beyond a local, carefully tended context can be difficult and is often unsuccessful (Clarke, 2008; Hubbard, Mehan, & Stein, 2006; McNeil, 2002). Second, the adaptability of innovations to new contexts is an important contributing factor in their wider implementation and spread (e.g., Coburn, 2003; Cole, 2005; Penuel et al., 2011). Designing for adaptability is, however, tricky and poses a two-horned dilemma. On the one hand, while insisting on strict adherence to ‘fidelity of implementation’ (O’Donnell, 2008) may preserve the organization and elements of an intervention’s original design, it also stifles educators’ abilities to tailor an innovation to local contexts. That may weaken the innovation’s fit to the local context and reduce the ownership local educators experience with regard to the innovation. On the other hand, allowing for local adaptation risks educators inadvertently undermining what made the original innovation successful, producing ‘lethal mutations’ (Brown, 1992) or depriving the implementation of ‘integrity’ to its original core principles and practices (LeMahieu, 2011). While the idea of designing for adaptability is common, research on adapting in practice is still rare.

This symposium brings together four different case studies of how a particular educational innovation called FUSE Studios has been and is continuing to be adopted and adapted in 137 different school-based implementations operating across 18 different U.S. states and two countries: the United States and Finland. (For an overview video about FUSE, visit www.fusestudio.net). When implemented with integrity of implementation—as prior research shows it can be at the scale of a large Midwestern public school district (Stevens et al., 2016)—FUSE represents a significant departure from typical classroom practice. Participating in FUSE involves students exploring a collection of about 30 STEAM (science, technology, engineering, arts/design, and math) challenge sequences that level up like video games. In-school implementation models
vary, but a common approach is for a FUSE Studio to meet for two or three periods during a school week. Examples of challenge activities include programming a robot to perform actions (“How to Train Your Robot”) building your dream home in a digital 3D environment (“Dream Home”), and a range of challenges that involve making 2D digital designs that students then 3D print (e.g. “Print my Ride” and “Eye Candy”). FUSE classrooms differ from traditional academic subject matter classrooms most fundamentally in the fact that students choose among the challenges, and the principle of choice extends to who they work with, how long they work on challenges, and whether they continue with challenges (or further levels within challenge sequences). The core commitment to choice is rooted in the goal of seeking to help students find, cultivate, and deepen their own STEAM-based interests. An outcome of the interest-based pathways that students navigate through FUSE because of choice is that peer-to-peer teaching and learning is the norm in FUSE classrooms, with teachers playing more facilitative roles. As well, in FUSE classrooms there is no testing, and grades are deemphasized or eliminated. Our prior field research on FUSE has shown common features of FUSE classrooms to include: (1) students devising and inhabiting diverse “learning arrangements” to do their work; (2) students developing and sharing “relative expertise” that emerges as they work on challenges of their own interest and choice; and (3) students pushing through frustration and learning from ‘failure’, since ‘failure’ is not penalized as it is in typical classrooms but treated as “just another try” (e.g., Ramey, 2017; Stevens et al., 2016). While our prior research has shown that these features are shared across implementations in schools within one large U.S. school district, the question we pursue here is whether and how these common, distinctive features of FUSE Studios are more broadly sustainable as it is introduced into new, more distant contexts.

The focus on a single educational innovation (FUSE Studios) for this symposium is strategic, because it allows for an analysis of how the same ‘package’ (Becker, 1972) is interpreted and implemented under different conditions, thereby making those conditions visible and showing the range of possibilities for an innovation, in relation to particular features of local contexts. Here, we follow the broad logic of studies of the Fifth Dimension, which employed a garden metaphor to ask about the relationship between ‘seeds’ (in this case, the FUSE suite of tools, materials, and recommended practices) and the local ecological conditions in which the seeds grow, thrive, mutate, wither, or die (Cole, 2009).

Extending the ecological metaphor, this symposium considers implementation in terms of a life-cycle, studying how the implementation of FUSE at different phases of its life-cycle. For the purposes of this symposium, we conceptualize implementation in terms of three potential phases: getting in, getting rooted, and spread. Getting in refers to how a school (or collection of schools) decides to implement and adapt their basic infrastructure to accommodate the innovation. Getting rooted refers to the phase in which local educators, working in partnership with the university-based FUSE team, work out the details of an implementation, adapting it and, at the same time, adapting local practices, to stabilize it within the local school context. Finally, spread refers to both the intentional and emergent ways in which FUSE has moved from two afterschool implementations in 2013 to 136 implementations spanning the US and two countries.

Each of the four contributions to this symposium represents a case study of implementation, at different phases in the life-cycle, and each contribution provides an analysis of how FUSE is interpreted, adopted, or adapted. The contextual conditions in which FUSE has been introduced vary considerably. The first contribution traces how FUSE evolved from an afterschool implementation to a stable, in-school implementation in collaboration with a large Midwestern school district. The second contribution focuses on a later stage in the spread of FUSE, in which FUSE is being adopted across a wide variety of geographically-distant schools. This case study is based on nine new schools implementing FUSE in distinct ways that are representative of patterns in the larger dataset. The third contribution focuses on the first year of FUSE implementation into the very different institutional and cultural contexts of public elementary schools in Helsinki, Finland, where FUSE is currently implemented in six schools. This analysis is based on the first two schools to implement FUSE in 2016. The final contribution is a case study of how FUSE is being implemented in one public school classroom that represents a different but growing species of FUSE adoption; while early adoptions of FUSE in public schools have largely been as stand-alone classes within a traditional school infrastructure, the growing interest in STEAM and makerspaces has led to FUSE being integrated into classes and spaces oriented toward these goals. This case study explores this species of implementation. Taken together, these cases allow us to explore adaptations of FUSE as processes of mutual appropriation (Downing-Wilson, Lecusay, & Cole, 2011). By focusing on a single educational innovation in different contexts, we will offer both concepts and specific empirical findings to contribute to questions of how learning scientists can bring their design offerings to wider audiences with integrity of implementation (LeMahieu, 2011). This 90-minute symposium will include an eight-minute introduction, fourteen-minute presentations, a ten-minute synthesis from the discussant, and fifteen minutes for audience questions.
Adaptation begets adoption: How an unusual educational innovation became part of the regular school day in a large Midwestern school district
Jaakko Hilppö and Reed Stevens

In this paper, we present a study of the adoption and adaption of an innovative educational program called FUSE Studios, in a large Midwestern school district. Our paper focuses on a time period during which the implementation of the program expanded significantly and became a stable part of all of the 27 schools in the district. In specific, we highlight two key moments in this process. Given that FUSE Studios can be characterized as a highly unusual program, in the context of conventional school practices (Stevens et al, 2016), our study of its implementation represents an information-rich case study on the spread of educational innovations. Moreover, our paper provides one of the first studies that looks in detail at how an innovative educational program gets in, gets rooted, and spreads within a school district.

In our study, we conceptualize the adoption and adaption process of FUSE Studios from an Actor-Network Theory (ANT) perspective (Latour, 2005; Fenwick & Edwards, 2010). In other words, we conceptualize FUSE Studios as an actor, a particular assemblage of human and non-human actors, that through various moments of ‘translation’, gets incorporated into the standing and relatively stable actor-network of the traditional public school day. In ANT, an actor’s agency is based not in its inherent qualities but from the network of associations in which the actor comes to be embedded; actor-networks have effects, like stability or change. Yet, which actors come to be part of any network cannot be determined in advance, but rather, need be uncovered by researchers by tracing the associations within the network. Prior work in ANT has been able to show that, most often, the scope of the actor-network that constitutes, for example, a successful pedagogical program, is far more extensive and heterogeneous than it might at first appear (e.g., Nespor, 2002).

The data for our study come from open-ended interviews (Patton, 2002) with key personnel working on both sides of the FUSE Studios research-practice partnership; this includes the FUSE program coordinator, its two creators/founders and district coordinators and administrators. In addition, we have used documents produced by both parties, such as public school board records, local newspaper articles, blog posts, email exchanges and promotional material to understand the adoption and adaptation process. In our analysis we used both the interviews, as well as the existing documentation, to create a retrospective reconstruction of the implementation process and its different phases (e.g. Miettinen, 1999).

During the time period analyzed for this paper (Spring 2013 - Summer 2016) the implementation of FUSE in the district grew from reaching approximately 380 students in five schools to reaching 4000 students in 27 schools, through four different implementation models. Our analysis highlights two significant moments of translation in this process to illustrate the complexity of adoption, thus illustrating the value of ANT’s sensitivity to heterogeneity: (1) when FUSE Studios was adopted and adapted as an in-school exploration class; and (2) when FUSE Studios was further adapted into a district-wide engineering and design class. Furthermore, our analysis shows how a heterogeneous set of different actors, like late busses, equity goals, state standards, 3D-printed objects, parents, and a large industrial company took part in how FUSE Studios was incorporated as part of the students’ educational experiences in the district. For example, after the initial implementation, to respond to the positive feedback on the program and to achieve the district's equity goals, the district administrators looked into afterschool clubs, as a way to provide the FUSE experience to all interested 5th and 6th graders. However, due to the lack of late busses, the district could not transport students to and from the five schools that had FUSE Studios. This, along with the new state science standards that the administration needed to comply with, led the administration to contact the FUSE design team and eventually to design a new FUSE Studios implementation with them. This new version was then introduced to all of the schools in the district.

Moreover, our analysis shows that the process also produced new actors that were able to connect, translate, and stabilize the various constraints and pressures directed toward the extending network of FUSE Studios in the district. For example, as part of moving FUSE Studios into the school day, the district created a new administrative position, a STEM Coach, and delegated the daily management of the implementation to that position. At the same time a new version of FUSE Studios, as an in-school exploration class, was created, through collaboration with the FUSE Studios design team and the district administration. Both the new STEM coach and the new implementation of FUSE Studios played consequential roles later in the implementation process.

In sum, our study contributes to the still-thin scholarship that investigates educational change processes from an actor-network perspective (Fenwick & Edwards, 2010). As such, our paper adds to the current literature on educational change by illuminating the complex, heterogeneous arrangements involved in enacting change and countering overly simplistic, often top-down, narratives of how educational innovations are implemented.
Removing the blindfolds and finding the elephant: From diverse anticipations to convergent experiences of an educational innovation
Kay Ramey, Jaakko Hilppö, and Reed Stevens

Because FUSE requires a technological and pedagogical infrastructure that is quite different from traditional school infrastructure, it faces particularly intense challenges related to scale-up and sustainability (Hargreaves, 2010; Rogers, 2003). There is a risk that as FUSE Studios gets adopted into new schools, it may adapt too much to local contexts, losing its core design components. Conversely, it may not adapt enough, making it unsustainable. Therefore, in coordinating with schools implementing FUSE, we have attempted to balance adaptability to local constraints (Clarke, 2008; Hubbard et al., 2006; McNeil, 2002; Penuel et al., 2011) with integrity (rather than fidelity) of implementation (LeMahieu, 2011). In other words, rather than mandating strict replication, we provide training and support to foster implementations that align with both core design principles of FUSE Studios and local needs and circumstances.

This approach to implementation provides an opportunity to understand the work that stakeholders put into adapting and sustaining educational innovations. It also provides us with an opportunity to understand the sociomaterial conditions that lead to successful scale-up. Accordingly, this study examines FUSE as a boundary object (Star & Greisemer, 1989) and examines, via an Actor Network Theory (ANT) perspective (Latour, 2005), how the associations between the ideas, practices, and artifacts that constitute this object change over time, in local contexts, and how they shape implementation.

We draw on data from 57 schools implementing FUSE as a new program during one academic year. Many of these schools are high-need schools, with large underrepresented minority and low socioeconomic status populations, that received FUSE as a grant. Data collected from these schools includes: (1) written applications submitted by schools to fund and implement FUSE; (2) recordings of phone conversations between schools and our team; (3) observations and video recordings of facilitator training sessions; (4) interviews with students, facilitators, and administrators; (5) observations and video recordings of students doing FUSE; and (6) social media and community discussion board postings related to FUSE implementation. Here we focus on analysis of data from 14 focal schools implementing FUSE in distinct ways that are representative of patterns in the larger dataset.

Analyses of schools’ applications for FUSE showed 24 perceived qualities of FUSE that stakeholders associated with, as reasons for pursuing FUSE for their school. Among these, the most common were “STEM”, “STEAM”, “career preparation”, “equity”, “21st century skills”, “problem-based learning”, “collaborative learning”, and “personalized learning”. During facilitator trainings, additional associations were made, including associations with specific components of the technical infrastructure of FUSE, such as the 3D printers provided to each school as part of the program. Later analysis of interviews and community discussion board posts showed variation in the ways in which FUSE was integrated into the school day and the sociotechnical networks that ended up comprising FUSE in different local contexts. For example, while some schools experienced difficulty setting up the necessary technological infrastructure or finding physical space to run the program, others had well-equipped makerspaces before beginning the program and merely lacked curriculum for those spaces. Similarly, while some schools ran “pure FUSE” a totally choice-based, ungraded STEAM exploration experience, others felt pressure to align FUSE activities with standards (e.g., NGSS, ISTE, Common Core) and to find ways to assess and attach grades to student progress during their FUSE experience.

However, despite differences in initial conceptualizations of FUSE and implementation models, our analyses suggest that the program maintains high integrity of implementation across diverse contexts. For example, despite the wide variety of associations with FUSE listed in schools’ applications for the program, in interviews with facilitators, administrators, and students after they’d begun FUSE, discourse converged around a description of a common set of student and facilitator experiences. We consistently heard stories of students helping each other and collaborating on challenges, pushing through frustration and learning from failure, discovering new capacities and interests, and demonstrating greater engagement and fewer behavioral problems in FUSE than in other classes, qualities of FUSE we’ve identified in our previous research (Ramey, 2017; Stevens et al., 2016).

Based on these analyses, we argue that the adaptable nature of FUSE is what allows it to both get in and thrive in a variety of different contexts. In other words, the program serves as a boundary object, simultaneously allowing different stakeholders to form a variety of different associations with the program but also carrying with it a set of core associations that are resilient to changes in local ecology. This finding challenges conventional wisdom that tested educational innovations can or should be imported into new contexts as is, without adaptation and with what has been called “fidelity of implementation”. In our analysis,
adapting is not a threat but a means for sustainable implementation, not only in FUSE but in scaling up other technology-rich STEM learning environments in diverse school contexts.

FUSE as a “nested” phenomenon: How an innovative intervention fares within an existing context of innovation

Peter Meyerhoff

The interaction of a design-based research project with its context(s) of implementation represents an ongoing theoretical and empirical challenge in the learning sciences (Penuel, Cole, & O’Neill, 2016). Each context has a particular social, material, and institutional history that constrains and guides any educational intervention. On one hand, researchers seek to design for a consistent experience at scale: once a program has been iteratively developed and improved, the goal is to make it resilient to changes in context as new sites are added (O’Neill, 2016). At the same time, the differences among contexts may constitute precisely the phenomenon of interest in a design research program (Cole & Packer, 2016). FUSE, an interest-driven, STEAM learning environment (Stevens et al., 2016), has grown rapidly, and early research has suggested that it maintains its essential core across implementation contexts (DiGiacomo, Van Horne, & Penuel, 2017). An important possible difference has emerged, however. During early implementations, no activities other than FUSE were allowed in the room. But as the program has grown, some schools have brought FUSE in as an available option within established classes that already provide some form of interest-driven, choice-based activity structure. This raises a possible scenario that may be new to the literature on implementation, which normally conceptualizes innovative programs as phenomena foreign to their environment.

How does an innovation like FUSE fare when it enters a context of implementation in which its new practices are already explicitly well-aligned? The answer is not self-evident. Perhaps local actors, seeing nothing new in the innovation, will reject it altogether. Alternatively, it could be that since people in the environment are well-prepared for the new ideas, they might enthusiastically embrace them and let go of what came before. To investigate this question, I examine one case of a nested implementation: the installation of FUSE within the Tech21 elective at Eagle Lake Junior High. I conducted 6 months of observations in Tech21, spoke daily with the teacher, interviewed 7 school and district leaders, and examined internal district memoranda. I watched students work and talked with them about their experiences. I made regular counts as to how many students were engaged in each activity at any given time, and frequently asked students why they had chosen one activity over another. In what follows, I show that FUSE ended up in a stable, parallel co-existence with the existing Tech21 program.

In 2015, before district leaders learned about FUSE, Eagle Lake remodeled the school’s old science room into a “STEAM Lab,” which they called a “collaborative makerspace”, and created a new class, Tech21. A memo from the district’s technology director to the superintendent and the school board declared that Tech21 reflected a vision for “choice driven activities” that “engage students in STEAM topics, while fostering the development of important 21st century skills.” Eagle Lake had filled the STEAM Lab with an assortment of the latest devices and tools—Spheros, Makey Makeys, Cubelets, FlyBrix, and many others. Students had laptops with access to online tools and activities such as TinkerCAD, Unity, Minecraft, Kerbal Space Program, and CodeCombat. By the end of the year, however, administrators grew concerned about what they believed was a lack of what they called “progression” in Tech21. Searching for more structure, the technology director found FUSE and purchased the program for the 2016-17 school year, handing it to the Tech21 teacher, Mr. J, to implement.

The existing technical infrastructure—mobile devices with students well-acccustomed to their use—made it easy for students to get started in FUSE. Moreover, the open-plan layout of the STEAM Lab encouraged the movement and collaboration that is characteristic of student work in FUSE. Mr J provided moderate encouragement to students to choose FUSE challenges. However, other Tech21 activities—Minecraft, Kerbal Space Program, and FlyBrix in particular—attracted significant participation. In each Tech21 class, activity in FUSE eventually stabilized to account for about one-third to one-half of activity. Students mainly either stayed in or out of the FUSE environment.

At the same time, students’ engagement, as evidenced by their focus on and attention to their projects and their active collaboration with other students, remained broadly consistent across FUSE or non-FUSE projects. Most students entered Tech21 and went immediately to their work and remained involved through the end of the period; a few students even came in during their lunch period to continue working on their projects. Whether it was constructing a working airplane out of FlyBrix and cardboard, writing a program to solve a Rubik’s Cube, or designing a “dream home” in FUSE, students in Tech21 worked over extended periods on
complex, elaborate creative and technical projects. The one snag that occurred affected participants in FUSE and non-FUSE activities equally: Eagle Lake struggled to find a way to assess and grade participation in Tech21.

In sum, FUSE came into Eagle Lake as an innovation located inside another innovation. It occupied a parallel position within the STEAM Lab alongside the existing activities in Tech21 and found a core base of participants. This research suggests that a nested intervention may achieve successful integrity of implementation and complement, rather than dislodge, the new practices already in place.

“Please, no hanging around, return back to your own works” - Teachers and students negotiating social and cultural rules for their engagement and learning in FUSE
Kristiina Kumpulainen, Anu Kajamaa and Antti Rajala, University of Helsinki

Despite a proliferation of implementation efforts of novel learning environments to schools, resources are seldom directed into longer-term follow-ups of these efforts. In response to this research gap, we investigate the first year of adaptation of FUSE Studios in two Finnish schools. Building on cultural historical theorizing and ethnographic logic of inquiry, in this study we focus on how students and teachers negotiate social and cultural norms and rules for their engagement and learning in FUSE, a novel technological infrastructure designed to support choice-based STEAM learning based on students’ interests (Stevens, et al., 2016). In specific, we are interested in potential tensions that can emerge when existing social and cultural norms of schools meet with those rules and norms that participants attach and negotiate for their engagement and learning in FUSE.

As no educational innovation functions in a vacuum, in this study we investigate the axiology FUSE embodies, the experiences it generates, and the actions it makes possible and forecloses, both for students and their teachers, within the cultural context of Finnish schooling. Our study holds that it is important to examine possible disjunctures, resistances, and tensions between different sets of norms and rules, when educational changes are implemented, because these can provide important information on how educational innovations are locally adapted and what features aid or hamper their effectiveness (see also Rajala & Sannino, 2015; Kennedy, 2005). To this end, in this study we ask: How do students and teachers negotiate social and cultural rules for their engagement and learning in FUSE Studios?; and What tensions emerge, and what are their consequences, when existing social and cultural norms of the school interact with those established for FUSE?

The ethnographically (Marcus, 1998) collected, empirical data for our study are derived from two Finnish public schools with children aged 7 to 12 years old (School 1: 251 students and 16 teachers, School 2: 535 students and 28 teachers). FUSE was introduced to these schools by the city, to support the implementation of the new Finnish core curriculum in practice. The teachers of the schools were provided with a 2-day training workshop on FUSE, combined with online tutoring from the developers.

The empirical data are comprised of video-records and field notes, of students’ and teachers’ social activity in FUSE, and student and teacher interviews, collected intermittently over one academic year. Sociolinguistic and ethnographic discourse analysis (Gee & Green, 1998) and interaction analysis (Jordan & Henderson, 1995) have guided the analyses. We analyzed moment-by-moment interactions and critical events in which tensions emerged with regards to the rules and norms for engagement and students’ learning practices in FUSE.

Our findings indicate that the forms of engagement and learning available to the students and their teachers in FUSE resonated in many ways with the Finnish core curriculum, which emphasizes connecting informal and formal learning and recognizing student expertise and local knowledge in solving multidisciplinary and authentic challenges. For instance, in their interactions in FUSE, the students actively applied and validated their previous experiences and knowledge, embedded in their social ecologies, in and out of school, in order to solve STEAM challenges of their preference. The students’ developing expertise and interests were also actively recognized by their teachers and peers in joint activities, as students were officially nominated as expert tutors of specific STEAM challenges. Here, the traditional teacher-student roles were transformed, as expertise became more relative. At an institutional level, the recognition of students’ expertise resulted in transformed social and cultural structures, as students were called upon from their regular class to the FUSE Studio to act as experts for a challenge that no teacher or other student could solve.

The findings also illustrate tensions. Not all students found interest in the STEAM challenges and the teachers struggled in motivating them. Also, some teachers resisted the freedom of student choice - an important FUSE design principle - to the result that they decided to close down some FUSE challenges, as they wanted to have more control over the content of the students’ work. Some forms of student engagement that characterize
FUSE were also found to result in tensions and restrictions. For instance, not all teachers appreciated the students’ “hanging around” in the FUSE Studios while the students followed and observed their peers’ work on challenges. These attitudes reflected the traditional norm of individual accountability for school work. Likewise, the forms of assessment built into FUSE (or lack thereof) created tensions as the teachers wanted to evaluate the students’ learning progressions in FUSE. For this reason, some teachers created additional portfolio and/or reflection tasks for their students. The interview data suggests that many of the teachers considered only formalized learning with a separate evaluation component as legitimately addressing the students’ learning.

Altogether, our study contributes to understanding local adaptation processes of FUSE into the everyday life of schools, with the actors’ point of view at the center. In this adaptation process, the adopters also actively changed the meaning of the practice. Hence, implementation goes along with transformation (Rogers, 2003, Kajamaa & Schulz, 2017). Our study shows how the teachers and students did not respond passively to FUSE but that their specific needs, objectives, sense-making and experiences importantly shaped their engagement and learning practices, leading to unexpected and creative solutions, which at times deviated from and contradicted with the original intentions and plans set forth for FUSE. The participants became not only adopters of the existing resources (i.e. the prefixed FUSE tasks), but actively drew from their previous learning experiences, resisted, initiated change, and challenged and shaped the implementation process. On this basis, we suggest that implementation of educational innovations needs to be viewed as a continuous process in which design, implementation and learning are intertwined.

References


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The Challenge of Assessing “Knowledge in Use”: Examples from Three-Dimensional Science Learning and Instruction

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Abstract: This symposium includes four papers focused on meeting challenges in the design and use of assessments of science proficiency for which students are expected to demonstrate their ability to explain scientific phenomena and solve problems by integrating disciplinary concepts with science and engineering practices. This view of multi-dimensional integrated science learning is exemplified by the performance expectations articulated in the Next Generation Science Standards. The four papers describe work that spans multiple grade levels and includes illustrations of the systematic design of assessments of knowledge-in-use for a range of life and physical science concepts, including a focus on energy. Illustrative tasks are provided together with data on student performance. The papers also consider issues of teacher implementation in classrooms, as well as methods that can be used to help teachers gain a deeper understanding of multi-dimensional science learning goals and effective assessment materials.

Symposium focus and overview
A key challenge in shaping science learning for the 21st century will be to develop new measures of learning that take into account what it means to be proficient in science (Pellegrino, 2013). The emergent view on proficiency, grounded in learning sciences research, emphasizes using and applying knowledge in the context of disciplinary practices. Referred to as knowledge-in-use, this perspective on science proficiency is a centerpiece of the National Research Council’s (NRC) Framework for K-12 Science Education (NRC, 2012), is embodied in the Next Generation Science Standards (NGSS Lead States, 2013), and emphasized in the NRC report on developing assessments to measure science proficiency (Pellegrino, Wilson, Koenig, & Beatty, 2014). Central to this view is that disciplinary content and practices should be integrated so that as students apply knowledge to make sense of phenomena and solve problems, they deepen their conceptual understanding of content as well as their understanding of how to do science. This view of the goals of science learning can by juxtaposed with results of international research on science achievement showing that students often possess only fragmented knowledge of isolated science facts and lack the abilities to use their knowledge to explain phenomena or solve meaningful problems (e.g., OECD, 2012).

The shift to integrating science practices with disciplinary core ideas and crosscutting concepts, as emphasized in the Next Generation Science Standards, is based upon studies of actual scientific practice and what we currently know about student learning (e.g., NRC, 2007, 2012). This research corpus points to the importance of integrating content (i.e., disciplinary core ideas and crosscutting concepts) and practices by emphasizing that rich science learning requires tight coupling of what students know and what they can do. This presents a different way of thinking about science proficiency in that disciplinary core ideas and crosscutting concepts serve as thinking tools that work together with scientific and engineering practices to enable learners to
solve problems, reason with evidence, and make sense of phenomena (NRC, 2012). It also signifies that measuring proficiency solely as acquisition of core content knowledge is no longer sufficient (see e.g., Pellegrino, 2013).

Knowledge-in-use learning goals comprise the standards in the NGSS and are articulated as Performance Expectations (PEs). Each NGSS performance expectation combines a science or engineering practice, disciplinary core idea, and crosscutting concept into a single statement of what is to be assessed at the end of a grade level or grade band. It incorporates all three dimensions by asking students to apply disciplinary knowledge and make connections to a crosscutting concept as they engage in a science or engineering practice. An example for middle school physical science is: Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

In order to identify factors affecting the development of science proficiency and examine the efficacy of different approaches to supporting students’ learning, assessments are needed that can reliably and validly assess students’ knowledge-in-use (Pellegrino et al., 2014). This symposium reports results from a set of projects focused on the challenges associated with the design, validation, and use of such assessments to support student learning and classroom instruction. The first paper describes a design approach that starts with a representation of the knowledge underlying each of the dimensions associated with specific performance expectations and then translates that into targeted learning performances and associated assessment tasks that can be used formatively in middle-school classrooms. The second paper applies a similar approach to the design of assessments focused on energy concepts at the middle school level. Results are reported on reliability and validity, including evidence of the assessments sensitivity for showing gains in student performance following instruction that emphasizes three-dimensional learning. The third paper describes work at the high school level on assessment of student understanding of energy together with efforts to build a system of assessments that can fulfill formative as well as summative purposes. The fourth paper considers some of the challenges associated with helping teachers gain an understanding of three-dimensional science learning and assessment. It discusses results from a contrasting cases approach that was used to support teacher learning at multiple grade levels about the properties of assessments of three-dimensional learning and their value for supporting instruction.

**Design of next generation science assessments: Measuring what matters**

James Pellegrino, Christopher Harris, Joseph Krajcik, Brian Gane, Kevin McElhaney, Phylis Pennock, Nonye Alozie, and Sania Zaidi

In this paper we overview our systematic and scalable approach for designing assessment items that measure student proficiency with new science learning goals that integrate disciplinary core ideas and crosscutting concepts with scientific practices. The assessment tasks are intended for formative use within classroom instruction. There is tremendous need for such assessment design work, as assessment plays a central role in supporting implementation of the new directions in science education both in the U.S. and internationally (Pellegrino et al., 2014). Our approach to meeting this challenge uses principles of Evidence-Centered Design (ECD; e.g., Almond, Steinberg, & Mislevy, 2002). ECD has been used in wide-ranging assessment design contexts, from the development of large-scale, high-stakes assessments to the design of classroom-based assessments. ECD emphasizes the evidentiary base for specifying coherent, logical relationships among the (1) learning goals that comprise the constructs to be measured (i.e., the claims we want to make about what students know and can do); (2) evidence in the form of observations, behaviors, or performances that should reveal the target constructs; and (3) features of tasks or situations that should elicit those behaviors or performances. We use ECD to systematically unpack science learning goals and synthesize the unpacking into multiple components that we call learning performances. Learning performances are knowledge-in-use statements that guide the development of assessment tasks and rubrics for measuring three-dimensional learning goals such as the performance expectations of the NGSS. Figure 1 overviews our overall design process that follows the logic of ECD and contains 3 distinct phases – Domain Analysis, Domain Modeling, and Task and Rubric Development. While the figure illustrates a linear process, the actual process is very iterative and recursive.

We begin Domain Analysis by first unpacking core ideas associated with a bundle of NGSS Performance Expectations at a given grade level or grade band. The process involves elaborating the meaning of key terms, defining expectations for understandings for the targeted student level, determining assessment boundaries for content knowledge; identifying background knowledge that is expected of students to develop a grade-level-appropriate understanding of a disciplinary core idea; and considering research-based problematic student ideas and misconceptions. Next, we unpack the science practices. The unpacking involves consideration of the core elements of the practice, intersections with other science practices and the evidence required to demonstrate the practice. This is followed by unpacking the crosscutting concepts, which involves identifying
the important elements of the concept and opportunities for intersections with the science practices and with the particular disciplinary core ideas that are the target of the assessment. Using the unpacking documents, we create a modified type of concept map, called an integrated dimension map. This map represents connections between the three dimensions (see Harris et al., 2016).

Domain Modeling involves 3 components. First we articulate Learning Performances. We use the integrated dimension maps as resources to help conceptualize and articulate a set of Learning Performances (LP) that constitute a trajectory towards mastery of each performance expectation (PE). Learning Performances are opportunities for students to demonstrate the knowledge-in-use they need at a specific point in the school year to be on track towards mastery of a PE by the end of the school year (Harris et al., 2016). For each PE, we develop multiple LPs. Once we have articulated LPs we move to specifying task design patterns in order to identify an “assessment argument” for constructing tasks, as per guidelines of ECD. Our assessment argument builds on the claim articulated in each Learning Performance by constructing a LP-specific design patterns that includes: (a) the focal (and additional) knowledge, skills, and abilities (KSAs) underlying the Learning Performance; (b) evidence statements that articulate how those KSAs can be observed in student performance; and (c) assessment task design features. We construct evidence statements by considering how we can observe student ability in each KSA; these statements are later used to develop assessment tasks and rubrics. Finally, we articulate characteristic and variable features for assessment tasks that help ensure the task can elicit the focal KSAs. In articulating these features, we use a Universal Design for Learning framework to also ensure that our design features result in tasks that are accessible to all students.

The final phase of the design process involves using the information detailed in the assessment argument to develop assessment tasks and rubrics. The task design depends on the specification of characteristic and variable task features and allows for assembly of multiple tasks within a “family” where the variations among the tasks can readily reflect intended levels of challenge. The task design process also takes into account the forms of evidence needed to support the learning performance claim and the ways in which that evidence will be scored and evaluated for purposes of rubric development.

We have used the design process outlined above to unpack 9 PEs from the physical and life science disciplines and have created over 100 assessment tasks. The designed tasks are technology-enhanced (e.g., use of simulation, modeling software, video) and many tasks use non-textual representations to elicit student responses (e.g., through drawing or modeling). Across a series of studies using multiple research methods, we have assembled data indicating that our tasks are functioning as intended, minimize construct-irrelevant variance, and support teachers’ classroom practice. For example, classroom observations have shown that teachers use the assessments in a variety of different modes, spanning a range between formative and summative use. Student cognitive lab studies have provided both data on task comprehensibility and identified issues of construct-irrelevant variance. Task performance studies have provided a preliminary set of data on item features (e.g., difficulty) that affect student performance and on the utility of our rubric design in affording partial credit scores based on the presence or absence of FKSAs in the student responses.

![Figure 1. Illustration of the major elements of the assessment design process.](image)
Assessing students’ progression in developing knowledge-in-use for energy
Knut Neumann, David Fortus, Joseph Krajcik, and Jeffrey Nordine

This paper details efforts to develop summative assessments of Middle School students’ knowledge-in-use about energy as part of an ongoing effort to compare two different approaches to teaching Energy in Middle School science instruction. Based on the Next Generation Science Standards we identified a set of performance expectations for elementary and middle school science to characterize the knowledge-in-use about energy expected of students at the end of middle school (NGSS Lead States, 2013). In authoring tasks, we used an evidence-centered-design approach and followed the procedures discussed in the preceding presentation and suggested by Harris et al. (2016). The procedure began with unpacking the performance expectations to identify major elements of the disciplinary core idea (DCI), the crosscutting concept (CCC), and the science and engineering practice (SEP). From these elements, learning performances were generated by combining one or more elements of the DCI, CCC, and SEP. Each of these learning performances represented a different aspect of a performance expectation, in order to ensure a sufficiently broad, yet concise specification of the construct (seeMessick, 1995). For each learning performance, an assessment argument was created which specified the evidence required to conclude that students have met the learning performance together with additional knowledge that students may need, as well as fixed and variable task features. The assessment argument served as a blueprint for the authoring of tasks. We authored a total 24 tasks assessing students’ knowledge-in-use about energy (see Figure 2 for a sample task).

Figure 2. Sample item assessing students’ ability to develop a model to describe Felix Baumgartner’s jump from the stratosphere using their knowledge about potential gravitational energy.

In addition to their function in the authoring of tasks, the assessment arguments also served as a basis for the development of scoring rubrics specific to each item to guide the interpretation of students’ responses. Assessments of students’ knowledge-in-use must not separately target students’ ability to engage in a SEP or their knowledge about a DCI or CCC independently, but their ability to engage in a SEP in the context of a DCI and CCC, assessments. Therefore, the scoring rubrics were designed to credit demonstrations of the integration of a SEP, with a DCI and CCC. To obtain insights into how reliably and validly the tasks assess students’ progression in developing knowledge-in-use about energy, the tasks were administered to N = 311 students from 8th grade classes at two schools in Midwest USA – prior to and after an instructional unit on energy. To examine the reliability and validity of our assessments, we first examined scoring quality. About 20 percent of student responses were scored by a second scorer, leading to good to very good agreement, p > .82. We then explored the extent to which the tasks, as a whole, functioned as a reliable measure of students’ three-dimensional learning about energy. Our analyses yielded reliability of α = .63. In a continued effort to examine the validity with which the developed task assess students’ knowledge-in-use, we investigated the correlation of students’ pre-test scores with their last grades in Science (rS = .33, p < .001), Mathematics (rM = .19, p < .001) and English (rE = .28, p < .001). Finally, we investigated the extent to which the assessment measures students’ progression in developing knowledge-in-use about energy in terms of score gains between pre- and post-test. In doing so, we found a significant and strong gain, Cohen’s$ d^1$ = 1.03.

The results suggest that our approach to developing assessments of students’ knowledge-in-use about energy is suitable to yield reliable and valid assessments. The reliability is below a typically applied cut-off value of $\alpha > .80$, but still satisfactory given the complex knowledge-in-use construct. In addition, the correlations of the pre-scores with student grades, and the strong gain in students’ scores from pre- to post-test suggest that the assessments indeed represent valid assessments of students’ progression in developing knowledge-in-use. We envision our procedure as a blueprint for developing high quality tasks to assess students’ learning as a function of instruction and to compare different instructional approaches in terms of their efficacy. The presentation will discuss in greater detail task development procedures, with sample tasks, scoring rubrics and scored students responses, and discuss how the data can be analyzed to obtain reliable and valid information about students’ progression in developing knowledge-in-use about a core science concept.
Toward a system of classroom assessments for three-dimensional secondary science learning: The case of the Aspire study
Erin Marie Furtak, Derek Briggs, and Rajendra Chattergoon

This presentation will draw examples from the ongoing work of the Aspire Research-Practice Partnership, a long-term, mutualistic collaboration (Penuel et al., 2011) between researchers at the University of Colorado Boulder and science curriculum coordinators in a culturally, linguistically, and socioeconomically diverse school district near a large city in the Western US. Our partner district has adopted sets of exit statements that are either aligned to or fully verbatim facsimiles of the Next Generation Science Standards and professional learning experiences are supporting changes in classroom practice. However, the secondary science teachers in the district are only beginning to realize these changes in their instruction.

We have taken the approach of developing, in partnership with the district and teams of high school chemistry, biology, and physics teachers, a system of classroom assessments aligned with this three-dimensional vision. To focus our work, we have dedicated our assessment design efforts to the disciplinary core idea and crosscutting concept of Energy cycling within systems. Consistent with the district’s focus on three-dimensional assessment, this has also included a focus on model-based explanation. We take as the centerpoint of this process of assessment design a model of cognition (Pellegrino, et al., 2001) based upon a hypothesized learning progression for energy (Neumann et al., 2013) that articulates the development of student understanding of energy forms, transfer/transformation, dissipation, and conservation.

Our design activities have started with tracing energy as a crosscutting concept using the original format of the Neumann et al. (2013) learning progression, which has involved determining how the energy concepts it articulates apply in chemistry and biology. At the same time, we have worked toward creating three coordinated forms of classroom assessment linked to this learning progression: a pre-post summative assessment that will allow us to model student growth within and across grade levels; a modeling performance task that engages students in model-based explanation of an energy phenomenon across disciplinary contexts; and sets of embedded formative assessments that engage students in modeling and explanation of energy cycling in individual instructional units. We describe each in the following paragraphs.

Building on pre-existing, multiple-choice and constructed-response item sets from Neumann et al. (2013), Park & Liu (2016) and Opitz (2016), we have created clusters of items that map onto the energy learning progression, including those that focus on energy as it manifests in content-specific disciplinary core ideas, as well as sets of linking items that create opportunities for students to demonstrate their understanding of energy as a crosscutting concept that bridges their learning experiences in physics, chemistry, and biology. Our initial pilots of these item sets have indicated that items associated with the upper end of the learning progression are more difficult for students than those associated with the lower levels. Furthermore, the factor structure of the items is dependent on whether students were enrolled in a biology course or a physics course.

Acknowledging that the pre-post summative assessment focuses primarily on student understanding of energy as a disciplinary core idea and a crosscutting concept, we also are seeking to assess students’ engagement in model-based explanation through a performance task. Working with the example of ethanol-fueled engines, this task asks students to trace how energy from the sun is used to power a bus as it drives up a hill, tracing energy transfer and transformation from corn to ethanol production to powering a piston in a bus engine. Our ultimate goal is to score the performance task on the same scale we use for the summative pre-post assessment. Initial efforts to pilot this item indicated that high school students weren’t even sure where to begin to think about this problem, since it was so far outside their learning experiences in school. Furthermore, we have received surprising feedback from scientists, who self-consciously admitted they were unsure of how to trace energy in the contexts outside their areas of expertise. This raises questions as to the validity of claims we might make about high school student learning when it pushes on the boundaries between disciplines acknowledged and enforced by scientists themselves.

In parallel, we have collaborated with high school science teachers to co-design and embed formative assessments in units of instruction in which energy is explicitly taught: potential and kinetic energy in 9th grade Physics, chemical reactions in 10th grade Chemistry, and matter and energy cycling in 11th grade Biology. This process of co-design works within a pre-existing professional learning model to support teachers in designing, enacting, and determining next instructional steps for formative assessments (Furtak & Heredia, 2014), and engages teachers in adapting pre-existing scaffolds to engage students in modeling (e.g., Kang et al., 2016).

Preparing teachers to notice key dimensions of next generation science assessment tasks
In this paper, we report on a strategy for helping teachers shift their vision for assessment. The strategy entails analyzing sets of multi-component assessment tasks for their adequacy in eliciting students’ science proficiency. The aim is to shift teachers’ attention toward the power of tasks to elicit each of three dimensions of proficiency emphasized within the Framework for K-12 Science Education (NRC, 2012): their understanding of disciplinary core ideas and crosscutting concepts, as well as their grasp of science and engineering practices. The conjecture we explored in this design study is whether analyses of assessment tasks can support teachers in noticing key dimensions of proficiency that are either present or absent. In this paper, we present evidence related to this conjecture, and we consider the kinds of tasks that make it easier or harder for teachers to discern the dimensions of proficiency tasks are intended to elicit.

There is strong evidence that professional learning experiences organized around task analysis can shift what teachers notice about the affordances of particular tasks presented to students. Task analysis can help teachers discern, for example, the level of cognitive demand of tasks and how these relate to student learning opportunities (Boston, 2013). Analyzing tasks can also help teachers discern opportunities for students to engage in disciplinary practices while solving problems and attune to the language demands of tasks (Johnson, Severance, Penuel, & Leary, 2016). Learning research also suggests that key to helping teachers notice the distinctive features of assessment tasks and their enactment will be to present them with a set of “contrasting cases,” that is, a set of tasks that vary with respect to key features. According to Bransford & Schwartz (1999), “experiences with contrasting cases can affect what one notices about subsequent events and how one interprets them, and this in turn can affect the formulation of new hypotheses and learning goals” (p. 70). Therefore, when selecting tasks, teachers need to be presented with a range of possible opportunities that allow them to discern salient features, such as the use of practices to explain core ideas and prompts for students to reflect on crosscutting concepts.

Participants in this study were a total of 99 teachers from a single US state, organized into groups of three by grade level. There were 12 groups analyzing tasks targeting fifth grade students, 5 groups analyzing tasks targeting first grade students, eight groups focused on middle school tasks, and eight focused on high school tasks. We presented each group with a set of five or six tasks, and we told the teachers that each task was intended to elicit student understanding of a “three-dimensional” standard or learning goal, that is, one that could assess students’ integrated understanding of core ideas, science practices, and crosscutting concepts. We created each task set to purposefully include 1-2 tasks that had great potential to elicit three-dimensional proficiency (e.g., multicomponent tasks that presented students with a phenomenon in which they had to use science practices and their understanding of core ideas and crosscutting concepts to explain), as well as 1-2 tasks that elicited only factual recall. Tasks were selected by researchers knowledgeable both about assessment and the specific demands of assessment outlined in the National Research Council report, Developing Assessments for the Next Generation Science Standards (Pellegrino, et al., 2014).

We asked the teachers to work in their groups to rate each task within their set on a scale from 1 (completely inadequate) to 5 (completely adequate) with respect to the prompts’ ability to elicit student understanding of the learning goal, which was printed at the top of the task for teachers to review. In addition, to entering their ratings for each task using a Google Form, groups entered reasons for their judgments. Later, we presented the summary ratings of tasks to the group and discussed them as a whole.

We calculated mean ratings for each task of the group, along with standard deviations for each, and compared them to an expert rater’s ratings for the task, a research analyst who had no part in assembling or creating the task but who had extensive experience in designing assessments to elicit three-dimensional science proficiency. This analyst also used an open coding approach (Charmaz, 2000) to identify reasons for teachers’ ratings. We found that teachers were able to distinguish tasks with respect to their three-dimensionality and that the relative rankings of tasks were similar to those of the expert coder overall. Each task set exhibited the full range of ratings for tasks (1-5), as intended, though the standard deviation of ratings varied across the tasks. The most extreme range was for the set of first grade tasks, where the standard deviation of ratings ranged from 0.45 to 1.34. An analysis revealed that the standard deviations were lower for each end of the scale. The correlation between the standard deviation and distance from the middle of the rating scale (3) was $r = -.803$. In addition, when their ratings diverged most from the expert rater’s, the farther the average rating was from the middle of the rating scale ($r = -.718$). Put together, these two correlations suggest teachers were better able to discern when three-dimensionality was starkly absent (e.g., on closed-ended tasks eliciting factual recall) or strongly present (e.g., in multicomponent tasks requiring students to explain a natural phenomenon).

The open coding also revealed that teachers did in fact attend to the dimensions as intended, but teachers also attended to concerns sometimes raised by experts about assessment (Table 2). Of the focal three
dimensions, the science and engineering practices were attended to most. Teachers also attended to cognitive complexity, as evident in language they used, such as “Depth of Knowledge” and “Bloom’s Taxonomy.” Both are terms in education and assessment that have been taken up widely in practice (Schneider, 2014).

Table 1: Dimensions of Tasks Teachers Noticed

<table>
<thead>
<tr>
<th>Dimensions of Tasks</th>
<th># of Responses Noticed</th>
<th>% of All Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science and Engineering Practices</td>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>Specific Elements of standard (nonspecific)</td>
<td>41</td>
<td>17</td>
</tr>
<tr>
<td>Cognitive Complexity</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Concern for Clarity of the Task</td>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>Disciplinary Core Ideas</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Cross-cutting Concepts</td>
<td>21</td>
<td>8</td>
</tr>
<tr>
<td>Concern for Equity</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
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We found some support for our conjecture that task analysis can facilitate teachers’ noticing of features of next generation science assessment tasks in ways that align with experts’ ratings. As an entry point for teacher learning, teachers readily discerned tasks that clearly had little potential to elicit students’ integrated understanding of core ideas, practices, and crosscutting concepts, as well as those tasks that clearly did. At the same time, the analysis revealed teachers did not as easily notice features of tasks that were partly flawed. Though this may simply have been an artifact of the tasks themselves, the fact they were not in agreement on these tasks and diverged from the expert’s ratings suggests otherwise. Their reasons, overall, revealed a wider range of concerns about assessment than just the three dimensions. We envision this type of activity as an entry point to a longer learning trajectory for teachers, in which they become proficient in designing high-quality multi-component tasks. As others have found, engaging teachers in designing assessment tasks is both promising and also challenging (e.g., Furtak et al., 2016; Shepard, 1997), in part because of the broad knowledge base required in both science and assessment. To judge whether task analysis can bootstrap teachers’ learning toward more productive design, then, we need to explore the effects of longer sequences of teacher learning, which will also require scaffolding that supports their knowledge building in science and assessment.

Symposium summary and implications
This symposium brings together cutting-edge work in the design, piloting, and use of multiple forms of assessment, all aligned with the purpose of assessing knowledge-in-use. Taken together, they represent elementary, middle, and high school science learning; classroom formative assessments, as well as tasks being designed for more proximal and distal uses; and international partnerships. They also raise a number of questions critical for the field to consider, including:

- While performance expectations often follow a thread of unfolding disciplinary core ideas or scientific practices, the NGSS also create opportunities to follow crosscutting concepts as they unfold across multiple grade levels. What does it mean to assess a crosscutting concept, and what new challenges for assessing knowledge-in-use are presented with a focus on crosscutting concepts?
- What are the different types of task formats being developed, and how do these change as we move from activities that are proximal to classroom instruction toward large-scale assessments?
- How do similarities and differences in international visions for science knowledge-in-use influence the ways we think about and design assessments, both at-scale, and in classrooms?
- What constraints and affordances can be identified when assessment development activities are conducted with teachers, schools, and school districts?

References


**Acknowledgments**

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Knowledge Analysis Outside the STEM Classroom

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Abstract: Knowledge Analysis has proven an important and useful set of methods for characterizing the constituent parts and processes of human reasoning and learning. However, its application has largely been limited to knowledge in a narrow selection of STEM domains, limiting the generalizability of its findings. This symposium draws together scholarship operating within the Knowledge Analysis tradition to investigate reasoning and learning in domains outside of STEM classroom subjects. In doing so, each paper explores the affordances and limitations of Knowledge Analysis to shed light on significant questions in their respective domains of knowledge, including: restorative justice practices, the ethics of drone warfare, undergraduate course design, and urban planning. By further expanding the use of Knowledge Analysis to include non-STEM subjects, we hope to raise important questions and offer richer and more generalizable views of knowledge and learning relevant to both STEM and non-STEM domains.

Keywords: Knowledge in Pieces, ideology, qualitative methods, education

Symposium overview

Knowledge Analysis (KA) is a central pillar of the learning sciences. Following diSessa, Sherin & Levin (2016) we use KA to refer to Knowledge in Pieces and related theoretical frameworks used to investigate human cognition through attention to relatively small units of meaning that are called up, revised, and re-organized through processes of perception and reasoning. Insights from within the KA tradition have reshaped our expectations for what novice ideas look like, emphasizing the role of contextually cued intuitive knowledge resources rather than fully coherent naïve theories (Smith, diSessa, & Roschelle, 1993). Scholars working in this tradition have built our understanding of how reasoning and learning occur at the micro level as well as over longer timescales (diSessa & Sherin, 1998). And, building on these insights, KA has provided a foundation for the design of learning environments that take advantage of learners’ intuitive understandings to facilitate learning processes (Hammer, 1996).

However, with a few notable exceptions (Jansson, Wendt & Åse, 2013; Markauskaite & Goodyear, 2014; Philip, 2011), KA has been applied to a relatively narrow range of knowledge domains. Physics has been most prominent among these (e.g. diSessa, 1993; Hammer, 2000; diSessa & Sherin, 1998; Smith et al., 1993). Moreover, while Knowledge Analysis has been applied outside of physics as well, to math, biology, chemistry, and computer science, for example, it has remained predominantly confined to STEM subjects.

While these studies have offered important insights, the similarity of subject matter in the existing body of KA literature is also limiting. First, it represents an empirical limit on our understanding of intuitive knowledge and learning processes in other domains of human knowledge and practice. It also represents a theoretical limitation. Similarity in domain content can obscure the distinction between features of knowledge organization and transformation that reflect general principles of human cognition, and those that reflect particularities of certain types of content. Moreover, the particular emphasis on STEM has often reified a view of scientific knowledge as objective and value neutral, obscuring the role of values and affect in the process of constructing meaning. In order to continue to deepen our understanding of human cognition, learning scientists would be well served to explore the use of a KA approach for illuminating a wide range of learning contexts and content.

This symposium draws together scholarship operating within the Knowledge Analysis tradition to investigate reasoning and learning in domains that have previously been little explored within this framework. In doing so, each paper explores the affordances and limitations of KA to shed light on significant questions in their
What are restorative justice practices? A cognitive account in elements and frames

Eleanor R. Anderson

In this analysis, I seek to investigate educators’ understandings of Restorative Justice Practices (RJP), an approach to school discipline and culture that eschews exclusionary punishment, and emphasizes problem solving and positive relationships. Like all learners, educators make sense of new ideas—including new programs and policies—through the lens of their existing knowledge (M. G. Sherin, 2002; Spillane, 2004; Spillane et al., 2002). Given that programs designed for educational reform are frequently built around novel ideas regarding content, instruction, or philosophy, this makes educational reforms highly susceptible to misunderstanding (Coburn, 2005; Spillane, 2000, 2004).

RJP is an umbrella term for a set of specific practices, as well as a philosophy that can be applied to a broad range of situations. Some RJP advocates fear that many teachers hold ‘punitive mindsets,’ requiring a radical shift in perspective to understand RJP fully. However, analyses of other knowledge domains have revealed that seemingly coherent misconceptions may also reflect relatively simple differences in the organization of smaller pieces of knowledge (diSessa & Sherin, 1998). Thus, an empirical investigation of teachers’ constellations of ideas about discipline and restorative justice is needed in order to assess (and facilitate) the task facing school leaders seeking to implement RJP.

I draw from interviews with 26 staff members at Rustin HS, an urban public school adopting RJP. The sample includes teachers, administrators and security staff plus two RJP experts who were supporting the school’s implementation process. Following Hammer et al. (2005), I characterize educators’ conceptions and misconceptions of RJP in terms of cognitive elements and frames.

Beginning with short ‘en vivo’ codes I identified 250 unique elements that educators attended to in characterizing a particular disciplinary response as exemplifying RJP or not, ranging from named practices, to sample conversational elements, to usage situations, to goals, and beyond. Next, I identified four cognitive frames.
In the current study, we situate the research within a line of inquiry that highlights the intersections and tensions between Knowledge in Pieces (KiP) and interaction studies (diSessa et al., 2016; Gupta et al., 2016; Kapon, 2016). We focus on computer engineering students and was typically taken by 2nd year (sophomore) students. We transcribed the classroom discussion to examine ethical sense-making in an undergraduate engineering classroom.

The study is situated in an undergraduate engineering classroom where didactic assumptions are brought to the forefront. The associated methods of data collection and analysis have brought the productive dimensions of students’ intuitive sense-making to the forefront. We attended to joint-meaning making processes (Parnafes, 2007; Scherr & Hammer, 2009; Rosenberg et al., 2006; Gupta et al., 2014), these studies haven't addressed why certain taken-for-granted assumptions become salient within a context and how interaction between participants afford or limit opportunities for students to take up and build on specific intuitive understandings. In other words, they haven't fully engaged the methods of conversation and interaction analysis (Goodwin, 2007; Goodwin & Heritage, 1990; Jordan & Henderson, 1995).

A recent emergent line of research demonstrates the analytical value that is added by working at the intersections and tensions between KiP and interaction studies (diSessa et al., 2016; Gupta et al., 2016; Kapon, 2016; Umphress, 2016). We situate the current study within this line of inquiry.

The context of our study is an undergraduate engineering classroom discussion on militarized drones at a research university in the United States. This one-semester course was a requirement for all electrical and computer engineering students and was typically taken by 2nd year (sophomore) students. We transcribed the students’ discussion of drones from the video recording of a 58-minute class session led by a teaching assistant. We used Philip (2011) to code taken-for-granted ideological assumptions—what Philip (2011) refers to as naturalized axioms and a social parallel to what diSessa (1993) refers to as p-prims—about the ethics of militarized drones. Additionally, we utilized methods developed in Philip et al. (2017) to examine how the interactionally achieved processes of ideological expansion and convergence shaped the salience and persistence of these stances in the participants’ shared discourse.

The analytical affordances of KiP highlighted the significance of taken-for-granted ideological stances in the students’ sense-making about militarized drones. For instance, a student remarked early in the discussion that militarized drones would make killing more widespread because it was more “convenient.” From a KiP perspective, this argument is based on the taken-for-granted assumption that “the easier it is to do something, the more likely it is that someone would do it.” Resonant with findings in the KiP literature, students also
demonstrated a range of contextually specific ideological stances that were often contradictory. As an example, one student’s ideological stances were highly varied over the course of the classroom discussion: civilian deaths are inevitable, no war can be humane, people resort to war because they are too lazy to engage with diplomacy, and a government has to protect its military despite the “civilian” toll on other countries. This range of ideological stances also points to the productive potential of such intuitions when meaning-making about the ethics of various scenarios.

Our analysis shows that despite the diversity of ideological stances within and across students, these stances increasingly converged, as an interactional achievement between participants, to the position that engineers’ ethical responsibility is limited to increasing the accuracy of drones to prevent the loss of civilian lives. Our analysis suggests that the process of ideological convergence made potentially expansive ideological stances less salient for some students and simultaneously more difficult to invoke for other students. Additionally, we show that marginalization of ideologically expansive stances constrained the possibilities for disciplinary and ethical learning. In sum, our paper makes a case for the analytical affordances of working at the intersections of KfP and interaction studies.

**Investigating university academics’ pedagogical sensemaking: A grounded dynamic perspective of teachers’ pedagogical resourcefulness**

Lina Markauskaite, Yael Kali, and Peter Goodyear

Studies that investigate university academics’ pedagogical knowledge often assume that teachers have coherent, well-articulated ‘theory-like’ knowledge and beliefs (Kember & Kwan, 2000; Prosser & Trigwell, 2017). Such conceptions are rather inflexible, and academics who hold a particular view deploy it consistently across many teaching situations. The theory-like conceptualizations of teachers’ knowledge are too coarse for investigating teachers’ everyday pedagogical sensemaking; ignore intuitive, less articulated kinds of knowledge that are important in situated decision-making; and do not explain why teachers’ knowledge observed in action often differs from their espoused views (Kane, Sandretto, & Heath, 2002). Our studies remedy this by investigating the mental resources university academics actually draw on in reasoning about course designs and teaching.

We draw on a line of theorization about people’s everyday knowledge, developed in the context of physics (diSessa, 1993; Hammer & Elby, 2002), and use this mental resource view to account for university academics’ pedagogical beliefs and knowledge. On this view, people have a large array of (mostly implicit) conceptual understandings of physical phenomena that they encounter in the world (diSessa, 1993) and a similarly large array of understandings of epistemological phenomena about how people learn and come to know (Hammer & Elby, 2002). By extension, we assume that people also have a rich array of mental resources for making sense of how people teach and are taught (Markauskaite & Goodyear, 2011, 2014). People develop these understandings in a variety of ways: by remembering specific situations, forming intuitive abstractions from a range of experiences, deliberatively reflecting on their understanding, being explicitly taught, etc. The grain-size of these pedagogical mental resources vary. Some can be quite small situation-specific units of meaning, similar to diSessa (1993)’s ‘p-prims’, and some might be broad theory-like generalizations and abstractions.

We have explored the nature of pedagogical mental resources in a number of studies, investigating university academics’ sensemaking about how to design courses and teach. This paper reports insights from three such studies and offers an integrative view on the nature of teachers’ pedagogical resourcefulness. We examined three contexts:

1. **General course design:** university academics’ explanations of their general course design decisions (Markauskaite, Bachfischer, & Goodyear, in preparation; Markauskaite & Goodyear, 2017).
2. **Activity context:** pedagogical sensemaking of an individual teacher as she explained her everyday teaching decisions (Kali, Goodyear, & Markauskaite, 2011; Markauskaite & Goodyear, 2011, 2014).
3. **Situated action context:** the kinds of mental resources used by academics in reasoning and making decisions in curriculum innovation team meetings (Markauskaite, Bachfischer, Kali, & Goodyear, 2017).

Our results reveal that the academics tended to draw on quite different mental resources in each of these contexts. In the general course design context, the academics often drew on mental resources originating in formal pedagogical knowledge and intuitively-formed generalizations about knowledge, knowing, learning and teaching (e.g. Knowledge needs to be backed up with the latest evidence; People learn through analysis of their own experiences and reflections). While most drew on a range of such generalizations, these mental resources closely resembled large macro-level theory-like pedagogical abstractions.
In the concrete activity context, the academic more often articulated their intuitive sense of the micro mechanisms about how people come to understand and how they should be taught in a particular situation. For example, the teacher articulated such teaching and learning mechanisms as Reiteration (i.e. knowledge that students tend not to remember could be taught by repeating it several times); Building-on (i.e. learning should start from simple concepts or tasks and should gradually be made more complex). Many of these micro-level mental resources originated in personal experiences about how people learn and how to teach and closely resembled small intuitive, contextually-cued pieces of knowledge that we call “pedagogical p-prims”.

In the situated action context, the academics often drew on knowledge of concrete experiences, affordances and constraints, such as experiences of how specific students reacted to a particular task design, or how a decision about how to teach relates to particular functions of software used on a course. In making these decisions, teachers drew on pre-existing mental resources, and also coordinated and combined various mental resources on-the-fly by taking into account affordances, constraints and other details of the situation.

Our findings suggest that academics’ pedagogical resourcefulness should be reconceptualized from a perspective that acknowledges the diverse, dynamic nature of teachers’ knowledge and their pedagogical sensemaking: grounded in concrete experiences and situations. Teachers’ pedagogical knowledge cannot be seen as an abstract theory or generic mental process that operates solely in the head. Rather this is knowledge that is firmly entwined with the physical and social environment. Mental resources are not stable (large or small) representations, but multimodal constructs that are dynamically recombined in various ways: with each other and with affordances of the emerging situation. They provide a highly populated, dynamically evolving knowledge base for interpreting and making decisions about new situations. This grounded dynamic view of mental resources extends current Knowledge in Pieces perspectives and provides a new way for theorising and studying learning in complex, ill-structured knowledge domains, such as teaching.

**Moving the goalposts: The role of values in students’ shifting interpretation of simulated urban planning data**

Arthur Hjorth

Recent efforts to reform social studies in K-12 emphasize, amongst other things, ‘complex causal reasoning’ about social issues and policy (NCSS, 2013). This raises two understudied questions: first a definitional question: what does it mean to reason causally about complex social issues? And second, a design question: how should we design learning activities that encourage and support this particular kind of thinking in social studies? This paper presents data from an Urban Planning curriculum unit in which undergraduate students used agent-based simulations to design cities. I find that students would often shift their interpretation of data in ways that aligned with their values, even if this meant making objectively dubious claims about the data. Taking a Knowledge-in-Pieces approach, I characterize the knowledge pieces and the process that students deployed when doing so.

In response to the first question, this paper argues that we can borrow from existing work on causal reasoning in STEM (e.g. Machamer, Darden, and Craver, 2000; Russ et al. 2008) to analyze, categorize, and assess student reasoning about social issues. However, we must also consider an additional component when studying reasoning about social issues; the role in which values guide the sense-making process during the active construction of knowledge. To address this somewhat unique aspect of studying reasoning about social phenomena, I propose a preliminary framework for analyzing students’ thinking based on Knowledge-in-Pieces (e.g. diSessa 1993) and Michael Freedman’s work on ideology and sense making of policy (Freedman 2005; 2008). In response to the second question, this paper borrows from a long tradition in using agent-based models as external representations of complex systems and “objects-to-think-with” (Papert 1980; Eisenberg 2003; Wilensky & Rand 2015). The fundamental principle here is that by providing an external representation of the causality in a complex system, and by providing a purpose for students to manipulate the system and see how these manipulations result in different outcomes, students can align their internal, conceptual model of the system with the external, computer-based model. Agent-based modeling-based classroom activities have been used successfully to support students while they learn to reason about complex phenomena like evolution, physics, chemistry (Wilensky & Jacobson, 2015).

Taking this work as a starting point, I designed and implemented a 3-day undergraduate unit in urban planning in which students in groups of 2-3 built and iteratively improved on virtual cities in an agent-based computer simulation. They were asked to set specific a measurable policy outcome as a goal, and then to design a city in the simulation that would meet this goal. At the end of each design iteration of their city, students were asked to assess whether they “reached their goal”. This paper expands on an interesting finding from an early analysis (Hjorth & Wilensky, 2014) of these data: the goals that students set for themselves were quantitative and
easily measurable, and given the data that was available to students in the simulation, in theory this ought to be a simple yes/no answer. But when students in the unit assessed whether they had achieved their goals, they would often shift their interpretation of the outcome data, if the outcome was ideologically acceptable to them. For instance, students would set a goal of reducing 'commute times to less than 30 minutes for everyone' (my emphasis) but would say that they reached their goal, even though they objectively did not, because ‘the poorest 20% had really good commute times.’ I observed similar shifts in the interpretation of data as a result of students’ ideological interpretations of data in other groups.

This paper bases its analysis on the video data and students’ written responses that were collected during the classroom implementation. The analysis has two purposes: first, to identify and characterize a set of different knowledge pieces that students activate when constructing meaning out of the simulation data. The second is to characterize the process of students’ re-organizing these knowledge pieces, forefronting some and backgrounding others, while making sense of the simulation data, in order to facilitate these value-laden shifts in data interpretation. These findings suggest that values qua knowledge can play a productive role in students’ interpretation of data, and that future curriculum development can leverage this by designing open-ended data interpretation activities with socially meaningful data.

References


**Symposium**

**Orchestration Tools for Teachers in the Context of Individual and Collaborative Learning: What Information Do Teachers Need and What Do They Do With It?**

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**Abstract:**

This symposium brings together research concerning orchestration tools aimed at supporting teachers in providing real time support to students in the classroom. Orchestration tools are based on the idea of capturing, analyzing, and visualizing student activities during class time and feeding them back to teachers to facilitate real time monitoring and support of students. With examples from the contexts of individual and collaborative learning, the symposium addresses two questions, namely what information about student activities teachers need, and how teachers use orchestration tools in their classrooms. Two papers focus on the first question, and furthermore investigate how teachers respond to initial versions of orchestration tools. The remaining two papers focus on how teachers actually use orchestration tools in their classrooms. The symposium as such offers examples of state of the art research and ample opportunity for discussing future directions in the field of teacher orchestration tools.

**Focus of the symposium – teacher orchestration tools**

Teachers play an essential role for student learning, as they are responsible for monitoring and orchestrating both cognitive and metacognitive processes, as well as social processes when it concerns collaboration among students (Kaendler et al., 2015; Prieto et al., 2011). Most computer-supported learning environments enable capturing of student activities, which can then be (automatically) analyzed and visualized on so called teacher orchestration tools to support teachers in the real-time orchestration of student learning (Verbert et al., 2014; Wise & Vytasek, 2017). In the growing field of research on teacher orchestration tools, important questions arise concerning the design and implementation of teacher orchestration tools (Van Leeuwen & Rummel, 2017). We need to ask what type of support teachers need from dashboards during their practice, and what factors enable or constrain the successful implementation of dashboards that provide support for teachers. This symposium brings together research concerning teacher orchestration tools, with examples from the contexts of individual and collaborative learning. The symposium focuses on two particular issues: 1) what information do teachers need that would help them to support their students, and how does that translate to design of an orchestration tool? Subsequently, 2) once the orchestration tool is designed, how do teachers actually use them in their classrooms? As an overarching question, we are interested in what lessons can be drawn about what makes orchestration tools helpful for teaching and learning.

**Outline of contributions**

The underlying structure of the symposium is a 2x2 design. The most prominent distinction between the papers is whether they address the design phase of orchestration tools, in particular the question of what information
teachers need and how they respond to initial version of orchestration tools, or the implementation of orchestration tools, in particular how teachers actually use the orchestration tool in the classroom. A further dimension to characterize the contributions on is whether they provide an example of teacher orchestration tools in the context of individual learning or collaborative learning. Table 1 shows the 2x2 design of the symposium and the corresponding contribution for each cell.

**Table 1: Overview of symposium contributions**

<table>
<thead>
<tr>
<th>Context</th>
<th>What information do teachers need?</th>
<th>What do teachers do with a dashboard in the classroom?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual learning</td>
<td>Holstein et al. (contribution 1)</td>
<td>Molenaar et al. (contribution 3)</td>
</tr>
<tr>
<td>Collaborative learning</td>
<td>Van Leeuwen et al. (contribution 2)</td>
<td>Schwarz et al. (contribution 4)</td>
</tr>
</tbody>
</table>

Holstein et al. (contribution 1) and Van Leeuwen and Rummel (contribution 2) focus on what information teachers need to make decisions during the real time support of their students, using several techniques for eliciting teachers’ thoughts. Holstein et al. followed a participatory design approach to elicit teachers’ needs for information. They also employed simulated class sessions and small studies in live classrooms to test initial versions of their orchestration tool. Van Leeuwen et al. used contextual inquiry and storyboarding to gauge teachers’ responses to situations in their everyday practice as well as future scenarios of how orchestration tools could be implemented.

Molenaar and Knoop-van Campen (contribution 3) and Schwarz et al. (contribution 4) present studies on how teachers actually use orchestration tools in the classroom. In both studies, quantitative as well as rich qualitative data was obtained about how teachers interpreted the orchestration tool and how it guided their practice. By doing so, Molenaar et al. for example demonstrate how differences in teachers’ experience with orchestration tools influences the extent and specific way of using the orchestration tool as well as the type of feedback teachers give to their students. Schwarz et al. observed and interviewed a teacher in two cohorts of supporting multiple collaborating groups, illustrating how the teacher detected the needs of the groups by a combination of using the orchestration tool and his own observations.

The four contributions together touch upon several recurring issues that are of interest to the ISLS community. For example, the role of teachers’ prior knowledge of their students is a recurring issue both in the design and implementation of orchestration tools. Another recurring issue is the way the teacher and the orchestration tool “complement” each other: which tasks are best performed by the teacher, and what specific role should the orchestration tool take on? Another overarching issue is the role of context. Although all papers are situated in the domain of mathematics, two papers concern individual learning, and the other two concern collaborative learning. As such, the question is whether teachers’ needs for information and how they use orchestration tools differs for these contexts – is the orchestration load on teachers different in these two situations, and what does that mean for designing orchestration tools?

**Outline of the symposium during ICLS2018**

Our plan for the symposium session is to first have brief reports about the four studies. During the four presentations, the audience is invited to share their questions and points for discussion through PresentersWall, a live feed that displays the audience’s input. For example, audience input could concern ideas about: (1) what lessons we can learn from the four studies concerning factors that make orchestration tools more or less effective, and (2) how the emerging field of teacher orchestration tools needs to develop and what might be promising directions for future research.

Then, the discussant (Alyssa Wise) is asked to respond to a selection of the audience’s input in light of the four presentations and in light of her own expertise. Finally, the floor will be opened for plenary discussion.

To summarize, by bringing together four studies concerning the design and implementation of teacher orchestration tools, our aim is to offer examples of new empirical work and to address important questions in this field that are of interest to the ISLS community. The following pages contain brief descriptions of all four contributions to the symposium.
Balancing between teacher and student needs in the design of classroom orchestration tools
Kenneth Holstein, Bruce M. McLaren, and Vincent Aleven, Carnegie Mellon University

Introduction
Teacher orchestration tools are frequently designed to support teachers in more effectively monitoring their students, under the hypothesis that this will ultimately lead to improved student learning (Molenaar & Knoop-van Campen 2017; Rodriguez-Triana, et al., 2017; Van Leeuwen, 2015). Such tools must also be both usable and useful to teachers; designed based on an understanding of teachers’ needs and desires for real-time support, and the actual challenges they face in orchestrating complex classroom activities (Rodriguez-Triana, et al., 2017). In our current work, we are designing real-time orchestration tools for classrooms using intelligent tutoring systems (ITSs). We examine teachers’ expressed desires for real-time analytics and students’ observed needs for teacher support, investigating how best to balance between these.

Methods
In the first phase of our design process, we adopted a participatory design approach (Hanington & Martin, 2012), working closely with K-12 math teachers to understand their desires for real-time analytics, and directly involving them throughout the design process (Holstein, Hong, Tegene, McLaren, & Aleven, 2018a; Holstein, McLaren, & Aleven, 2017). The resulting prototype is a pair of mixed-reality smart glasses, which augment teachers’ perceptions of student learning, metacognition, and behavior – displaying real-time indicators floating directly above students’ heads. The indicators shown by Lumilo are ideas generated and iteratively refined by teachers, and implemented using established student modeling methods (e.g., Desmarais & Baker, 2012).

To understand how teachers might use Lumilo, prior to deploying in real classrooms, we conducted a series of simulated class sessions, using a new prototyping method called Replay Enactments (REs). In each of six sessions, historical student interactions were replayed in ITS interfaces, on separate computers in a classroom setting (but with no actual students present). During 40-minute replay sessions, teachers wore Lumilo, while monitoring the “class”. If a teacher thought they would intervene with a “student” at a given time, the teacher would approach and enact the help session aloud (Holstein et al., 2018a). Meanwhile, Lumilo tracked teacher activity moment-by-moment. Analyses of data from 6 REs suggested that Lumilo can guide teachers’ time towards students who would otherwise exhibit lower learning in the software, as measured by posttest scores, controlling for pretest (r = -0.17, p < 0.01) (Holstein, et al., 2018a). However, the magnitude of this correlation suggested room for improvement. We adopted a causal model search approach (Spirtes, Glymour, & Scheines, 2000) to identify mediators of this observed relationship, which could inform a redesign.

Results and discussion
Through our co-design process, 8 indicator types emerged. These included “misuse of the software” (divided into gaming-the-system/help-abuse and making rapid attempts), unproductive persistence or “wheel-spinning” (Beck & Gong, 2013), high/low recent performance, help avoidance (Aleven, Roll, McLaren, & Koedinger, 2016), and prolonged inactivity. Importantly, we found that some of these alerts were valuable to teachers for reasons other than guiding interventions. For example, teachers found alerts about high recent performance valuable, in part, because they found such alerts personally motivating (Holstein et al., 2017; 2018a).

Using data from REs, we found that teacher time allocation while using Lumilo was strongly driven by alerts of student rapid attempts or gaming/help-abuse, but less strongly by high recent error rate or unproductive persistence (Holstein, McLaren, & Aleven, 2018b). Other alert types did not significantly drive teacher time. The causal model learned with FCI (Spirtes et al., 2000) on data from 115 middle school math students suggested that, out of 7 teacher-generated ideas for negative alerts, only one corresponded to a student state with a direct harmful impact on student learning: unproductive persistence (Beck & Gong, 2013). Based on these analyses, we iterated upon Lumilo’s design, prioritizing alerts about unproductive persistence and its identified causes (help avoidance or gaming/help-abuse). In subsequent studies, teachers using this updated prototype in live classrooms continued to make use of all alert types. At the same time, the strongest predictors of teachers’ overall time allocation were alerts of unproductive persistence, followed by help avoidance and gaming/help-abuse, suggesting the redesign may have been effective in redirecting teachers’ time to student behaviors with the greatest impact on learning (Holstein, McLaren, & Aleven, 2018b; 2018c).

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Considering teachers’ informational needs and the role division between teacher and orchestration tool in the context of collaborative learning.
Anouschka van Leeuwen, Ruhr-Universität Bochum / Utrecht University and Nikol Rummel, Ruhr-Universität Bochum

Introduction
Teacher orchestration tools are hypothesized to support teachers in monitoring and supporting student learning (Van Leeuwen, 2015). The study presented here served as input to developing a teacher orchestration tool in the context of collaborative fraction assignments. It was examined what information teachers need to make informed decisions, and what role division between teacher and orchestration tool best serves teachers’ practice.

Method
Elaborate sessions lasting 1.5 hours were held with 10 primary school teachers (8 were female), in which multiple techniques were used for eliciting teachers’ thoughts. The teachers’ mean age was 30.2 (SD = 3.9). On average, they had 8.2 years teaching experience (SD = 7.4). The interviews consisted of two parts. In the first part of the interview we used contextual inquiry, which means understanding of teachers’ experiences was sought by asking how they would act and react in certain situations (Hanington & Martin, 2012). Teachers were prompted with different types of situations that may occur during orchestration of collaborative learning, and were asked to explain as fully as possible how they would act and what information they would need to make decisions. Second, storyboarding was used to elicit teachers’ responses to four scenarios of how a teacher could use an orchestration tool (see Table 2 for an example). With storyboarding, drawn stories are used of how intended users may interact with the object under study (Hanington & Martin, 2012), in this case the object being teacher orchestration tools. The storyboards differed in the function the orchestration tool fulfilled, ranging from only displaying information, to alerting the teacher, to advising the teacher what to do.

Table 2: Example of storyboard

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students are collaborating in dyads. Teacher walks through the classroom with dashboard. 2. Dashboard gives an alert about group 1, who made relatively many mistakes and asked for a lot of hints. Teacher notices another group raises their hand, but decides to go to group 1 first. 4. Teacher gives explanation until group 1 grasps the idea, then walks to the group that raised their hand.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and discussion
The contextual inquiry elicited 6 types of information that teachers use during collaborative learning to decide whether a group needs help: background information about the students in a group (like mathematical ability), whether groups get stuck (either because a task is too easy or too difficult), whether students show understanding of task-related concepts, whether groups are involved with the task (or display off-task behavior), the quality of the interaction between group members, and whether the group shows metacognitive understanding of their own strategies and progress. The storyboarding revealed that teachers would especially appreciate it if orchestration tools could help them with noticing students’ misconceptions or point them to problems in the group interaction early on, in order to enable timely intervention. Also, teachers expressed need...
for support with monitoring multiple groups at the same time. The results are used as input for a follow up study in which we examine how teachers use orchestration tools that fulfill different roles.

Acknowledgments
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Experience matters: The impact of dashboards on teachers’ feedback
Inge Molenaar and Carolien Knoop-van Campen, Radboud University

Introduction
Teacher dashboards provide teachers during lessons with concurrent information about students’ abilities, progress, performance, and errors made (Molenaar & Van Schaik, 2017; Van Leeuwen et al. 2014). Teachers can use this information to adapt their teaching practices to the students’ individual needs, but only when teachers are aware of the data, able to interpret the data properly, and can translate their interpretation into appropriate pedagogical actions (Molenaar & Knoop-van Campen, 2017; Verbert et. al. 2014). We expect that teacher experience with dashboards is likely to influence how they use dashboards during teaching. Therefore, this study examines how teachers’ dashboard usage during lessons influences feedback given to individual students, and how this is associated with teachers’ experience.

Method
Primary school teachers (N = 40) were observed during one mathematics lesson (50 minutes) taught in grade 2 to 6. Adaptive educational technology (Snappet) is used on a daily basis in these classrooms. While students made exercises on their tablets, realtime data of learner progress and performance were shown on dashboards. The observations were performed by Snappet-coaches (expert-teachers with a coaching function). They were trained to observe teachers’ feedback (task, person, process, social & metacognitive) and initiating actions (dashboard, student, teachers) using the Classroom Observation App. A distinction was made between in-experienced (N = 12), middle (N = 12) and experienced (N = 16) teachers. Both teachers themselves and observers indicated teachers’ experience in using the adaptive educational technology. The agreement-rate between teachers and observers was 70%, in case of disagreement the observers coding was followed. None-parametric analyses were performed with Independent-Samples Kruskal-Wallis Tests.

Results
On average teachers gave 49.95 times (SD = 26.79) feedback to an individual student during a lesson and no differences in feedback frequency were found between in-, middle and experienced teachers. Teachers consulted the dashboard on average 7.83 times (SD = 8.06) during a lesson and as expected experienced teachers consulted the dashboard more often (M = 11.63, SD = 8.96), compared to middle (M = 6.08, SD = 11.63) and in-experienced teachers (M = 4.92, SD = 8.24), $H(2) = 8.61, p = .014$. On average 72% (SD = 26%) of a teachers’ dashboard consultations were followed by feedback and this did not differ between the three groups. Most feedback was given on teachers own initiative (58%) or in response to students’ questions (29%), only 13% of the feedback was provided after dashboard consultation. Although they did not differ in the frequency of giving feedback, experienced teachers provided feedback more often after dashboard consultation (17%) compared to middle (9%) and in-experienced teachers (10%), $H(2) = 7.38, p = .025$ (see Figure 1). Additionally, a significant difference was found with regard to the type of feedback given: experienced teachers gave more feedback related to the task (34%) compared to in-experienced teachers (21%), $H(2) = 8.91, p = .012$ (see Figure 2).
Discussion
Results indicated that even though the majority of the dashboard consultations resulted in feedback given to individual students, only a small part of all feedback was initiated by a dashboard consultation. We found evidence that more experience teachers gave more feedback based on dashboard consultations and they also differed in the type of feedback given. Teachers with more experience provided more task related feedback to students. This indicated that these teachers not only use the dashboard more often to inform their feedback actions, but that they also used the dashboard information differently to customize feedback to the needs of individual students. This demonstrated that dashboards indeed support teacher to adapt their teaching practices to the need of individual students and especially after teachers gained sufficient experience in using the orchestration tools.

Orchestrating deep learning: A case-study in a geometry class
Baruch Schwarz, Hebrew University; Naomi Prusak, Hebrew University; Osama Swidan, Ben-Gurion University; Avi Segal, Ben-Gurion University; and Kobi Gal, Ben-Gurion University

Introduction
This paper is about orchestration of deep learning in a collaborative setting. We elaborate on the idea of critical moments in group-learning, events whose occurrence may lead to a particular development at the epistemic level regarding the shared object. We relied on research in educational psychology to identify seven critical moments: (a) idleness, (b) off-topic-talk, (c) technical problems, (d) explanation or challenge, (e) confusion, (f) correct solution and (g) incorrect solution. We conjectured that the teacher’s identification of critical moments may facilitate further guidance towards deep learning among students. The complexity of small group settings in a classroom context does not allow teachers to be aware about these critical moments, though. Figure 3 describes the SAGLET system, based on the VMT environment (Stahl, 2009), which allows teachers to observe multiple groups engaging on problem solving in geometry. In Figure 3, we see that a teacher observes four
She is informed about a correct solution in room 696 and about a technical problem in room 697.

Figure 3. The SAGLET system, based on the VMT environment (Stahl, 2009).

**Method**

SAGLET capitalizes on machine learning techniques to inform on on-line critical moments, by sending alerts to the teacher, who decides then whether (and how) to use the alerts in his/her guidance of students. One teacher in an elementary school used SAGLET in order to help multiple groups of students solving difficult tasks in geometry. We observed how the teacher mediated two cohorts of multiple groups at two different times in a mathematics classroom. The teacher was trained to use the SAGLET system, and designed challenging problems in geometry that necessitated collaboration between Grade 6 students. Five groups of 2-3 were formed.

**Results**

We show that in both cases, the teacher could detect the needs of the groups (partly thanks to the alerts) and could provide adaptive guidance to all groups. We identified five kinds of intervention. Most of the interventions were of a scaffolding argumentation type. We see that the scaffolding of argumentation is the most frequent type of intervention. As mentioned before, this kind of intervention fits the CSCL spirit according to which guidance is ancillary to the co-construction of meaning. We saw that the forms of this scaffolding are varied, and included challenges or refutations expressed either in a chat mode or through GeoGebra. The most frequent intervention after the scaffolding of argumentation is the monitoring and supervision of the execution of the task – an intervention that refers to orchestration. The request for justifications and the social validation have a flavor of both orchestration and support to meaning making. It is noteworthy that the less frequent type of intervention is the encouragement of collaboration. After one preparatory session with SAGLET, students were already accustomed to collaborate – a fact that indicates that VMT affords collaboration.

**References**


Networked by Design: Interventions for Teachers to Develop Social Capital

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Abstract: Previous research on the use of social network analysis in education has demonstrated how the methodology can reveal patterns of interactions that enable the sharing of resources. For more than a decade, we have read about the promise that building networks can bring in terms of enacting instructional improvement. However, few studies have aimed at reporting on the designs and enactments of intentional structures for building teachers’ social capital through the development of social networks. Even fewer have discussed the deliberate mechanisms and methodologies used in the interventions. In this structured poster symposium, we present six current efforts in building teachers’ social capital with an emphasis on what this work is and how it is done. This group of researchers work with a variety of teacher populations both in formal and informal environments to solve important issues in the building of educational and teaching capacities.

Introduction

In 1975, Lortie provided an in-depth picture of teaching as an isolated, technical job in his seminal book, School Teacher. Since then, the concept of teaching has shifted where collaboration and inquiry are celebrated and working alongside fellow professionals in professional development activities is a central goal (Blandford, 2012; Lieberman & Mace, 2008). In addition to acquiring human capital, teachers are expected to develop their social capital via participation in communities of practice and networking (Lovett & Cameron, 2011). Social capital, defined as capacities developed through direct and indirect relationships in social networks (Coleman, 1988), has been a focus of scholarship in understanding educational change, particularly through studies of social networks. The concept of social capital has provided educational researchers and practitioners with valuable perspectives on patterns in social interaction and relationships that impact productivity, resource management, community building, organizational trust, and intervention dissemination (Bryk & Schneider, 2002; Penuel et al., 2013). Over the last decade and a half, Social capital and social network research in education has risen steadily. For example, between 2005 and 2010, the number of studies on social networks in schools increased ten-fold (Daly, 2010).

Mainly through survey and interview data, social network studies in education have revealed insights about how teachers access expertise, the efficacy of leadership structures, how advice, professional, and personal networks support teaching, and why and how school reforms spread through districts (De Laat & Schreurs, 2013; Leana & Pil, 2006; Spillane & Hopkins, 2015; Yoon et al., 2017). This critical mass of research on the potential for social capital and social networks to impact educational contexts has encouraged scholars and school leaders to move toward researching and designing interventions informed by this research. However, few studies exist about these interventions, how they have been implemented, what mechanisms promote change, and importantly, how the interventions have improved teaching and learning. We need to have clear models and strategies of those interventions that work. In this presentation, we aim to provide a range of specific, real-world examples of social
capital and social network professional development interventions and their outcomes from macro-level (e.g., district-wide) to micro-level (e.g., communities of practice) interventions.

Symposium organization
The participants in this symposium have been intentionally selected for the range of research in social network and social capital interventions so that audience members can witness the broad applicability and impactful nature of these theories in multiple teacher education contexts. The content of the presentations vary along research characteristics such as population size and scale (e.g., multi-state cross-school networks to case studies of a preservice course), knowledge domains (e.g., complex systems to mathematics content), and formal and informal settings (e.g., elementary school teaching to afterschool digital learning). They also vary in terms of the mechanisms used to construct social ties and capital such as intentional rewiring, working in the open, and integrating instructional coaches. However, they are all similar in working from the underlying assumptions that social network and social capital interventions provide access to expertise, resources, trust, common instructional goals, common language, and a moral purpose for improving the status quo. The goal of this structured poster symposium is for audience members to walk away with a tangible set of strategies they can immediately put into place with the macro or micro-level populations that they work with. The following session organization will be used:

1. Welcome and introduction by session chair (3 min)
2. Two-minute summaries of individual poster presentations in the large group (12 min)
3. Small group poster rotations (50 min)
4. Large group panel discussion (25 min)

In the large group discussion, we will address questions from the audience and then move to discussing the common affordances and challenges of doing social network and social capital research in various contexts and at various scales.

Symposium participants and study summaries

Building networks to support effective use of science curriculum materials in the Carbon TIME Project
William R. Penuel, University of Colorado Boulder; Elizabeth de los Santos, University of Colorado Boulder; Qinyun Lin, University of Colorado Boulder; Stefanie Marshall, Michigan State University; Charles W. Anderson, Michigan State University; and Kenneth A. Frank, Michigan State University

An enduring challenge in science education is how best to support effective use of curriculum materials. The potential of high-quality curriculum materials to support student learning in science is well documented (Furtak, Seidel, Iverson, & Briggs; 2012). Curriculum materials provide a “toolkit” that teachers use to support classroom instruction (Remillard, 2005). Teachers and students use these tools in different ways that are consequential for the quality of student learning. Some adaptations may enhance learning when they result in curricular experiences that are a better fit to student needs and local policy contexts (e.g., Penuel, Gallagher, & Moorthy, 2011). Other adaptations may diminish the potential of curriculum materials (e.g., Lynch, Szesze, Pyke, & Kuipers, 2007). A central challenge for the field is to support teachers in making adaptations to materials to fit their local contexts better, while still maintaining integrity to the principles that underlie the design of coherent science curriculum materials (DeBarger, Choppin, Beauvineau, & Moorthy, 2013). Developers of such materials, for their part, also need ways that teacher feedback and adaptations can inform subsequent revisions to make them more usable in a wider range of contexts.

This presentation explores one set of strategies for supporting such adaptations: building and supporting social networks comprised of teachers, curriculum developers, and researchers, some of whom are experts with knowledge of both curriculum and local contexts. The project that is the context for the presentation is focused on supporting effective use of a set of science curriculum materials called Carbon: Transformations in Matter and Energy, or Carbon TIME. A team led at Michigan State University developed the materials to support student development along a set of empirically validated learning progressions for carbon cycling and energy flow in socio-ecological systems (Jin & Anderson, 2012; Mohan, Chen, & Anderson, 2009). In the current National Science Foundation-funded project, which is organized as a DBIR project focused on the effective use of the materials, the network structure consists of cross-school networks in three states, led and facilitated by researchers,
curriculum developers, and professional development staff at multiple universities. These networks are designed to promote interactions between teachers and provide opportunities for teacher participants to interact with people with significant expertise in the curriculum materials. The aim is to directly influence how teachers use the curriculum materials in their classrooms through network activities, which in turn reshapes a third network, namely that of students and teacher(s) in the classroom.

In this presentation, we discuss the theoretical framework we are using in our project. Then, we describe how these theories have informed the design of network activities and our research. In the concluding part of the presentation, we present some initial high-level findings from the first two years of our research.

Open source culture as inspiration for design of educator learning networks
Rafi Santo, New York University

Open source culture and the notion of ‘open networks’ has led to important shifts in the ways that learning, collaboration and invention occur in fields ranging from science (Nielsen, 2012) to journalism (Gillmor, 2004) to business (Chesbrough, 2006). However, there is limited work that has explored how education might leverage ideas of open networks and associated open work practices. While the movement to promote development of Open Educational Resources (OECD, 2007) has drawn on open source culture to argue for more extensible and available educational materials, it’s conception of ‘open’ has focused on the ‘content’ of education - curricula, assessments, syllabi - but has not actively looked at the practices of open learning and design by collectives of educators. Such exploration is worthwhile, especially given the increasing downwards pressure on teachers in the age of accountability, associated deprofessionalization and decreasing valuation of educator creativity and collaboration. The open work practices described in this presentation provide a needed contrast to these trends in the professional life of educators.

This presentation explores how a designed organizational network of over 70 informal learning organizations, Mozilla Hive NYC Learning Network, drew on open source cultural practices as a means to promote socially driven collaborative learning among its educators. Hive NYC includes major cultural institutions such as Carnegie Hall and the American Museum of Natural History, the city’s library systems and parks department, grassroots community-based organizations such as Dreamyard and the Brooklyn College Community Partnership and other youth-serving nonprofits that focus on particular pedagogical approaches and specialties like the Institute of Play, Global Action Project, the LAMP, Beam Center, and Iridescent. Member organizations develop learning initiatives around web and game design, film and music production, informal science, “maker” education, journalism, youth organizing, media and digital literacies, coding and electronics, and other emerging digital technologies. At the same time, they share a common interest in promoting youth pathways with technology and exploring new pedagogies enabled by technology.

I advance the notion of “Working in the Open” (Santo, Ching, Peppler & Hoadley, 2014; 2016), a set of work practices that value transparency, an experimental stance and open contribution, and I argue that it represents a departure from existing industrial influences of scientific management and Taylorism in education. I’ll discuss five core practices associated with “working open” -(1) Public Storytelling and Context Setting, (2) Rapid Prototyping ‘in the Wild’, (3) Enabling Community Contribution, (4) Public Reflection and Documentation and, lastly, (5) Creating Remixable Work Products, and will share how these practices are distinctive in their emphasis on promoting open participation in learning and design activities within networks of educators. Following this, I’ll share how Hive NYC stewards supported educators in the network to engage in working open practices both through enculturation and modeling these practices and through providing a consistent ‘platform’ of participation structures where educators could work openly with one another.

Designing Educational Infrastructures for Improvement: Instructional coaching and professional learning communities
James P. Spillane, Northwestern University Megan Hopkins, University of California, San Diego; and Matthew Shirrell, George Washington University

The US education system is at a crossroads in its efforts to facilitate teacher professional learning that supports instructional improvement. Given that teacher quality is the greatest predictor of student achievement, federal accountability policy as well as state and local teacher evaluation policies over at least the last decade have focused much attention on measuring teachers’ performance. Pressure to improve individual teacher performance has been particularly acute in schools deemed underperforming as measured by students’ scores on standardized tests of achievement (e.g., Diamond & Spillane, 2004). In response, many reform efforts have concentrated on supporting
teachers’ professional learning via “sit and get” professional development or one-on-one coaching, in the hopes that, over time, these reforms will foster improvement on a larger scale (e.g., Mangin & Dunsmore, 2015).

Such efforts, however, overlook an essential component of teacher professional learning—social relationships, or what sociologists refer to as social capital; that is, the resources for action that reside in the relations among people (Coleman, 1988). Social relationships afford access to resources like information, advice, expertise, materials, and trust that can facilitate positive change in teachers’ beliefs and practices (e.g., Daly, Moolenaar, Bolivar, & Burke, 2010; Penuel, Frank, Sun, Kim, & Singleton, 2013), and support valued school processes and outcomes like teacher commitment and student achievement (Goddard, Goddard, & Tschannen-Moran, 2007; Leana & Pil, 2006). Given that supporting social capital development is related to positive outcomes for both individual teachers and schools, it is critical that school and system leaders attend to and support teachers’ social relationships as they undertake the complex work of teaching.

A growing body of scholarship seeks to identify the mechanisms that facilitate social relationships between teachers, pointing to various features of the educational infrastructure that support social capital development in schools, such as grade-level assignment and formal leadership positions (Spillane, Hopkins, & Sweet, 2015). Nonetheless, normative dimensions are also critical for facilitating social relationships (Hopkins & Spillane, 2015), where teachers in schools with shared norms such as trust and collective responsibility are more likely to interact about instruction in ways that enable its improvement (Bryk & Schnieder, 2002). Yet to be fully understood, however, is how these features of the educational infrastructure facilitate change in teachers’ practices, both the work practices they engage in as they interact with one another about instruction as well as their classroom practices, especially in contexts where teachers are under pressure to improve.

In this presentation, we explore one school district’s intentional efforts to design an educational infrastructure that fostered collaboration among teachers in its lowest performing elementary schools at a time of mathematics curricular reform, and examine the ways in which this infrastructure shaped teachers’ interactions and classroom practices. We will show how the integration of instructional coaches and the redesign of an organizational routine focused on teacher collaboration (i.e., Professional Learning Communities, or PLCs) worked in tandem to facilitate teachers’ interactions around the implementation of an inquiry-oriented mathematics curriculum. We also show how these features of the district’s infrastructure facilitated changes in teachers’ practices over time, such that their work practices as well as their reported classroom practices came to approximate those in the highest performing schools in the district.

Stimulating teachers’ learning in networks: Awareness, ability, and appreciation

Femke Nijland, Open University of The Netherlands; Daniël van Amersfoort, University of Glasgow; Bieke Schreurs, PXL University College; and Maarten de Laat, University of Wollongong

Learning in networks is receiving increased attention in Dutch primary education. It is perceived as a way to stimulate teachers professional development (Vaessen, Beemt, & De Laat, 2014) and to provide teachers with the opportunity to regulate their own professional development in line with their professional needs (De Laat & Schreurs, 2013). In education, such alignment is particularly important since teachers often perceive their professional development as unrelated to their classroom practice (Lieberman & Pointer Mace, 2008). In addition, learning in networks is believed to lead to a more efficient flow of complex knowledge and routine information within the organization (Coburn, Mata, & Choi, 2013), stimulate innovative behavior (Coburn et al., 2013; Moolenaar, Daly, & Sleegers, 2010) and result in a higher job satisfaction (Lovett & Cameron, 2011). In this respect learning in networks can be perceived as an effective approach to for both professional and organizational development.

In this presentation, we report on a three-phased mode 2 research (Nowotny, Scott, & Gibbons, 2003) intervention for stimulating teachers’ learning in face-to-face learning networks at a between school level. The intervention was informed by insights from literature on what works in learning in networks, and was developed in close cooperation with the participating teachers and principals. The main aim of the project was to study how learning networks could emerge, building upon the informal social networks already in place within the organization. We did so by creating awareness of learning in networks, by offering tools for the development of networking abilities that facilitate learning in networks, and by providing insight in the usefulness of these activities for the appreciation of their value creation. Our intention was to accompany participating teachers and principals on a journey into the what, the how and the why of learning in networks. The main question answered in this project is: How does stimulating awareness, developing networking ability and offering insight into the outcomes of learning in learning networks, contribute to learning in social networks for professional development within an organization for primary education?
We report on eight learning networks that were established between five schools, resulting in more learning ties between teachers, new perspectives for participating teachers on the nature of learning and an overall greater recognition of the emancipatory role of networked learning.

Mechanisms that couple intentional network rewiring and teacher learning to develop teachers’ social capital for implementing computer-supported complex systems curricula
Susan A. Yoon, University of Pennsylvania

Complex systems can be found in structures and behaviors in all aspects of our world—from nanoscale networks to cities, ecosystems, and climates. Scientists have focused on investigating and managing issues related to complex systems that impact our lives, such as the spread of disease, power grid robustness, and biosphere sustainability (National Academies, 2009). Likewise, the recent Next Generation Science Standards (NGSS) highlight crosscutting concepts that reflect important aspects of complex systems (e.g., scale, structure and function, stability and change). Classroom interventions based on software that model complex systems, such as StarLogo and NetLogo (Klopfer et al., 2009; Wilensky & Rand, 2015), have also been created along with accompanying curricula that can be implemented in the science classroom (Yoon et al., 2016). This heightened emphasis on complex systems in educational policy and resources raises challenges for educators who must teach to the NGSS. In a review of the educational literature (Yoon, Goh, & Park, in press), we found a dearth of studies on both teacher learning about complex systems and how best to support teachers in professional development (PD). Furthermore, we know that the success of the NGSS is contingent on the quality of teaching, yet these standards require substantial shifts in teaching practice (Wilson, 2013). And it is widely known that the lack of high-quality PD opportunities make adopting reforms challenging (Blandford, 2012). We need more information about how to develop pedagogical content knowledge and curricula with respect to complex systems in PD activities that are aligned with teacher learning and classroom practice (Yoon et al., 2015).

For several years our research team has focused on addressing this major gap in complex systems research. Initial efforts in PD were predominantly aimed at developing teachers’ knowledge and skills of computational modeling, complex systems, and scientific practices to support curricular integration (Yoon et al., 2017a). Such efforts in building knowledge and skills in individuals can be considered developing human capital (i.e., increasing personal capabilities that enable people to act in new ways; Coleman, 1988). Due to the complex nature of teacher learning and instructional orchestration, however, we came to understand the necessity of building opportunities for teachers to interact about problems of practice and to share implementation strategies as they emerged. Thus, our emphasis shifted in later PD activities to building teachers’ social capital (i.e., capacities developed through direct and indirect relationships in social networks; Coleman, 1988).

In this presentation, we discuss a 2-year design and development study that was part of a project called BioGraph: Graphical Programming for Constructing Complex Systems Understanding in Biology, funded by the U.S. National Science Foundation from 2010 to 2015. The goal of the project was to create teaching and learning resources for high school classrooms centered on the use and construction of computational agent-based models of biological systems. We will begin with highlighting differences in human capital and social capital foci between the first and second years of PD and implementation. We will then describe our theory of change based on strategies of intentional rewiring (Valente, 2012) that are tightly coupled with theories of teacher learning—these strategies are: seeding interactions to improve tie quality; birds of a feather to improve depth of interactions; targeted problems of practice to improve trust and motivation to share; and expertise transparency to improve access to expert practice. We conclude with details about improvements in teachers’ confidence levels that were primarily influenced by their network activities in the second year.

Translating the Connected Learning framework for teacher educators: Lessons from the field
Kira Baker-Doyle, Latricia Whitfield, and Katie Miller, Arcadia University

In the last 20 years, global digital connectivity has given rise to a “networked era,” (Castells, 1996), in which individuals can connect easily across distances, sharing news, stories, and ideas. As such it has changed our ability to access resources and information in social networks, and, some would argue, has mediated cultural practices of communication (Jenkins, 2006; Wesch, 2009). Connected Learning is a relatively new framework for learning that aims to broaden educational opportunities and equity during this era through fostering socially embedded, interest-driven networks of learning in and outside of the classroom. (Ito et al., 2013). The framework was
developed by a team of researchers and practitioners at the Digital Media Learning Lab at MIT between 2010-2013, and has proliferated mainly through grant-funded educational programs for out-of-school youth. The core principles of Connected Learning focus on developing learners’ social capital to gain greater equity and opportunity in education.

Recent social network studies in education have shown that teachers benefit from strategically building professional support networks (Moolenaar, Sleegers, & Daly, 2012; Van Waes, Van den Bossche, Moolenaar, De Maeyer, & Van Petegem, 2015), therefore, Connected Learning has the potential to serve as an important framework for teaching pre-service teachers how to build professional networks of support and improve their practice. Yet, since its inception the Connected Learning framework has mainly been studied in out-of-school learning organizations, such as the Digital Youth Network, which applied the framework to design an effort to foster connections between STEM afterschool programs across Chicago, IL (Barron, Gomez, Martin, & Pinkard, 2014). As such, there is a crucial gap in research on how the Connected Learning framework can be (or has been) used to design teacher education (Baker-Doyle, Mirra, Trust & Lohnes-Watulak, 2017). To address this gap, we examined the experiences of graduate education students (pre-service and in-service teachers) in a course that was designed on the principles of Connected Learning, and also taught the graduate students about how to use the Connected Learning principles to design their own future classrooms. This presentation reports on findings from Year 1 of a three-year longitudinal study.

The Connected Learning framework consists of three learning principles and three design principles (which we elaborate upon in the literature review). We decided to examine one design principle of Connected Learning in our analysis of Year 1 data: engagement in “production-centered” or “making” activities. We sought to study the participants primarily as learners, in how they used and made sense of activities and practices based on this principle of production-centered learning. Furthermore, since the core focus of Connected Learning is on building social capital, we wanted to know how these activities might serve to foster social capital. Ultimately, this study provides insight into how a teacher education program can teach strategic social networking, and how the Connected Learning framework in particular supports this aim.

Thus, our research questions were: What does engagement in “production-centered” learning activities look like in a teacher education course? How do learners’ participation in these practices change over time? And, what are recurrent themes relating to social capital development that emerge through production-centered learning experiences? In this presentation, we discuss lessons for teacher educators that seek to translate the Connected Learning framework into their practice and curricula to promote strategic social networking for professional growth.

References


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Moving Forward: In Search of Synergy Across Diverse Views on the Role of Physical Movement in Design for STEM Education

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Abstract: Inspired by the current embodiment turn in the cognitive sciences, researchers of STEM teaching and learning have been evaluating implications of this turn for educational theory and practice. But whereas design researchers have been developing domain-specific theories that implicate the role of physical movement in conceptual learning, the field has yet to agree on a conceptually coherent and empirically validated framework for leveraging and shaping students’ capacity for physical movement as a socio–cognitive educational resource. This symposium thus convenes to ask, “What is movement in relation to concepts such that we can design for learning?” To stimulate discussion, we highlight an emerging tension across a set of innovative technological designs with respect to the framing question of whether students should discover an activity’s targeted movement forms themselves or that these forms should be cued directly. Our content domains span mathematics (proportions, geometry), physics, chemistry, and ecological system dynamics (predator–prey, bees).

Introduction
Inspired by the current embodiment paradigm turn in cognitive science (Barsalou, 2008; Wilson, 2002), researchers of STEM teaching and learning are seeking to understand implications for educational theory and practice. In particular, design researchers are developing domain-specific theories that implicate the role of physical movement in conceptual learning (Abrahamson & Lindgren, 2014). These scholars conjecture that learning disciplinary content is contingent on enacting particular situated movement routines for participating effectively in the performance of socially constructed tasks in material–virtual settings. And yet two decades since the pioneering movement-based design studies (Nemirovsky, Tierney, & Wright, 1998), our community has still to agree on the specific role of movement in STEM learning (Hall & Nemirovsky, 2012; Lee, 2015). In particular, although embodiment theories hold sensorimotor activity as constitutive of learning, knowing, and reasoning, the field has yet to agree on a conceptually coherent and empirically validated design framework to leverage and shape this resource in education (Abrahamson & Sánchez–Garcia, 2016; Kelton & Ma, 2018). Thus, as the embodiment dust begins to settle on the fertile design-research meadows of the learning sciences, this symposium convenes to ask, “What is movement in relation to concepts such that we can design for learning?”

We all seek a cohesive theoretical framework for conceptualizing the fundamental role of physical movement in content learning. Also, we all believe that fine-grained ethnographic accounts as well as high-resolution data-mining analyses are necessary for providing empirical evidence for the validity of arguments grounded in embodiment theory. Collectively, we furnish diverse evidence supporting an implication of physical actions as critical catalysts in the emergence of new forms of reasoning. Where our designs differ, however, is in
their study rationale and procedure with respect to why, when, and how students should enact these movements. Our most striking dimension of variability pertains to students’ agency in determining the movements. Some of the designs espouse a “bottom up” view, where students freely explore the space of movement possibilities to discover the activity’s targeted dynamical forms, whereas other designs espouse the antipodal “top down” view, in which students are cued to perform certain forms. It is intriguing that these mutually exclusive positions can co-exist. But what if these views are complementary? That would point to potential synergy in theory and design, moving forward. Moreover, the transparency of physical movements, as compared to covert reasoning in traditional sedentary activities, may enable us to revisit enduring problems of pedagogy with respect to the value of guided discovery learning (Abrahamson & Kapur, 2018; Klahr, 2010).

The session will open with introductory words. Six paper contributions then follow, spanning content domains of mathematics (proportions, geometry), physics, chemistry, and ecological systems (predator–prey, bees). Our Discussant, Dr. Oskar Lindwall, will then draw on ethnomethodology principles to interrogate implicit theoretical assumptions underlying the contributing researchers’ respective design architectures and data-analysis methods. Regardless of specific techniques for fostering new movement, each activity appears to breach familiar interaction practices. Much of what we call skill learning could in fact be characterized as teachers and students negotiating new discursive routines and establishing what is learnable within the respective contexts. Illuminating this “dark matter” of STEM education could enhance the quality of design.

**An ecological dynamics view on movement-based mathematics learning: On the emergence of sensorimotor schemes in sociocultural settings**

Dor Abrahamson and Arthur Bakker

A multiyear research collaboration between UC Berkeley and Utrecht University is pursuing the multimodal embodied roots of mathematical concepts. Complementing clinical data with action logs and eye-tracking input, we have been able to implicate subtle micro-processes in the emergence of new sensorimotor schemes anticipating effective problem solving of tablet-based manipulation tasks. In particular, we have demonstrated student construction of attentional anchors (Hutto & Sánchez-García, 2015), information-invariant constellations of environmental features facilitating the situated enactment of complex, dynamical physical actions. Our empirical work has been centered on better understanding the role of attentional anchors in conceptual development. Being design researchers, we are conducting this investigation via further developing and evaluating an educational artifact, the Mathematics Imagery Trainer (Abrahamson & Trninic, 2015).

**Figure 1.** A student invents and uses an emergent attentional anchor to guide the enactment of proportional bimanual movement: He focuses on an imaginary line between the fingertips of his left- and right-hand indexes, keeping this imagined line at a constant angle to the x-axis while moving the line to the right.

Figure 1 shows a sequence of stills from a video of a low-tracked middle-school mathematics student working on a bimanual control activity. In this activity, Orthogonal Plusses, the left hand moves a cursor up and down along a vertical axis while the right hand moves another cursor right and left along a horizontal axis. The activity’s task objective is to make the screen green. Unknown to the child, the screen will be green only when the cursors’ respective vertical and horizontal displacements from the bottom-left corner (the “origin”) relate according to a ratio, here 1:2. The orange spots on the screen are post-intervention overlays of the child’s eye-gaze foveal locations. This student is looking not at the fingertips of his left or right hands that are manipulating the cursors but rather at screen locations that bear no stimuli or contours at all. This dynamical pattern, his idiosyncratic and extemporized attentional anchor, is serving the student as a means of managing an otherwise overwhelming motor coordination task. The student explained that he is imagining a diagonal line connecting his fingertips (top-left to bottom-right); that he is sliding this projected percept along to the right, maintaining its angle constant relative to the screen base. In turn, note how operating this attentional anchor sends his foveal spotlight along a diagonal trajectory from the origin and up to the right along what amounts to a linear function corresponding to the ratio, $y=x/2$. This spontaneous invention of a new perceptual category, the imagined line, thus mobilized the child to construct new mathematical notions relevant to the curricular targets.

Our findings have thus empirically corroborated central theoretical constructs from Piaget’s philosophy...
of genetic epistemology, such as reflecting abstraction, that is, an argument for the pivotal role of new sensorimotor schemes in conceptual development (Abrahamson, Shayan, Bakker, & Van der Schaaf, 2016). In so doing, we have also supported tenets from enactivist theory regarding the emergence of conceptual structures from spontaneous solutions to pragmatic problems of environmental adaptation: “(1) perception consists in perceptually guided action; and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided” (Varela, Thompson, & Rosch, 1991, p. 173).

Drawing on complexity-science research in sports performance (e.g., Chow, Davids, Button, & Renshaw, 2016), we have imported the theory of ecological dynamics to the learning sciences. From this view, we model mathematical ontogenesis systemically as emerging from complementary contributions of embodied and sociocultural forces. Students develop proto-conceptual sensorimotor schemes by using available instruments to achieve contextual objectives specified in the social enactment of cultural practices, such as designed educational tasks. We are particularly interested in the pervasiveness of empirical cases where students themselves create these instruments ad hoc in a struggle to complete task objectives within fields of promoted action (Abrahamson & Sánchez-García, 2016). Given suitable design, students do not need movement direction.

**Insight out: Embodied game play improves mathematical insight and proof**

Mitchell J. Nathan and Candace Walkington

Grounded and embodied cognition (Barsalou, 2008; Shapiro 2014) frames intellectual behavior as grounded in situated action, mental simulation, and bodily states. Evidence is mounting that mathematical reasoning draws on the coordination of motor and language systems (Abrahamson & Trninic, 2015; Alibali & Nathan, 2012; Hall & Nemirovsky, 2012). Our theory of Grounded and Embodied Mathematical Cognition (GEMC) hypothesizes that cognition–action interactions can run forward (thoughts drive actions) and backwards (actions induce cognitive states) through a process of action–cognition transduction (Nathan, 2017). We investigated the empirical implications of GEMC for mathematical reasoning and proof performance in pre-college geometry. Justification and proof are fundamental to secondary and post-secondary mathematics education (e.g., Stylianides, 2007), but students struggle to develop effective proof practices (Knuth et al., 2009).

GEMC posits that body-based (nonverbal) forms of reasoning, as exhibited by gestures that show dynamic mathematical reasoning, can allow for key mathematical insights when reasoning about geometric relationships. When motor system activation is coupled with language system activation, in the form of dialog, self-explanations, or pedagogical cues, GEMC predicts that both insight and the formulation of valid proofs will be enhanced. We explored the implications for theory and learning environment design. Specifically, GEMC-based design principles led us to make The Hidden Village, a videogame where players must copy actions of tribal village members that sometimes model relevant geometric relationships in body-based form. Shape properties are then explicitly explored when players test and justify in-game geometry conjectures (Figure 2).

![Figure 2. The Hidden Village; (a) Scene with full village map; (b) & (c) Directed actions turn green when players’ actions match using Kinect™; (d) Conjecture multiple choice; (e) Tribal elder and earned shape.](image)

We analyzed middle and high school players’ (n=35) speech and gestures from 6 geometry conjectures presented in random order in The Hidden Village. Directed actions (2 factors: math relevant vs. irrelevant arm movements) and pedagogical cues (2 factors: explicit in-game links relating relevant actions and conjectures vs. none) were varied within subjects. Our scoring rubric for valid proofs looked for 3 defining criteria, from Harel and Sowder (1998): proofs exhibit operational reasoning about mathematical entities, a logical chain of inference, and generality. Insight scores reflected partial proofs addressing key relations.

Results support theory-based predictions about the processes linking action and cognition. Players’ dynamic gesture productio predicts: (1) mathematical insight (Odds=8.1, $d=1.2$, $p<.001$); and (2) proof performance (Odds=11.5, $d=1.3$, $p<.001$). Predictions for the efficacy of our game-based intervention showed mixed support: (3) in-game relevant directed actions without pedagogical cues does not predict insight performance; however, (4) directed actions coupled with explicit pedagogical cues linking players’ in-game actions to the math conjectures predicts players’ production of dynamic gestures while justifying their proofs.
(Odds=4.0, $d=0.8$, $p=.001$); (5) insight performance (Odds=3.1, $d=0.6$, $p<.001$); and (6) proof performance (Odds=4.7, $d=0.9$, $p<.001$). Most players reported no conscious awareness of the connection between the directed actions and the conjectures that were posed when receiving no pedagogical cues.

Our theory-based videogame design reveals the potential of GEMC to improve mathematical reasoning through action-based interactions elicited through game play. More broadly, embodied theories invite assessment of nonverbal behaviors such as gesture production, and interventions aimed at new forms of learning experiences through movement (Lee, 2015). Finally, we conclude that a design approach that cues explicit reflection on directed physical movements seems to be the most beneficial for learning of mathematical proofs.

**Embodied explanatory control: simulations that prompt users to enact causal mechanisms**

Robb Lindgren and David E. Brown

Common across theories of embodied cognition is the notion that thinking has “deep roots in sensorimotor processing” (Wilson, 2002, p. 625). Barsalou (2008) argues that cognition is grounded in simulations of perceptual and motoric experiences, and recent empirical work has shown that seeding learning interventions with designed physical activity (e.g., experiencing angular momentum by holding a spinning bicycle wheel) can lead to conceptual gains (Kontra, Lyons, Fischer, & Beilock, 2015). Indeed, much recent work in embodied learning has focused on ways to solicit meaningful bodily action in designed environments, especially technology-enhanced environments (Lee, 2015). There is significant diversity in this work, particularly in how the technology solicits body-action and what makes the activity meaningful. We argue that those decisions can be guided by theories that pertain to the particular kinds of learning and skills that an intervention seeks to cultivate. In our work, we are focusing on students’ causal explanations of scientific phenomena (e.g., molecular interactions). We briefly describe how notions of explanatory reasoning have guided our design of an embodied simulation interface. Clement (2008) describes explanatory models as a type of scientific model that is created by scientists to explain the hidden structures and the unobservable mechanisms behind observable phenomena. We define students’ explanatory models as imagistic models in which a student can visualize the interactions of unobservable elements such as molecules to explain why observable phenomena happen (Brown, 1993). Dynamic visualizations, such as computer simulations, allow a student to “see the unseeable,” and with physically interactive simulations students have the opportunity to build metaphors that connect abstract mechanisms (such as molecular collisions) with sensorimotor experiences (feeling real-world objects colliding).

![Figure 3. From left: The GRASP gas pressure simulation; Jada showing gas molecules hitting a wall; A “ghost hand” guiding the learner to make a fist and become the molecules.](image)

With our GRASP Project (GestuRe Augmented Simulations for supporting exPlanations) we have been faced with the challenges of how to build those metaphorical connections between student movement and computer simulations of science phenomena such as gas pressure. Previous “embodied” simulations have given students control of macroscopic elements, such as using gestures to move a virtual wall that changes the volume of a container holding a gas, which are often visualized as balls bouncing around inside the container. We refer to this type of control as embodied phenomena control (EPC). With EPC, the learner is able to either represent or manipulate some observable aspect of a physical system. But because our work is targeting the construction of explanatory models described above, we have focused instead on gestures that control the interactions of the molecules themselves (Figure 3, left). With embodied explanatory control (EEC) students use gesture to affect pressure by tapping their palm (representing the movable wall) with their fist (representing the molecules). Quick tapping leads to high pressure and slow tapping leads to lower pressure. This particular gesture emerged from preliminary interviews with students like Jada (Figure 3, center) who, when productively reasoning about gas pressure, started tapping her fingers at different rates against the palm of her hand. Leveraging these productive cases, we cued students to represent the causal mechanisms with similar gestures by employing interactive interface techniques such as “ghost hands” (Figure 3, right) and “fading” to facilitate the connection between the body and the visualization (e.g., the hand becomes the molecules). It is important to note that even at the molecular level it would be possible to give learners control by having them directly manipulate elements of the simulation...
(e.g., grabbing molecules and tossing them), but embodiment theories suggest that gestures more naturally connect with knowledge when they are enacting processes and simulating actions (Hostetter & Alibali, 2008). Thus, we let students’ hands represent simulation elements rather than manipulate them. In our design-based research study over 30 students to-date have used the GRASP gas pressure simulations, and initial findings (Brown, Mathayas, & Lindgren, 2017) have demonstrated powerful effects of EEC in focusing student attention on the molecular mechanism for gas pressure. Simultaneous studies of other gesture-controlled simulations such as the causes of seasons are helping us to understand how EEC control can be used for other unobservable mechanisms such as the distribution of light rays on the Earth’s surface.

The ELI-Chem Simulation: Grasping Chemical Bonding by the Hands
Asnat R. Zohar and Sharona T. Levy

This design-research project seeks to solve a fundamental problem in learning about matter: understanding the chemical bond as dynamic equilibrium between attraction and repulsion forces. Molecular phenomena cannot be experienced directly, so students learn about them in the absence of intuitions derived from their experience of the world (Taber & Coll, 2002). Therefore, the concept of chemical bonding is difficult to grasp precisely because there is no analogous physical experience of simultaneous attraction and repulsion. Moreover, mainstream curricula often mislead students by: presenting chemical bonds as different categories (e.g., ionic, covalent) without relating them on the basis of shared principles; and explaining chemical stability of molecular structures using the octet-rule heuristic (i.e. with eight electrons in the outer shells) rather than the more fundamental balance between electrostatic attractions and repulsions (Nahum et. al, 2007; Taber & Coll, 2002).

Students understand STEM concepts by grounding them in their intuitions (Clement, Brown, & Zietsman 1989; diSessa, 1993; Núñez, Edwards, & Matos, 1999). Drawing on embodied cognition theory, we conceptualize this grounding as resulting from purposeful actions (Dourish, 2004; Kirsh, 2013; Wilson 2002). Applied to education, embodiment theory implicates concepts as emerging from situated bodily interaction via reflection, discourse, and modeling (Abrahamson & Sánchez–García, 2016). The embodied design framework specifies how to create opportunities for students to develop new sensorimotor schemes and then shift into scientific reconceptualizations (Abrahamson, 2014), such as universal electrostatic interactions underlying chemical phenomena.

We designed and developed the ELI-Chem environment (Embodied Learning Interactive simulation-based environment, Zohar & Levy, 2015). The base of the learning environment is a chemical bonding computer simulation displaying the attractive and repulsive forces between two atoms and the resulted potential-energy diagram. Using a mouse, students interact as an atom with another atom, exploring changes of forces and energy. By connecting a joy-stick and a haptic device to the simulation, the ELI-Chem system offers sensory-motor experiences of the attractive and repulsive forces at four increasing degrees of embodiment (Figure 4). The study is framed as an experimental pretest-intervention-posttest design with four treatment conditions: animations, mouse-, joy-stick- and haptic-based participation in the model. The participants are forty-eight (n=48) 12th grade chemistry students, randomly assigned to one of the four conditions (12 in each). The independent variable is the embodiment level; the dependent variable is conceptual change, tested with a pre- and post-test questionnaire and using the activities' worksheets of 40-minutes work with ELI-Chem. Main concepts addressed were repulsive and attractive forces, chemical stability and potential energy diagram.

Our findings show that there is an increase in students’ conceptual understanding in all four levels of embodiment, with significant higher learning gain in the haptic condition. From explanations based on the ‘octet rule’ depicting the atoms as static “touching” balls, students turn to consider the dynamic balance between attraction and repulsion forces. In the qualitative results we have seen four important differences between the forms of interaction: the modes of perception used to access information which become more varied as the level
embodiment rises: from seeing, through active manipulation to feeling the forces. As these modes increase in number, the resolution of the information accessed and described increases as different parts of the parameter space become distinct. Since the new component introduced to the students’ conceptual model involved repulsive forces, we can see how more scientific descriptions are provided at the higher levels of embodiment. Finally, multiple perspectives of the phenomenon are adopted by students who experienced higher levels of embodiment.

Complexity Learning via Elicited Movements: MMLA of Embodied Design
Alejandro Andrade, Joshua A. Danish, and Adam V. Maltese

A wealth of empirical findings suggest physical movement is considerably involved in all thinking and knowing (Barsalou, 2008; Wilson, 2002). Educational researchers have been investigating how physical movement could be harnessed in the service of content learning. Indeed, design researchers have demonstrated instructional interventions that foster student development of targeted movement repertoires, which in turn enable the grounding of STEM concepts (Abrahamson & Sánchez-García, 2016; Lindgren, 2015). Evaluating these interventions requires new research paradigms along with appropriate data collection tools. Specifically, multimodal learning analytics (MMLA, Blikstein & Worsley, 2016) research methods utilizing sensing technologies to capture, integrate, and interpret student perceptions and actions, can elucidate implicit processes of embodied learning. We report on results from implementing an action-based embodied design for complexity reasoning. These results were obtained by applying MMLA to explore patterns in fine-grained physical movements students performed as they engaged in a technology-facilitated activity. The patterns were inferred from low-level computer logs and then statistically analyzed through latent states and motion-sequence models.

We chose the challenging subject matter of dynamically stable predator–prey ecosystems (Hmelo-Silver, Marathe, & Liu, 2007).

Figure 5. From left: Barchart dynamically shows predator and prey population count; a student remote-shadows the moving bars; then explains; automatically generated motion-logs show movement analytics.

Fifteen 3rd/4th graders (ages 8-10) were asked to observe and follow two moving population bars depicting predator and prey counts in a running simulation (Figure 5). Due to feedback loops in animal interactions, the two bars present an off-phased sinusoidal motion pattern, in which population counts do not always move in opposite directions. Students’ hand movements are sensed by motion detectors and inscribed over time, through software translation, in the form of two corresponding line graphs. Thus, the line graphs show us, both in real time and as an electronic trace for subsequent reflection and analysis, not what the bars depict but what the students perceive and enact the bars to be depicting. Following each task, we asked students either to reflect on relations between their hand motions and the simulation content or to predict hand motions under various scenarios. These questions prompted the students to consider that at any given moment in the predator–prey ecosystem there are two forces acting simultaneously (i.e., negative and positive feedback loops). This activity abides both with embodiment theories that assign complementary roles to language and sensorimotor activity in conceptual growth (Alibali & Nathan, 2012) and exemplary embodied designs that often steer students to articulate the situated physical actions they have learnt to perform (Abrahamson & Lindgren, 2014).

Comparison of student performance on pre-/post-assessments after this short tutorial shows increase in content understanding of the double feedback loops as well as notable increase in spontaneous gestures that resemble the elicited gestures. These co-speech gestures appeared to support students in ad hoc reasoning, not only in expressing ready-made inferences. They thus mark salient moments where students’ understanding was developing. MMLA of student–computer interaction reveal five distinct movement patterns during the simulation activities, and these patterns correlate with different learning gains: (a) frequently pausing after each movement stroke predicted high learning gains; (b) enacting fluid movements predicted ceiling scores; and (c) lack of sync with the sinusoidal motion pattern predicted lower scores. Consequently, students’ movement patterns, as they engage with visualizations of quantitative models, can predict the quality of their content learning (Gerofsky, 2011). We have thus validated both a learning design and a MMLA method. We also concluded that students benefit from elicited movement, provided they reflect on situated meanings of these movements.
STEP-bees and the role of collective embodiment in supporting learning within a system

Joshua A. Danish, Noel Enyedy, Megan Humburg, Asmalina Saleh, Maggie Dahn, Christine Lee, Xintian Tu, Bria Davis, and Chris Georgen

In our work, we have developed a sociocultural framework for embodied cognition (Danish et al., in preparation). Our goal in doing so is to build upon prior findings about how the body supports individual cognition (Lindgren & Johnson-Glenberg, 2013) and extend these with a theoretical framework—activity theory (Engeström, 1987)—which explicitly addresses both the sociocultural nature of individual learning and the unique characteristics of collective group activity into a combined framework that provides more robust insight into how we can design for and analyze embodied activity in rich sociocultural contexts. In doing so, we take a view of embodiment as activity that explicitly relies upon the use and movement of the body. We then explore embodiment (e.g., gesturing and moving within the space) simultaneously from the perspective of how it impacts the individual learner, how it impacts the collective activity in which a group of students are interacting, and how the two are interrelated. For example, in the current project we build upon the notion of play, which Vygotsky (1978) defined as consisting of both an imaginary situation and a set of rules. Engagement with the imaginary situation in play frees learners to explicitly explore and negotiate the rules of their social world (Elbers, 1994). Within STEP-Bees (see Figure 6), students take on these new roles through a combination of play-acting and movement through the physical and simulated space, a process through which they are able to articulate and revisit their ideas about the concepts they are embodying.

The design of the STEP-Bees environment leverages embodied activity as a tool for learning by allowing multiple students to coordinate their movements within the context of a mixed-reality participatory simulation. Two groups of 2nd grade students (N=16, ages 7-8) participated in seven days of activities, with each group led by one of their classroom teachers. The students each took on the role of a honeybee, physically moving through the space as a bee would, foraging for nectar and communicating flower locations with their peers via a waggle dance, and their movements were tracked using computer vision and translated into an on-screen simulation which was projected in the front of the room. The overall goal of the sequence of activities was to help students explore the patterns and connections within the complex system of a beehive through coordinating their physical movements with feedback. Classroom interactions were videotaped to examine how students coordinate their actions within activities; individual pre-post interviews measured their learning gains.

Students exhibited significant pre–post learning gains for all four learning targets: Communication (t(15) = -12.199, p < .001), Cycle (t(15) = -3.159, p = .006), Complex Systems (t(15) = -5.217, p < .001), and Pollination (t(15) = -7.904, p < .001). Analysis of classroom video reveals that students’ embodiment provided opportunities for coordination with various sources of feedback (peers, simulation, teacher). As individual honeybees, students had to attend to their peers’ waggle dances (represented by their body movements) to find flowers with good nectar, and peers, in turn, had to adjust their waggle dances in response to feedback that their communication was unclear. This coordinated cycle of communicating via physical movements and adjusting movement in response to peer feedback encouraged students to reflect on the interconnected nature of a beehive. Students’ exploration of this complex system was further supported via a need to coordinate with the simulation, which provided additional feedback on how students should move through the space. Receiving nectar at a flower would draw other students towards that point in space, whereas the presence of a predator would steer students’ movements away from that location. Our analyses reveal how the embodiment provided a powerful resource for individual students to think with, as did the ongoing feedback that they received from their peers and the simulation itself. Thus, the combination of individual embodiment, peer feedback, and feedback from the simulation provide a stronger set of resources for learning than any one component alone.
References


Gerofsky, S. (2011). Seeing the graph vs. being the graph: Gesture, engagement and awareness in school mathematics. In G. Stani & M. Ishino (Eds.), *Integrating gestures* (pp. 245-256). Amsterdam: JB.


Unpacking Dimensions of Evidentiary Knowledge and Reasoning in the Teaching and Learning of Science

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Abstract: Although the study of evidentiary reasoning has a long history in psychology and science education, much of this scholarship has focused on how people coordinate evidence with knowledge claims. Less attention has been paid to our notions of evidence itself and how these develop, especially in the context of schooling. In this symposium, presenters draw from scholarship in science studies and the philosophy of science, cognitive work on epistemic reasoning, and research in science education to unpack dimensions of evidentiary reasoning. Our collective focus is on identifying aspects of evidentiary knowledge and reasoning that prevail in scientific practice but are typically absent from classroom implementations of inquiry in science education. Further, the symposium will address sources of challenge for teachers and students as they engage with evidence in the science classroom and discuss ways in which educators can scaffold the development of more sophisticated reasoning with and about evidence.

The study of evidentiary reasoning has long been a focus of psychologists and science educators. Psychologists interested in scientific reasoning have focused on how people develop the ability to coordinate theories with evidence. Science educators have examined how the design of learning environments can influence students’ understanding and use of evidence in contexts of argumentation and inquiry. Despite this rich history of interest, there is surprisingly little discussion in the literature about our notions of evidence itself. Science educators have typically posited that phenomena become “evidence” when connected to a knowledge claim by argument. Although this definition is a helpful starting point, it needs much unpacking to be useful in the design of learning environments. The scholarship in contemporary science studies suggests that scientific evidence is not a simple unitary construct but rather a rich, multidimensional construct. For example, reasoning with evidence involves considerations of its relevance, significance or weight, quality, and concordance with other lines of evidence, in relation to some circumscribed set of hypotheses or models under consideration. Scientific disciplines typically evolve internal methodological norms, standards, and procedures for gathering and evaluating evidence. For example, scientists working in a discipline share knowledge of relevant variables and plausible mechanisms. As part of their education, they learn how variables are typically operationalized in investigative designs, norms and standards for the precision and accuracy of instrumentation, experimental procedures, and measurement, bandwidths and density of sampling, models for aggregating and analyzing data, and conventions for communicating results. Both the psychological literature on scientific reasoning and the science education literature have neglected many of these aspects of evidentiary knowledge and reasoning. In this symposium, we aim to advance research by attempting to address three core questions:

1. What are some dimensions of reasoning with evidence that are prevalent in scientific practice but are mostly missing from classroom implementations of inquiry?
2. What aspects of reasoning with evidence are most challenging for students and teachers to engage with in the science classroom?
3. What are some ways we can scaffold and support students’ engagement with more sophisticated ways of reasoning with and about evidence?
This symposium will be conducted in an interactive format. The co-chairs will briefly introduce the rationale and core questions that the symposium will address (3-5 minutes). Each individual presentation will take approximately 12 minutes. Presenters will draw from their theoretical and empirical work to offer a lens for considering what it means to think with and about evidence in the context of scientific work. The empirical work that will inform the questions addressed by the symposium draws from several grade bands ranging from primary (Manz) and middle school (Berland & McNeill; Duncan, Chinn, & Barzilai) to secondary and post-secondary settings (Samarapungavan, Clase, Pelaez, Gardner, & Misra). Additionally, the presenters examine reasoning in an array of task settings for evidentiary reasoning, including discourse about evidence in contexts of explanation and argumentation, reasoning with digital data such as simulations, from personal every day experiences of phenomena, and from data collected during laboratory investigations. Our two discussants (Wylie and Sandoval) bring different perspectives to the symposium. Wylie, a philosopher of science, has most recently engaged in a program of research (with her collaborator Robert Chapman) that examines evidentiary reasoning in anthropology and how the methodological norms and standards employed in the discipline allow anthropologists to reach consensus about evidence. Sandoval, a learning scientist, has been at the forefront of work on the design of science learning environments to support students’ evidentiary reasoning. During the last segment of the symposium, our two discussants (Wylie and Sandoval) will lead a critical consideration of the presentations, engage the audience in questions and discussion of the issues, and synthesize crosscutting theoretical and practical themes and directions for future work.

“In real nature, does the wind blow three times?” Making the representational nature of evidence visible in classroom investigations

Eve Manz, Boston University

This paper addresses one important aspect of scientific reasoning that is typically left out of students’ experience constructing and critiquing claims and evidence—namely, the relationship between an investigation and the phenomenon it is meant to represent. I use a second grade landforms experiment as a context for analyzing student reasoning about evidence. I show how opportunities to consider how the experiment represented (or failed to represent) the focal phenomenon of wind and water shaping land both supported episodes of rich reasoning and provided challenges for teachers and students.

While empirical investigations have long been a focus of research, we know little about how students reason about the transitions represented in Figure 1 and how this reasoning might be supported in classroom learning environments. Whether in contexts of inquiry, or explanation and argumentation (e.g., Kuhn & Pease, 2008; Masnick & Klahr, 2003; Toth, Suthers, & Lesgold, 2002), prior studies focus on the relationship between experiment and evidence, overlooking experiments’ function as a way to get a grip on aspects of the world that are difficult to isolate and test in situ (for two reviews, see Cavagnetto, 2010; Manz, 2015a). I conceptualize the relationships between evidence, explanations, and empirical work using a framework drawn from literature in Science Studies (e.g. Gooding, 1990; Latour, 1987) and Science Education (Lehrer & Schauble, 2006; Manz, 2012; 2015b). Figure 1 represents these relationships using an elementary school experiment which has been redesigned to more accurately represent scientific work: here, the empirical investigation (placing plants in different light conditions to study their success) is generated to understand a complex phenomenon (a backyard characterized by patterns of shade and light and a corresponding distribution of plants). Observations and evidence are determined in light of an understanding of the phenomenon, and must be made sense of both to draw a conclusion about the investigation and to develop an explanation or explanatory model (here that, different plants are successful in different light conditions).

The analysis presented here focuses on a second grade landforms investigation co-designed with five second grade teachers by adapting lessons from a commercial science kit. The original kit did not provide direction for teachers to support students to think about the transitions represented in Figure 1. In the re-designed lessons, students first examined photographs and discussed how wind and water might shape land; designed investigations using straws and spray bottles to test their ideas; developed, presented and critiqued claims and evidence about how wind and water move earth materials; and then discussed the phenomenon again based on their investigations. Data collected and analyzed for all lessons included videotape of classroom instruction, classroom artifacts, field notes, student work, and an individual semi-structured interview with teachers. Analysis showed that (1) how the experiment represented the focal phenomenon was a relevant question for students and (2) that it influenced how they generated and evaluated evidence. First, in designing experiments, differences in students’ strategies for representing the phenomenon, supported the generation of different forms of evidence. For example, some groups squirted the spray bottles at the earth materials and used measures of distance the materials traveled as evidence, while others decided to first put water into petri dishes,
then move the water; producing forms of evidence such as floating or absorption of water. Second, students bounded their conclusions based on the levels of variables represented in their experiments: that is, many were unwilling to claim that the experiment showed that wind cannot move rocks, as there were rocks in the world bigger than those tested and more extreme forces of wind and water were likely to move rocks. Third, students questioned whether the design of experiments represented “real-world” processes. One student argued against his teacher’s attempt to ratify the choice to blow three times on each material by stating “Because in real life, in real nature, does the wind blow three times and wait for ten minutes, and then blow three times again?”

Opening the experiment up to these choices, tensions, and disagreements provided important opportunities for students to move past objectifying evidence (Sandoval & Çam, 2011) However, these openings also provided challenges to teachers, particularly when students sensibly argued against canonical aspects of evidence production that are reified in school practices. I end with a conundrum that I will explore further in the symposium: are some classroom experiments more useful for reasoning about evidence if we focus on the opportunities that emerge from their problematic aspects, rather than their function in producing “evidence” to support desired content understandings? What might this mean for how we design science learning environments and support teachers to orchestrate them?

How can personal experiences be leveraged as “scientific evidence” In K-12 classrooms?
Leema Berland, University of Wisconsin-Madison, and Katherine McNeill, Boston College

There is a shared understanding throughout the education world that we learn by connecting prior knowledge/experiences with new knowledge (NRC, 2015). In science education, this means that students should be enabled—nay encouraged—to bring their prior experiences into the class’ sense making discussions. However, this call, while easy to make and almost universally supported, has deep underlying complexities. In science, scientists dialogically build knowledge about natural phenomena (Ford, 2012) by manipulating representations of that phenomenon (Duschl, 1990). This suggests a particular definition of scientific evidence in which the information is both phenomena based and transformable (McNeill & Berland, 2017). Consequently, a tension can arise between the everyday experiences students bring to the classroom and a particular view of what counts as scientific evidence.

For instance, Table 1 includes an example from two middle school students during a life science unit. The task asked students to analyze data from an online simulation and to choose which of two provided claims (Desiree’s or Abde’s) is better supported by evidence. In this conversation, we see a tension in terms of what the two students are using to justify their claims. Ignacio is focused on the simulation and talks about “what we’ve seen” and “his energy.” Ignacio is using the scientific evidence from the simulation, which consists of data. In contrast, Julie is focused on her own experiences with running and eating. Her language focuses on “you eat a lot” and “you run faster.”

Table 1: An example from two middle school students during a life science unit
This discussion illustrates a tension that often occurs in classrooms. We want students to be collaboratively connecting to their everyday resources to make sense of what is happening in the classroom. But, how can we dialogically build knowledge based on phenomena that we have not all experienced? How can they use these resources in their sense making if they do not question and interpret them? How can they fold these resources into their sense making so they work in concert with observations and experiences they make in their classroom? In short: Is it possible for Julie’s experience to be a productive resource for sense making in this discussion?

In this paper, we argue that it is possible to leverage everyday resources in ways that allow the class to use them as a piece of evidence as they interpret their more formal observations (what we might call scientific evidence). This is possible when teachers and students work with these resources in ways that are consistent with three design heuristics for identifying and using evidence: phenomena-based, transformable and used dialogically. Table 2 uses the design heuristics to show both how Julie and Ignacio did position her everyday resources in the conversation and how Julie, Ignacio, or a teacher, could have positioned them (we show this as non-italicized text). The presentation will explore this further, exemplifying the various ways everyday resources might be used in class discussions of evidence and how these discussions can be refined in ways that allow the everyday resources to be leveraged as evidence.

<table>
<thead>
<tr>
<th>Phenomena-based</th>
<th>Low</th>
<th>High</th>
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<tbody>
<tr>
<td>Information students have been told, or information that is not directly and obviously connected to experience (e.g., the hypothetical: “if you eat a lot before you run you just, you know, you run faster you”)</td>
<td>Information that is based in observed experiences (e.g., I run a lot and I run differently depending on when and what food I eat)</td>
<td></td>
</tr>
<tr>
<td>Transformable</td>
<td>Asking students to describe what they have seen, or not engaging with it (i.e., Have you ever gone for a long run?) (We note this question, while not encouraging transformation, may set it up by shifting the conversation to a specific phenomenon.)</td>
<td>Asking students questions that challenge their interpretations of the experience (i.e., When do you eat large meals for running – close to the run, the week before, etc.?)</td>
</tr>
<tr>
<td>Used Dialogically</td>
<td>Experiences or information that are not shared and not easily related to other experiences (i.e., Everyone’s body is different, that is what works for me)</td>
<td>Experiences that are common enable students to question and challenge one another (i.e., emphasizing the commonality: “if you eat a lot before you run you just, you know, you run faster”)</td>
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Problematizing and expanding our conceptualization of evidence in science instruction

Ravit Golan Duncan, Clark A. Chinn, Rutgers University, and Sarit Barzilai, University of Haifa

Research in science education has investigated students’ reasoning with and about evidence in the context of evidence use in arguments to support or refute claims (e.g. Berland & McNeill, 2010), as well as use of evidence in constructing and evaluating models (e.g. Passmore & Svoboda, 2012). Yet we argue that despite these efforts, the construct of evidence remains relatively undifferentiated in the science education community and in science instruction. One consequence of this uniform view of evidence is that classrooms often feature evidence that is
epistemically simpler than evidence in science. Whereas evidence in science varies noticeably in amount, scope, comprehensiveness, methodological quality, robustness, technical complexity, and types of inferential connections to explanations, evidence in science classrooms is often simplistically used to determine whether or not evidence supports or contradicts a claim, and stating a reason why.

We thus argue that there is still a need to problematize and unpack the nature and development of evidential reasoning. To make progress, we must complexify the construct of evidence and explicitly deal with a wider range of dimensions of reasoning with and about more authentic forms of evidence. We therefore propose a theoretical framework for reasoning with and about evidence that expands current conceptualizations of evidence. The main objective of this framework, which we call grasp of evidence, is to complexify the concept of evidence in ways that will facilitate introducing more authentic forms of evidence and more sophisticated ways of engaging with evidence in science classrooms. Our work builds on recent insightful analyses by McNeill & Berland (2017) and by Samarapungavan (in press).

We focus on developing a grasp of evidence, which draws on Ford’s (2008) construct of grasp of practice. For Ford, a grasp of practice involves internalization of two interrelated roles critical for scientific knowledge building: constructing and critiquing claims (Ford, 2008). “Grasp” implies that the knowledge at hand is not purely declarative, but also includes knowledge of how to engage in critique, as well as epistemic justifications about why such critiques are necessary and which are relevant. Such a grasp is socially constructed and negotiated within a community of scientists (or learners). From a lay perspective, a grasp of evidence affords becoming a competent outsider, and making informed decisions about the credibility of scientific claims and evidence even in the absence of deep domain knowledge (Feinstein, Allen, & Jenkins, 2013). The grasp-of-evidence framework consists of two “axes.” The first axis theorizes four dimensions that comprise grasp of evidence:

- **Analysis**: To reason with evidence, one must first identify and comprehend its components (e.g., goals, methods, results, conclusion) and their interrelations. Science studies have shown the prominence of reading and comprehending in the work of scientists (e.g., Tenopir, King, Boyce, Grayson, & Paulson, 2005). This involves analysis of studies into its components, and understanding how these components fit together.

- **Evaluation**: The second cluster of practices involves evaluating evidence. These are the familiar processes of evaluating the full range of methods used in a particular study—whether this means critiquing someone else’s study or thinking through how to construct studies that withstand critical evaluation. Evidence evaluation is a central evidentiary practice in science (e.g., Staley, 2004).

- **Interpretation**: The third cluster of practices involves interpreting evidence. These practices are also at the grain size of the individual study, as scientists work out how to interpret or reinterpret the results of a study in terms of one or more models, explanations, or theories under consideration. Understanding the nature and strength of the relationships between the evidence and competing claims and models is thus a core aspect of working with evidence (Chapman & Wylie, 2016; Galison, 1997).

- **Integration**: The fourth cluster involves integrating evidence. In science this involves a variety of processes for identifying bodies of relevant evidence, considering how types of research fit together to support one model over another, and weighing evidence in various ways (e.g., Solomon, 2015).

The second axis of our theoretical framework derives from the AIR model of epistemic cognition (Chinn et al., 2014), which posits that epistemic cognition includes three central components: (A) **Aims and value** are the goals that individuals and communities set (aims), such as knowledge, and the importance of that knowledge (value). (B) **Epistemic Ideals** are the criteria used to evaluate whether epistemic aims have been achieved and the quality of resulting scientific products such as evidence or models. (C) **Reliable epistemic processes** are the diverse processes used to achieve epistemic aims, such as protocols for carrying out observations or conducting experiments, approaches to conducting meta-analyses, and so on. The framework involves applying the AIR model to unpack and specify the four dimensions of grasp of evidence. As an example, consider the evidence interpretation dimension. The core epistemic aim we associate with evidence interpretation is determining model validity using strong evidence. By strong evidence we mean evidence that is more tightly interconnected to one model and thus supports that model differentially over others. Several ideals can be used to judge evidence strength including its relevancy to the model in question, its ability to provide support (or to refute) core aspects of the model (as opposed to peripheral ones), and its diagnosticity (differentially supporting one model while refuting another). To meet these ideals students can engage in reliable processes such as careful consideration of which part of a model evidence supports, designing experiments that can provide diagnostic evidence, and so on.

We argue that a framework for grasp of evidence can help educators and education researchers in at least three ways: (a) it can help decide how to engage students in reasoning with and about evidence; (b) it can provide the basis for better assessments of reasoning with and about evidence; and (c) it can suggest
instructional approaches that can help students develop a grasp-of-evidence.

**Deconstructing evidence: Contextualizing students’ understanding of methods for gathering and interpreting evidence in biology**
Ala Samarapungavan, Kari Clase, Nancy Pelaez, Stephanie Gardner, and Chandrani Misra, Purdue University

In this presentation, we draw from a conceptual framework for contextualizing students’ evidentiary reasoning in disciplinary knowledge and practices in biology (Samarapungavan, in press) and from our recently initiated empirical work as part of the Exploring Biological Evidence (EBE) project (funded by the National Science Foundation) to address the core questions posed by this symposium. Scholarship in science studies has emphasized the role of shared disciplinary norms and standards for inquiry and the generation and valuation of evidence as a basis for scientific consensus (Chapman & Wylie, 2016; Giere, 2010). For example, Galison (1997) has examined how the theoretical commitments of particle physicists shape their design of experiments, strategies for data reduction and decisions about whether the data represent something “real” in the world. Psychologists and educators have long recognized that science learners may interpret phenomena differently from scientists because they draw on different funds of knowledge. Indeed, research in psychology and science education has placed considerable emphasis on this aspect of evidentiary reasoning (Lehrer, & Schausle, 2006). The kinds of scaffolds that have been used to support students evidentiary reasoning tend to be generic in nature. For example, technology prompts in WISE (a digital inquiry environment) urge students to evaluate evidence for “usefulness” and “relevance” as they generate scientific explanations (Kali & Linn, 2008). Educators have paid much less attention to the rich methodological knowledge embedded in disciplinary practice that shapes and constrains fruitful evidentiary reasoning for scientists. Yet it is precisely this kind of knowledge that becomes critical to more advanced science learning in the secondary and post-secondary years, a period in which US students, for example, show sharp declines in interest for and achievement in science. The EBE project attempts to address this gap by designing and evaluating the impact of varied types of disciplinary scaffolds to support students’ considerations of methodology in evidentiary reasoning. We will present preliminary data from our first round of implementation to illustrate how the contextualization of school inquiry practices in theoretical and methodological aspects of relevant disciplinary knowledge, can be used to enhance students’ evidentiary reasoning. Based on a synthesis of research from science studies, the psychology of scientific reasoning, and science education, Samarapungavan’s (in press) Conceptual Analysis of Disciplinary Evidence (CADE) framework highlights four broad, reciprocally related, categories of evidentiary relationships in scientific practice that are shaped by disciplinary knowledge. Because of space constraints, we focus here on the three of the four CADE categories to illustrate our approach:

1. **Theory to Evidence** relationships involve the framing and articulation of potentially testable models. Disciplinary knowledge circumscribes and problematizes focal phenomena that scientific models are designed to represent and explain. These relationships come to define what counts as evidence, where we should look for it, and how we will collect, interpret and use it. Recent science education research has grappled with ways of connecting the theoretical and empirical in student reasoning and sense making during inquiry (Berland & McNeill, 2017; Manz, 2012; Sandolav, 2005, 2014). For example, our own prior work as well that of others shows that in the teaching and learning of evolutionary biology in secondary school, discussions of natural selection often focus on species features and behaviors that confer survival benefits, such as success at finding food or evading predators (Samarapungavan, 2011, Sandolav & Reiser, 2004). In contrast, little attention is paid to reproductive success which biologists consider to be the mechanism by which population changes occur over generationy. Therefore, to support evidentiary reasoning about evolution, disciplinary scaffolds might include reminders to consider the specific factors needed for the preservation/transmission (or lack thereof) of traits and behaviors across generations of species (i.e, reproductive success).

2. **Evidence to Data** relationships involve models for designing and executing investigations including the set up and use of instrumentation for data gathering, as well as models for aggregating and analyzing data. The work presented by Manz suggests that even young science learners (second graders) can begin to consider the extent to which their designs for gathering evidence make sense given what they know in a particular domain. However, these aspects of evidentiary reasoning remain problematic at more advanced levels of science learning. For instance, disciplinary research traditions develop contextualized internal norms and standards for sampling, which include knowledge of appropriate sample sizes but also such things as what intervals or range of values to sample. Students often have not learned (or have learned but do not remember to contextually employ) such disciplinary norms as they engage in inquiry. While students thinking about natural selection might know that they need to look at survival data over a time span rather than a single point in time, they often pick a time span that is too short to observe evolutionary adaptations because they do not consider the
reproductive cycles of a particular species and how long it will take for several successive generations of that species to reproduce. To support a more effective methodological framing of student inquiry from evolutionary data bases such as the Galapagos finch simulation (Howard Hughes Medical Institute, 2015), disciplinary scaffolds might explicitly prompt students to consider the time it takes for a species to produce a new generation of members, and to consider how many generations they would need to observe in order to draw conclusions about evolutionary change.

3. Evidence to Theory relationships include disciplinary contextualizations that constrain the interpretation and evaluation of evidence gathered from a particular set of investigations. They involve evaluations of the evidence along such dimensions as the consistency of evidence across related experiments, strength of effects, boundary conditions, relationships to a previously established body of evidence in the field, or relationships to some set of disciplinary models. In the practice of science, evaluations of evidence are highly contextualized in disciplinary knowledge. For example, a member of our research team (Pelaez) asked undergraduate biology students to design an aqueous media for diluting, preserving, and observing red blood cells from specific animals (rabbit, cow, goose, chicken, etc.). Preliminary analyses of student work suggest they had trouble integrating pH and osmolyte concentration variables in their treatment of blood cells from different animals (Pelaez & Liu, in preparation). Later, given a table of normal blood serum parameter ranges including pH and osmolyte concentration measures (extracted from published research studies), they had trouble selecting and integrating all the relevant blood serum parameter evidence for clustering species on an evolutionary tree. In constructing a tree for a set of species including the birds and mammals, some compared absolute differences in the numerical upper value for some osmolytes with overlapping ranges, which is less meaningful than small differences in other osmolytes with non-overlapping ranges. Furthermore, even those who successfully clustered species based on the blood serum evidence had trouble integrating all of the evidence. Many drew an evolutionary tree with guinea pigs and rabbits correctly clustered on a branch with a more recent ancestor than with a cow, but they ignored evidence for putting the chicken and goose together on another branch that shares an even more distant common ancestor with the rabbit, guinea pig, and cow (Pelaez & Liu, in preparation). Although the students were given generic prompts to consider “variability” in their data set, had learned about the specific osmolytes under consideration in prior coursework, and had studied the chronology of evolutionary processes, they did not spontaneously use disciplinary knowledge to contextualize their interpretations of the evidence in the lab. Disciplinary scaffolds to support students’ evidentiary reasoning in this instance would include prompts to first identify and explain how and why the range and distribution of serum pH and osmolyte values for each animal differs, second to consider what magnitude of differences in value would be considered significant by biologists, and third to explain their findings in terms of the chronology of evolutionary processes that produced diversification (Kong et al., 2017) resulting in the different mammal and bird species. Making such considerations explicit should help students interpret the evidence for different evolutionary relationships in ways that are more consistent with disciplinary norms of biology.

Although, educators have made important strides in trying to understand and support the development of evidentiary reasoning in science learning, we propose that in order to support sophisticated epistemic reasoning in the teaching and learning of science, educators must unpack the notion of evidence itself and reconnect it to its disciplinary contexts.

References


Pelaez, N. J., & Liu, C. (in preparation). *Opportunities and problems with a model of the use of evolutionary trees (MUET) for tree thinking in the laboratory classroom.* Unpublished manuscript.


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Knowledge Integration in the Digital Age: Trajectories, Opportunities and Future Directions

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Abstract: Researchers from around the world have shaped knowledge integration (KI), a framework that captures the processes learners use to build on their multiple ideas and refine their understanding. KI emerged 25 years ago from synthesizes of experimental, longitudinal, and meta-analytic studies of learning and instruction. Advances in KI have resulted from partnerships that combine expertise in learning, instruction, classroom teaching, assessment, technology, and the disciplines. This structured poster session includes partnerships that have advanced design of instruction, assessment, professional development, learning technologies, and research methodologies. Participants report on new technologies, including games, to strengthen KI; instructional designs that take advantage of collaboration to support KI; and extensions of KI to integrate science with other disciplines. They summarize exciting results and identify promising opportunities for advancing STEM instruction to promote intentional, life-long learners in the digital age.

Introduction
This structured poster session brings together partnerships using the knowledge integration (KI) framework to advance their research programs. Over the past 25 years, KI research has documented how learners grapple with multiple, conflicting, and often confusing, ideas about scientific phenomena and led to the identification of design-principles (Kali, 2006) and learning processes (Linn & Eylon, 2011) that promote coherent understanding (Kali, Linn & Roseman, 2009). KI design principles have been refined in designs of instruction, assessment, professional development, and technologies. For example, the Web-based Inquiry Science Environment (WISE), used in many of the works presented in this session, supports authoring and customization of instruction, logging of student interactions with simulations or virtual experiments, and random assignment of students to conditions within classes (see Study 1, 2, 7, 8).

Researchers studying KI have identified four interrelated reasoning processes that students use to integrate and make sense of their ideas. The posters address ways to use and strengthen all these processes:
• **Elicit ideas.** Prompting students to articulate and explicate their existing ideas (e.g., making predictions or brainstorming initial ideas) ensures that new ideas can be considered alongside pre-existing ones for inspection and refinement (see example in Study 5).

• **Add ideas.** Through carefully designed guided activities and representations (Parnafes & diSessa, 2004) students can encounter new scientific ideas to add and connect to existing repertoire (Study 3, 4, 6, 8).

• **Distinguish ideas.** Learners need support in developing coherent ways to evaluate the scientific ideas they encounter. Designed instructional activities featuring critique, informative data displays, or trade-offs can help students to develop criteria for distinguishing useful, relevant ideas from unproductive and irrelevant ones (Kidron & Kali 2015; see Study 1, 2, 4, 6, 7).

• **Reflect and integrate ideas.** Students reflect on their repertoire of ideas by applying criteria to evidence, making note of contradictions and identifying instances where additional information can help to resolve weaknesses, gaps or inconsistencies in understanding. In doing so, students reformulate both their criteria and their accounts of scientific phenomena (see examples in Study 1,3).

This structured poster session includes partnerships that have advanced design of instruction, assessment, learning technologies, and research methodologies. The studies represented in the posters explore KI in a variety of age levels and contexts: middle schools, high schools, and university courses. Participants report on new technologies, including adaptive guidance to support students’ use of science practices to strengthen disciplinary explanations (studies 1, 2, 3). Studies report on instructional designs that strengthen socio-cultural aspects of learning (studies 4, 5) by supporting collaborative interactions and a culture of interdependence among students. Further innovations extend KI beyond science to guide and assess student reasoning in complex, multidisciplinary, real-world challenges (studies 6, 7, 8). Taken together, the use of KI across research programs expands our understanding of learning in the digital age and provides a shared framework for advancing STEM instruction to promote intentional, life-long learners.

The Chairs will set the context of the poster session by discussing how KI is building robust learning sciences findings that have powerful practical implications for education. Each of the eight partnerships will have two-minutes to introduce their poster. Attendees will visit each poster to discuss research findings, the impacts, and research implications. Posters will be clustered around: new technologies, including games, to promote intentional, life-long learners.

Study 1. Teacher customization of automated guidance to strengthen revision for knowledge integration
Marcia C. Linn and Libby Gerard

In this study, we combined teacher guidance with automated guidance to strengthen the frequency and quality of student KI essay revision in inquiry science units. The NGSS have shifted the focus of science instruction from recall of factual information to the integration of science practices, disciplinary core ideas, and crosscutting concepts. Revising KI essays aligned with NGSS involves an iterative, recursive process of constructing understanding while revising ideas (Bransford, Brown, & Cocking, 1999; Osborne, 2014). Advanced natural language processing (NLP) techniques, enabled us to design adaptive KI guidance for student written essays embedded in inquiry units to encourage students to revise. Across multiple studies, the adaptive KI guidance proved to be more effective in improving learning than other types of guidance typically assigned in a middle school classroom (Gerard, Matuk, McElhaney & Linn, 2015). Yet, we noticed a troubling pattern: students struggled to use guidance to revise their essays. Across 5 studies, 27% of students on average made no revision; only 42% made productive revisions that integrated or linked relevant pieces of evidence together. The remaining 30% tacked on a disconnected idea to the end of their initial response.

We partnered with a 6th grade teacher implementing the WISE Plate Tectonics unit with her 201 students (53% non-White; 34% receive a free/reduced price lunch) to customize the automated guidance system to promote revision among her students. To establish goals, the system assigned a score for each essay revision. To provide struggling students just in time support, the teacher set alerts to notify her in real-time if a student scored a 2 or lower (out of 5), after their first revision. The teacher set the expectation that all students should achieve a top score through revision. To support them, she required students to check-in with her after they received automated guidance and made a revision, and before they submitted their essay a second time.

Analysis of 37 audio recordings of teacher-student guidance interactions, suggest that the teacher used the automated KI guidance as a starting point to strengthen students’ essay revisions. First, the teacher had the
student read the guidance they received aloud. Then she probed for elaboration (e.g. You said the blob goes up because it is hot. Well if it is hot, is it more dense or less dense?). If the student needed further assistance, the teacher directed the student back to the model and focused their attention on a particular piece of evidence. After the conversation the teacher guided the student to express how they planned to revise their essay (e.g. You mentioned some great ideas. What are those to include [as you revise]?). The teacher’s customization increased the number of students who revised their essays (96%) and the quality of their revisions (N=100 pairs, \( \text{M}_{\text{gain(revised-initial)}}=0.48 \), \( \text{SD}=0.81 \), \( t(99)=5.93 \), \( p<0.001 \)).

Engaging teachers in customizing an automated guidance system can improve student revision of essays for KI. Customizing encouraged the teacher to take ownership for the revision process, generating criteria for successful essay revision and developing strategies to help students engage in a successful revision process. Future research should explore extending teacher customization beyond the automated guidance and into the use of aggregate analyses of automatically scored student essays to inform customizations that address the class’s evolving ideas.

Study 2. Leveraging log data from simulations to understand students’ knowledge integration processes
Emily Toutkoushian, Kihyun “Kelly” Ryoo, Kristin Bedell, Marcia C. Linn, and Amanda Swearingen

Simulations can provide students with opportunities to engage in science practices by allowing them to manipulate variables, plan and conduct virtual investigations, and collect and analyze data to deepen their understanding of complex scientific phenomena (NGSS Lead States, 2013). Advances in new technologies enable the automatic collection of massive amounts of data while students are interacting with simulations, including time-stamped logs of students’ clicks, variable manipulations, and use of evidence to answer reflection questions (Rupp, Nugent, & Nelson, 2012). Such log data can provide powerful insights into how students engage in science and inform the design of effective automated feedback to help students’ learning with simulations (e.g., Gobert et al., 2013). However, interpreting log data so that it is useful for educational purposes can be difficult and needs to be guided by relevant learning theories. KI offers a theoretical framework for how students develop an integrated understanding of scientific phenomena through eliciting initial ideas, adding new ideas, distinguishing among ideas, and sorting ideas into a coherent framework (Linn & Eylon, 2011).

This study explores whether and how log data from simulations can be utilized to delineate the relationships between student actions and the four KI processes. The study involved 148 students from 11 eighth-grade science classrooms at two low-income, linguistically diverse schools. Student pairs completed two simulations focusing on states of matter and chemical reactions at the molecular level during two weeks of web-based inquiry instruction. Both simulations were scaffolded by prediction questions, a data table, and reflection questions. We use cluster analysis to group students based on similarities across variables from the interaction data, data table, and embedded questions and then find the characteristic learning patterns of those clusters of students. Our preliminary findings illustrate how students at different levels in the KI process demonstrated distinctive, characteristic patterns while interacting with simulations. For instance, students who had a low KI score on the reflection questions, indicating that they were mainly “adding” ideas in the simulations, tended to engage in more actions related to procedures (i.e., resetting or saving the simulation) than directly manipulating variables within the simulations (i.e., changing the amount of thermal energy). By contrast, students with the highest score on the reflection questions, indicating that they were “sorting” ideas, had the fewest total actions compared to other students and tended to engage mostly in directly manipulating variables or interacting with the graph displaying the simulation results. These interaction patterns can be leveraged to provide adaptive, automated guidance to help students move between KI levels as they investigate a simulation, This study provides implications for making decisions about the design features and automated guidance for simulations to support students’ KI learning processes.

Study 3. Scaffolding KI in a digital game through adaptive self-explanation
Douglas B. Clark, Satyugjit Virk, Jacqueline Barnes, and Deanne Adams

Prompting students to engage in self-explanation can enhance KI by encouraging students to engage in meta-cognitive activities to monitor what they do and do not understand (Chi, Bassok, Lewis, Reimann, & Glaser 1989; Roy & Chi, 2005; Chi & VanLehn, 1991). Such meta-cognitive activity is highly beneficial to KI (Clark & Linn, 2013). Research suggests that self-explanation functionality can effectively support KI in the context of digital games. Research also highlights challenges, however, in balancing and integrating the demands and abstraction of self-explanation functionality with the demands and structure of the game. These challenges are particularly
true for games that are, themselves, cognitively more complex. The current study presents an approach that adapts the abstraction of self-explanation prompts based on a player's performance.

The current study was conducted with 210 students in the 7th grade classrooms of two teachers in two different middle schools in the southeastern United States. In the navigation-only condition, players programmed their trajectories without any self-explanation prompts. In the navigation+abstract condition, these navigational challenges are paired with a self-explanation prompt that focuses on abstract connections between the navigational challenges and Newtonian relationships. In the navigation+adaptive condition, the navigational challenges are paired with self-explanation prompts that adaptively increase from low abstraction (in which the prompts focus concretely on navigational moves) to high abstraction (in which the prompts focus more abstractly on the navigational challenges in terms of overarching Newtonian relationships).

The results demonstrate that students in this condition (a) scored significantly higher on the post-test than students whose self-explanation prompts were not adaptively adjusted and were always abstract and (b) scored higher, but not significantly so, than students who did not receive the self-explanation functionality. Analyses of gameplay metrics suggest that trade-offs in terms of progress through the game may explain some aspects of these posttest comparisons. Analyses also demonstrate that both self-explanation conditions significantly outperformed the navigation-only comparison condition on a gameplay metric that suggests deeper model-based thinking and KI. These hypothesized differences parallel the distinctions between model-based reasoning and constraint-based thinking reported by Parnafes and diSessa (2004). Future research should explore extending the adaptive self-explanation functionality beyond the current platform into a broader range of digital platforms targeting KI.

Study 4. Orchestration supports for knowledge integration in a blended learning community curriculum for Grade 12 Biology

Alisa Acosta and Jim Slotta

Our work is grounded in a pedagogical model of learning communities called Knowledge Community and Inquiry (KCI; Slotta, 2014), wherein students work as individuals, small groups and a whole class to generate a shared community knowledge base and to use that knowledge base as a resource for subsequent inquiry activities. An important aspect of KCI is the design of curricular scripts (Fischer, Kollar, Stegmann, & Wecker, 2013) which specify the activity sequences, materials, student groupings, and technology elements that serve to guide the inquiry toward particular learning goals. Orchestration refers to the enactment of the script, binding it to the local context of learners, classrooms, curriculum, and instructor, and giving it concrete form in terms of materials, activities and interactions amongst participants (Tchounikine, 2013).

In collaboration with a high school biology teacher, we co-designed and implemented a KCI curriculum and corresponding technology environment called CKBiology within two sections of a Grade 12 Biology course. Students contributed to a shared community knowledge base in three ways: 1) By providing written explanations for various terms or concepts, 2) by identifying relationships between pairs of terms or concepts, and 3) by peer-reviewing explanations that had been written by other students. The concepts were presented in a concept map, with links representing the identified relationships, and concepts with completed explanations appearing in blue, uncompleted explanations in grey, and 'incomplete' or 'incorrect' explanations (as a result of peer review) containing a yellow dot. This knowledge base captured the KI processes of adding and distinguishing ideas, and was projected at the front of the classroom as students were working, serving as an orchestration support for both students and the teacher. This allowed gaps or disagreements in the knowledge base to become visually prominent, leading to impromptu class discussions, negotiations, and improvement. Through these activities, we argue that the teacher led the students to develop collective KI within the overall knowledge base.

The knowledge base then served as a resource for subsequent "review challenge" activities. In the first review challenge activity, students chose an area of specialization (i.e. immunology, endocrinology, nephrology, neurology) and worked within these specialist groups to solve a series of challenge problems. For each student, we generated a recommendation score based on the quantity (i.e. # of explanations written) and quality (i.e. # of negative peer reviews received) of their contributions to the knowledge base for each area of specialization. In the second review challenge activity, students formed jigsaw groups containing one representative from each specialization. Playing the role of medical practitioners, the groups integrated their diverse expertise in order to diagnose a virtual patient with ambiguous symptoms. Students were guided through this activity via a series of questions in the CKBiology platform, which included ordering the appropriate lab tests, negotiating and explaining the reasoning behind their diagnoses, and identifying possible treatment options—thereby integrating
the knowledge they had acquired over the course of the unit. The poster will illustrate how KCI builds on KI to strengthen community learning.

**Study 5. Cognitive processes and collaborative supports for knowledge integration among youth designing games for science learning**

Camillia Matuk, Christopher Hovey, Talia Hurwich, and Juan Pablo Sarmiento

We explore youth’s learning through their design of educational science games. Such games are unique learning opportunities because they require designers to integrate diverse areas of knowledge, including experience with games, an understanding of science, knowledge of effective pedagogical strategies, and a facility with the design process (c.f., Khaled et al., 2014). As with other complex, real-world problems, this task is best accomplished by a team of interdependent collaborators with distributed expertise, rather than through the equal roles typically assigned to students in traditional classroom settings. But what roles do learners take on in such situations? What is learned, and by whom? How is that learning supported by, and made visible in the game design process? We investigate these questions through our design and enactment of a youth workshop for designing games for science learning.

Our participants were eleven 7th grade youth from a public middle school in a large urban city in the eastern United States. Up to 4 facilitators were present on any given day, as well as two teachers from the students’ school. In our 5-day long elective workshop, we tasked students with creating games to teach players about the measles virus. Their games were intended to accompany the comic book, *Carnival of Contagion* (worldofviruses.unl.edu, Diamond et al., 2012), which touches on the pathology and cultural history of the measles virus, and frames vaccination as a social responsibility. The first four days of the workshop took place at a university-based game studies center. Activities guided students in brainstorming design ideas from their reading of the comic, developing and play-testing prototypes, and refining their designs. On the final day, students exhibited their games and hosted a game jam for their peers at school.

Our workshop was informed by research suggesting that dispositions toward STEM develop best during playful, social interactions in which learners can express their ideas, goals, interests, and curiosities; engage in activities driven by shared purpose; and have opportunities to realize the personal relevance of STEM (e.g., Clegg & Kolodner, 2013). We also draw on principles for encouraging disciplinary engagement (Engle & Conant, 2002. Following these principles, we gave students interdependent roles (science wizard, play engineer, and concept artist) intended to help them express agency in their individual responsibilities, as well as to appreciate their peers’ unique contributions to their shared goal (cf. Jiang, Shen & Smith, 2016). We also created end-of-day deliverables to encourage student accomplishment of key milestones in the design process. Finally, we created activities that addressed individual expert responsibilities, as well as ideas that crosscut roles and that addressed science game design (e.g., how to align learner and player mechanics), the design process (e.g., how to move from idea to prototype), and the social aspects necessary for productive collaboration (icebreakers, teambuilders).

Our data include field note observations, audio recordings of design activities, student interviews, facilitator reflections, iterations on students’ game design artifacts, and responses to surveys. By drawing illustrative examples from our analyses, we describe how students learned to integrate their understanding of science and games throughout their design process. We document the challenge of facilitating this process given students’ diverse starting points in their understanding of science, design, games, and pedagogy. Further we describe how different teams approached their interdependent roles, sometime successfully and sometimes not. The teams illuminate the challenges of building a culture of interdependence among learners who are used to school’s traditional power structures.

This work adds to the larger program of research on KI by examining how interdependent collaborative learners make connections among their ideas and the contributions of others concerning science discipline ideas and game design. Future work might explore what aspects of KI are useful in such settings, and which might need to be elaborated or adapted.

**Study 6. Extending the knowledge integration rubric to assess interdisciplinary understanding**

Adi Kidron and Yael Kali

We expanded the KI rubric (Liu, Lee, Hofstetter, & Linn, 2008) to assess interdisciplinary understanding for undergraduate students studying a semester-long interdisciplinary course. The course was based on the Boundary Breaking for Interdisciplinary Learning (BBIL) model (Kidron & Kali, 2015). We used different learning technologies to design features (e.g., video-recorded lectures, collaborative documents, structured feedback...
activities) that embodied our BBIL design principles: break boundaries between disciplines with an interdisciplinary curriculum and a cross-cutting theme, and between learners by using a learning community approach (Bielaczyc & Collins, 1999).

We refer to interdisciplinary understanding as a synthesis of ideas, data, information, methods, tools, concepts or theories from two or more disciplines (Boix-Mansilla, 2010). Therefore, to assess interdisciplinary understanding we combined KI (Linn, 2006, Linn & Eylon, 2011) and interdisciplinary learning as a pragmatic constructionist view (ILPCV) (Boix-Mansilla, 2010). Both frameworks focus on integration processes to promote cognitive advancement. We created a rubric that enabled us to code the different dimensions of interdisciplinary understanding, as conceptualized in ILPCV, and systematically quantify different idea connections, as practiced in KI. In the context of interdisciplinary understanding, the definition of ‘connection’ was broadened to include: links between ideas within the same discipline (referred to the rubric as ‘disciplinary grounding’); links between ideas from different disciplines (referred to as ‘idea connection’); links between disciplinary ideas and the cross-cutting theme (referred to as ‘disciplinary analysis through integrative lens’); and links between ideas from several disciplines and the cross-cutting theme (referred to as ‘synthesis’).

We used the BBIL rubric to diagnose the quality of students’ interdisciplinary understanding in two different contexts: within a course and between courses. Our data for assessing interdisciplinary understanding were 1,000-word essays students wrote twice during the interdisciplinary course. The essays asked students to integrate different disciplinary perspectives taught in the course to address a novel question.

In the first case (Kidron & Kali, 2015), we found that students’ interdisciplinary understanding improved significantly between the essay they wrote for the mid-course assignment ($M=67.2, SD=29.4$) and the essay they wrote for the final assignment ($M=82.5, SD=22.0$) \([t(31)]=2.96, \ p<0.01, \ d=0.59\]. In the second case (Kidron & Kali, forthcoming) the rubric enabled us to find a significant difference \([t(45)=1.85, \ p=0.04]\) between students of two parallel courses: the quality of the interdisciplinary synthesis was higher for students who learned in an online learning community ($M=1.85, SD=1.09$) compared with students who learned the same contents individually ($M=1.30, SD=0.95$).

These findings illustrate the potential of KI to support design for and understanding of interdisciplinary thinking processes. It illustrates a way to analyze student reasoning about complex interdisciplinary problems. By doing so, it bridges traditional boundaries between disciplinary and interdisciplinarity reasoning. In an era that poses complex challenges to humankind (e.g., climate change, mass immigration), bridging these boundaries and developing new ways to assess interdisciplinarity are a key goal to the learning sciences.

**Study 7. Using a knowledge integration perspective to explore connections among science, mathematics, and engineering modeling practices**

*Jennifer L. Chiu, Jim Bywater, and James Hong*

National standards in the United States emphasize instruction where students participate in and use science and mathematical practices (e.g., Common Core Standards Initiative, 2010; NGSS Lead States, 2013). Engaging students in disciplinary practices can help students understand the nature and development of mathematical and scientific knowledge, create motivation and interest in learning, and make mathematical and scientific concepts more meaningful (e.g., Osborne, 2014). However, students often hold fragmented and even contradictory ideas across science, math, and engineering contexts and struggle to connect disciplinary ideas and practices to everyday contexts.

This poster explores how a KI perspective (Linn & Eylon, 2011) can be used to promote the practice of modeling across science, mathematics, and engineering (e.g., Weintrop et al., 2016). We examine the similarities in national standards by exploring the mathematical practices, such as *model with mathematics: science and engineering practices, such as developing and using models and using mathematics and computational thinking;* and engineering design strategies, such as *representing ideas and conducting experiments* (Common Core Standards, 2010; Crismond & Adams 2012; NGSS Lead States, 2013). In the context of an engineering design project implemented in a mathematics classroom we explore how KI design principles in WISE help students engage in modeling practices. Students ($n=44$) from two middle-school geometry classes participated in a project with the goal of designing ice cream cones, which included interactive geometry models as well as hands-on prototype building and testing. Using a variety of data sources (e.g., pre/posttests, embedded assessments, log files, video recordings), we found that computer-based, scaffolded engineering design helped students engage in modeling practices to learn targeted content. We discuss how KI principles supported students to make interdisciplinary connections. This work shows that WISE can be extended to mathematics and engineering to distinguish modeling practices across disciplines, and how integrating those practices to develop targeted conceptual understanding.
Study 8. Elaboration of KI processes in a WISE module in order to support the development of socio-scientific reasoning
Hava Ben Horin, Yael Kali, Tali Tal, and Ornit Sagy

Research has shown that instruction based on the KI framework, using WISE, improves the integration and transfer of scientific knowledge among communities of students (Chiu & Linn, 2011; Roseman, Linn & Koppal, 2008). WISE authoring tools enable designers to embed digital scaffolds and epistemological prompts that promote student understanding of the nature of science (Linn, Clark & Slotta, 2002). We design and refine WISE instruction to develop students’ socio-scientific reasoning and ability to resolve socio-scientific issues (Sadler, Barab & Scott, 2007). Socio-scientific reasoning includes practices needed for negotiation and resolution of controversial, science-related, socio-scientific issues (SSIs). Socio-scientific reasoning involves (a) recognizing the inherent complexity of SSIs, (b) analyzing SSIs from multiple perspectives, (c) appreciating the need for ongoing inquiry into SSIs, and (d) taking a skeptical stance toward potentially biased information. To develop socio-scientific reasoning, students need to integrate scientific, practical, and contemporary knowledge using epistemic thinking (Romine, Sadler & Kinslow, 2016).

In this research, we expanded the KI opportunities in an existing WISE module that addresses a SSI concerning environmental impacts on asthma (Tate et al., 2008). We added scaffolds to support the integration of scientific, contemporary, and epistemic knowledge. For example, a google map was used as a collective knowledge base (Lui & Slota, 2014), allowing students to continuously add and evaluate evidence about the distribution of irritants. We implemented the changes during three iterations of design based research with four 8th grade classes. Data came from observations, interviews, and assessments. We compared pretest and posttest performance on: (a) students’ integrated scientific understanding and (b) their socio-scientific reasoning. Findings revealed improvement of students’ integrated scientific knowledge from pretest to posttest. Refinement of the instruction across iterations appears to improve outcomes. The potential of the KI processes to support students’ development of particular aspects of socio-scientific reasoning is reflected in the student responses, student interviews, and class observations. Our poster will discuss the elaboration of how each of the four KI processes strengthened students’ socio-scientific reasoning. This research suggests refinements to KI supports for the development of socio-scientific reasoning. Moreover, this research points to ways to strengthen the KI framework to support the process of epistemic knowledge development.

References


Kidron, A., & Kali, Y. (forthcoming). Online learning communities as a pedagogical approach for promoting interdisciplinary understanding through knowledge integration.


Crowdsourcing and Education: Towards a Theory and Praxis of Learnersourcing

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Abstract: Due to the scale of online environments, large numbers of learners interact with the exact same resources, such as online math homework problems and videos. It is therefore essential these are of the highest quality to help learners. Ideally, online educational resources would constantly improve based on data and input from each learner, giving a better outcome for the next. This symposium explores issues around the use of crowdsourcing to harness learners’ interactions with resources like online problems and videos in order to improve these resources for the next learner. We hope to explore the benefits and limitations of thinking about learners through the lens of crowdsourcing, to imagine learnersourcing. We will discuss four ways in which researchers have leveraged crowdsourcing to help students learn in a variety of educational contexts, and in doing so we will also discuss ways in which educational theory can guide the future of learnersourcing.

Introduction

Due to the scale of online environments, large numbers of learners interact with the exact same resources, such as online math homework problems and videos. It is therefore essential these are of the highest quality to help learners, but it is difficult to know how best to design these before deploying them ‘in the wild’. Ideally, online educational resources would constantly improve based on data and input from each learner, giving a better outcome for the next. This symposium explores issues around the use of crowdsourcing to harness learners’ interactions with educational resources in order to improve these resources for the next learner.

Crowdsourcing is the outsourcing of jobs or tasks to a large number of (amateur or novice) people, typically through the use of technology, rather than relying on a single expert (Saxton et al., 2009). Crowdsourcing (especially when referred to as “human computation”) can be viewed from the perspective of using humans to do something that state of the art artificial intelligence is not capable of doing (Law & von Ahn, 2011). Unfortunately, crowdsourcing does not always have the reputation of being human-centered; for example, using crowdsourcing to harness the “computational power” of people to complete microtasks, as is often done on websites such as Amazon Mechanical Turk and Crowdflower, does not evoke the image of a technology we want to use with our students. But recently, researchers have been exploring many ways in which crowdsourcing can be used in more human-centered applications (Bigham et al., 2010; Lasceki et al. 2014; Andolina et al. 2017) as well as finding ways to value the people behind crowdwork (Kittur et al. 2014; Salehi et al. 2015; Gaikwad et al. 2015). Moreover, with the growth of crowdsourcing, researchers and educators are beginning to realize how students can interact with resources generated and improved by their peers in meaningful ways for a more enriched learning experience (Weld et al. 2012; Heffernan et al. 2016; Paulin & Haythornthwaite, 2016). In this symposium, we explore various ways to tap into that potential of crowdsourcing to help learners in a variety of settings, from massive open online courses (MOOCs) to online learning platforms used in K-12 classrooms to instructors using crowdsourcing in their own classrooms. We will look at not only practical ways that several researchers have used crowdsourcing in these settings, but also the theoretical insights from the learning sciences and broader educational theory that motivate their approaches. We hope to explore the benefits and limitations of thinking about learners through the lens of crowdsourcing, to imagine learnersourcing (a term originally coined by Juho Kim (2015)).

This symposium explores in depth some of the different ways that researchers might understand and approach various conceptions of learnersourcing. We will discuss the similarities and differences in ways that four research groups have used crowdsourcing to impact learners in different settings. Despite the different
settings and various approaches to crowdsourcing, one theme that exists across the four presentations in this symposium is that crowdsourcing can help both the learners involved in generating new content, as well as the learners who then engage with the crowdsourced content. This vision of how crowdsourcing can impact students, is nicely described by Duffy and Cunningham (1996) in a metaphor for their account of constructivist instruction:

In his popular novel *The Name of the Rose*, Umberto Eco (1983) describes a medieval library, a labyrinth of passages, stairways, and chambers filled with books...learning is illustrated by Brother William, the main character of the novel, feeling and groping his way through the library. As Brother William constructs a path (or pattern of connections) through the library, one of only many possible paths, he is transforming his means of participating in the community of scholars, both those using the library (constructing their own paths) and those who have written manuscripts contained therein."

**Learnersourcing and the Learning Sciences**

Learning scientists can benefit learnersourcing in a number of ways by (1) bringing theories to bear on pedagogically valuable ways of approaching learnersourcing, (2) studying how teachers and researchers can effectively use learnersourcing to help learners, (3) studying how learners can effectively engage with learnersourced resources, and (4) creating systems that can support effective forms of learnersourcing. In doing so, the learning sciences can benefit from better theoretical insights on how students learn and interact in ways mediated by learnersourcing. These insights might transcend beyond learnersourcing into other areas of the learning sciences, such as computer-supported collaborative learning. Moreover, this symposium will discuss how effectively integrating crowdsourcing and education requires bridging insights from psychology and education with systems and algorithms from computer science. Our hope is to show the promise of forming new collaborations between learning scientists and computer scientists. Such collaborations can have a long-lasting impact on the future of the learning sciences. Finally, this symposium is particularly relevant this year, as crowdsourcing is also a topic of interest to the Learning @ Scale and Artificial Intelligence in Education communities, both of which are having co-located conferences with ICLS this year. Our hope is to bring together researchers from these fields.

**Symposium synopsis**

The symposium will include four presentations. Juho Kim will present work on learnersourcing for helping learners more effectively navigate and use online instructional videos, such as those in MOOCs. Joseph Jay Williams will then report on a system that prompts learners to self-explain, presents those explanations to future learners, and then discovers which explanations future learners find most helpful by using machine learning to conduct dynamic experiments. The ASSISTments group will report on their work on deploying a platform used in many K-12 classrooms that allows students to provide their work as assistance for other students. The group will also describe an instance of *teachersourcing* in their platform, broadening the scope of how crowdsourcing can impact educational practice. Finally, Thomas Hills discusses how he used crowdsourcing in his undergraduate level course on the psychology of persuasion in order to allow students to create content that influenced the course by bringing their own interests to the table. As the discussant, Carolyn Rosé will share her insights on the similarities and differences in the approaches taken by the four presenters, how approaches to learnersourcing relate to the learning sciences and computer-supported collaborative learning, and what are some of the limitations of learnersourcing as currently envisioned.

A goal of this symposium is to see how theoretical insights from the learning sciences, psychology, and broader educational theory can guide the application of ideas from crowdsourcing. For example, Joseph Jay Williams’ considers how crowdsourcing explanations from students can be of pedagogical value to those students by building upon the literature on self-explanation. Similarly, Thomas Hills describes how his use of crowdsourcing is guided by theories of learner-centered education such as constructivism and related principles coming from cognitive psychology.

Given that the symposium is about crowdsourcing, the session will also include two interactive crowdsourced components. First, we will ask attendees at the beginning of the session to tell us (through a Google form) their first impression of applying crowdsourcing to education (whether that is a thought, idea, question, or concern). We will then ask them the same question at the end of the session. Our goal is to have attendees reflect on what they think about crowdsourcing and give us a sense of the attendees’ prior background and opinions and how our session might have changed their opinions. Second, we will have a crowdsourced Q&A session, where attendees can “upvote” and comment on questions, both so that questions that are of
greatest interest will get answers by participants, but also so that online discussions can start and continue among attendees. We will now describe the contributions of each of the four presentations.

**Learnersourcing: Improving learning with collective learner activity**  
Juho Kim

My research has focused on improving the video learning experience online. My primary approach has been learnersourcing, in which learners collectively generate novel content and interfaces for future learners while engaging in a meaningful learning experience themselves. Millions of learners today use educational videos from online platforms such as YouTube, Khan Academy, Coursera, or edX. Learnersourcing can improve the content and interfaces in a way neither experts, nor computers, nor existing crowdsourcing methods can achieve at scale. My research demonstrates that interfaces powered by learnersourcing can enhance content navigation, create a sense of learning with others, and ultimately improve learning.

I draw on several fields to design learnersourcing applications: crowdsourcing to aggregate small contributions into meaningful artifacts; social computing to motivate participation and build a sense of community among learners; content-based video analysis techniques such as computer vision and natural language processing to complement learner input; and the learning sciences to inform the design of learnersourcing tasks that are pedagogically meaningful. I explore two types of learnersourcing: **passive learnersourcing** uses data generated by learners’ natural interaction with the learning platform, and **active learnersourcing** prompts learners to provide specific information.

**Passive Learnersourcing: Natural learner interactions improve video learning**

In traditional classrooms, teachers adapt their instruction to students based on their level of engagement and confusion. While online videos enable access for a wide audience, instructors and learners are disconnected; it is as if instructors are talking to a wall without feedback from learners watching the video. I created a thread of research that leverages natural learning interaction data to better understand and improve video learning, specifically using thousands of learners’ second-by-second video player interaction traces (e.g., clicking the play button in the video player).

**Data analysis of 39 million MOOC video clicks**

Exploratory data analyses of four massive open online courses (MOOCs) on the edX platform investigated 39 million video events and 6.9 million watching sessions from over 120,000 learners. Analyzing collective in-video interaction traces revealed video interaction patterns, one of which is interaction peaks, a burst of play button clicks around a point in a video indicating points of interest and confusion for many learners. Figure 1 shows one such interaction peak; notice that the peak occurs just before the video transitions visually from showing the instructor walking through code and showing the instructor speaking. I identified student activity patterns that can explain peaks, including playing from the beginning of new material, returning to missed content, and replaying a brief segment (Kim et al., 2014b). These analyses have implications for video authoring, editing, and interface design, and provide a richer understanding of video learning on MOOCs.

**Video interface that evolves with data**

LectureScape (Kim et al., 2014a; see Figure 2) is an enhanced video player for educational content online, powered by data on learners’ collective video watching behavior. LectureScape dynamically adapts to thousands
of learners’ interaction patterns to make it easier to rewatch, skim, search, and review. LectureScape introduces a set of data-driven interaction techniques that augment existing video interface widgets: a 2D video timeline with an embedded visualization of collective navigation traces; dynamic and non-linear timeline dragging; data-enhanced transcript search and keyword summary; automatic display of relevant still frames next to the video; and a visual summary representing points with high learner activity.

**Active Learnersourcing: Learner prompts contribute to new learning materials**

![Crowdy: Learnersourcing workflow for summarizing steps in a how-to video.](image)

We asked if learners, both an intrinsically motivated and uncompensated crowd, can generate summaries of individual steps at scale. This research question resulted in a learnersourcing workflow that periodically prompts learners who are watching the video to answer one of the pre-populated questions, such as “what was the overall goal of the video section you just watched?” (Figure 3) (Weir et al. 2015). Learners’ answers help generate, evaluate, and proofread subgoal labels, so that future learners can navigate the video with the solution summary. We deployed Crowdy, a live website with the learnersourcing workflow implemented on a set of introductory web programming videos. The 25-day deployment attracted more than 1,200 learners who contributed hundreds of subgoal labels and votes. A majority of learner-generated subgoals were comparable in quality to expert-generated ones, and learners commented that the system helped them grasp the material. A controlled experiment with 300 crowd workers on Amazon Mechanical Turk showed that participants’ retention of knowledge in statistics covered in video was higher with Crowdy than with a baseline video interface, and comparable to seeing expert-generated subgoals.

**Generating explanations using crowdsourcing and machine learning for dynamic experimentation**

Joseph Jay Williams

To help students learn from solving online problems and receiving feedback, it can be beneficial to provide explanations for how to solve these problems after student make their attempts. However, instructors have limited time and resources to generate quality explanations for all the problems they create, and many MOOCs or online resources only provide correct answers. We developed the Adaptive eXplanation Improvement System (AXIS, Williams et al, 2016) to investigate how to crowdsource explanations from learners by prompting learners to generate self-explanations (Chi et al, 1989; Williams & Lombrozo, 2010). We then used machine learning to guide a dynamic experiment that discovered which explanations learners rated as being helpful and analyzed that data in real-time in order to present the highest rated explanations more frequently to future learners.

Learners attempted to solve four mathematics word problems (in algebra and probability) and were provided the correct answer after entering their own. In addition, they would be assigned one of the explanations from the current AXIS pool (the first few learners did not receive any explanations) and asked to rate how helpful the explanation was for their learning, on a scale from 0 (not at all helpful) to 10 (extremely helpful). They were also prompted to explain in their own words why they thought the answer was correct, as it would help them learn. If a learner's explanation was longer than 60 characters and the learner rated their explanation as likely to help others, the explanation would be added to the pool to be presented to future students.

Assignment of explanations to learners was initially done with equal probability, but as learners provided ratings of explanations, higher rated explanations were presented more frequently than lower rated explanations, using weighted randomization. More precisely, we used a statistical machine learning algorithm to calculate the probability that an explanation was higher rated than all the others in the pool (based on a Beta-Binomial model & algorithm commonly used to optimize websites, Chappelle & Li, 2013) and used those probabilities to set the weights for randomization (e.g. transitioning from 50/50 to 60/40 to 80/20). The output
was therefore a probability distribution over a constantly increasing pool of explanations (as learners generated new self-explanations). The probability distribution was updated every time a learner rated an explanation, so that the probability of future learners receiving an explanation was proportion to the evidence that this was the highest rated explanation.

Benefits of explanations for learning

To evaluate whether the explanations that emerged also led to benefits for learning, we conducted an additional experiment. Participants were randomly assigned to receive: No explanation (original problems), learner explanations from AXIS explanations, learner explanations that AXIS gave low probability to (got low ratings), and as a gold standard, explanations written by an instructional designer. The second experiment recruited 564 new participants.

Explanations from the system led to improved learning over the default practice, where learners simply solved problems and received answers. Participants were significantly more likely to solve future problems after receiving AXIS explanations, when compared to practicing problems that did not have explanations. A pairwise comparison within a mixed-effect model revealed a significant increase in accuracy from the initial problems to the assessment problems ($M = 12\%$ versus just $2.7\%, SE = 0.027, p < 0.05$). It might seem obvious in hindsight that providing any explanation will increase learning and success on future problems. However, the learnersourced explanations that AXIS discarded did not provide any learning benefits beyond normal practice of math problems ($M = 2\%$ vs $3\%, p = 0.86$) and were significantly less beneficial for learning than explanations delivered by the AXIS policy ($M = 12\%$ vs. $2\%, SE = 0.04, p < 0.029$). The AXIS explanations also increased success in solving novel transfer problems that required going beyond the explicit information in the explanation (differences of 9-12\%, $SE = 0.03, 0.04, p < 0.01$).

Finally, there were no significant differences in learning between learnersourced explanations curated by AXIS, and the explanations written by the instructional designer themself (all $p$s > 0.30). Overall, this illustrates how we can rely on self-explanation to make the learnersourcing experience pedagogically meaningful for the learner, as well as using machine learning for dynamic experimentation to identify and then present learnersourced content that is helpful for future learners.

Crowdsourcing in ASSISTments: PeerASSIST and TeacherASSIST

Thanaporn Patikorn, Korinn S. Ostrow, Douglas Selent, and Neil T. Heffernan

ASSISTments is an online learning platform that is being used by over 600 teachers and 50,000 students worldwide (Heffernan & Heffernan, 2014 & Heffernan et al., 2016). The platform is built on the idea that it assists students in learning while providing formative assessments to teachers. As such, ASSISTments values the role of both students and teachers in how the platform is used. Three years ago, we ran a large-scale randomized controlled trial on ASSISTments in the state of Maine. We discovered that one teacher participating in the study, Mr. Chris LeSiege, wrote tutoring messages for every problem in his textbook so that he could better assist his students when they were doing their homework. After meeting with Mr. LeSiege and discussing his vast content creation, we realized the potential of crowdsourcing for ASSISTments, including how it could allow teachers to create and share content, expanding and improving the ASSISTments system, while strengthening the relationship between the system and its users as well as amongst users. As a result of this revelation, we have developed two features that utilize crowdsourcing: PeerASSIST and TeacherASSIST.

PeerASSIST

As its name suggests, PeerASSIST allows students to help their struggling peers by sharing solutions to their homework as worked examples. When a student is struggling, PeerASSIST will automatically select and show them a correct solution submitted by one of their classmates. The goal is not to have higher-performing students completing homework for lower-performing students, but rather to have moments of struggle turn into moments of learning. A peer’s worked solution might provide the necessary “Aha!” moments that an automated answer or hint provided by ASSISTments may fail to ignite. As with the AXIS system (see above), PeerASSIST is driven by multi-armed bandit algorithms that aim to select peer work that will maximize the likelihood that a struggling student will correctly answer the next question in their assignment. Teachers can also designate some of their students as “star students,” whose contributions will be more heavily weighted for prioritization in PeerASSIST’s selection process. Over a seven month period, PeerASSIST distributed worked examples for over 250,000 problem instances (from around 12,000 unique problems) to over 1,000 students.
TeacherASSIST
While this symposium primarily focuses on learnersourcing, we are also exploring teachersourcing in ASSISTments through TeacherASSIST. This feature will allow teachers like Mr. LeSiege to easily create tutoring feedback messages for not only their own problems, but also for problems sourced from textbooks or written by the ASSISTments Team. We are currently allowing beta teachers who are testing the system to share tutoring messages they have created with other teachers. For example, other teachers in Mr. LeSiege’s school or district who use the same textbook and problems will be able to also access the tutoring messages that he created for his students. In future versions of TeacherASSIST, we hope to refine our model into a platform that not only allows teachers within the same school or district to create and share with each other, but to broaden sharing capacities across the United States, and perhaps the world, allowing teachers to communicate and build upon each other's content and thereby improve student learning. It is our vision for the future that TeacherASSIST and PeerASSIST will work in parallel to serve as valuable crowdsourcing tactics to strengthen the feedback available within ASSISTments while simultaneously working to simplify platform usage for teachers and provide robust, collaborative learning opportunities for students.

Crowdsourcing content creation in the classroom
Thomas Hills

This presentation will describe the Propaganda for Change Project, a case study for how crowdsourcing was successfully implemented in an undergraduate psychology course in 2013 with over 100 students (Hills, 2015). The course aimed to teach students about the psychology of persuasion and influence. Rather than taking an approach of direct instruction, the course was designed with a more learner-centered educational approach. Due to the large number of students in the course, traditional approaches to learner-centered education where the instructor would give individual attention to students would be difficult. Instead the course used crowdsourcing to scale the learner-centered approach in two ways by (a) having students find examples of content in the real world that were of interest to them and that highlighted various aspects of persuasion and influence and to write a blog post about it, and (b) having students create their own video as their final project that would utilize the principles of the course to create a persuasive prosocial message. All of the content created by students was shared on this blog: http://persuasion-and-influence.blogspot.co.uk/. The crowdsourced content had value in two distinct ways. First, it gave the instructor talking points in class to illustrate the course topics in ways that were meaningful to the students. By leveraging examples of advertisements that students found relevant to their own lives, the instructor could bring up pertinent examples that were shared on the blog in class. Additionally, the instructor could encounter many more examples (and perhaps better ones) that he himself could have curated. To further help the blog become an essential part of the course, the instructor created questions on the final exam where students had to describe the forms of persuasion used in images taken from the blog. Second, the content generated by students is publicly available on the course blog and so it can be read by (a) students currently in the course, (b) future students who can take inspiration from students who took the course previously, and (c) the general public. Indeed, the blog currently has over 700,000 views, with around 400 views per day from people around the world. The quality of student blog posts exceeded expectations. Many students were thankful (both in person and in evaluations) that the course dealt with real world content and they felt it prepared them for job interviews. Having described the course, we will now turn to discussing the types of crowdsourcing the course used, and the theoretical principles from psychology and educational theory that can help guide them.

Found content and produced content
There are two types of crowdsourced content used in the course: found content and produced content. Asking students to find examples of persuasion in their lives and write a blog about it is an example of found content. The concept of found content is similar to that of found objects in art (e.g., Marcel Duchamp’s Fountain). By having students describe found content, students get experiences with detecting ideas from the course in the real world as well as finding ways to relate the content back to the principles taught in the course by explaining it (to themselves and to others). Having students create a persuasive video for positive change is an example of produced content. This is the type of crowdsourced content that typically comes to mind and that the other presentations in this symposium have focused on.

Educational theory, cognitive psychology, and content creation
Having students find and produce content is supported by several educational theories and principles from cognitive psychology. Having students contribute content to the course builds on the idea of learner-centered education. Many learner-centered theories exist in the educational literature that support the idea of crowdsourced content generation. For example, we build on the recently developed idea of the student as producer (Neary and Winn, 2009), which posits that “undergraduate students working in collaboration with academics to create work of social importance that is full of academic content and value” (Neary and Winn, 2009). This approach also builds on a central idea in a variety of constructivist theories that students naturally try to make sense of their experiences by relying on their prior knowledge and experiences (Resnick, 1987; Raskin 2002), so it is our role as instructors to help students make sense of the world around them and learn to participate in a community of learners (Duffy and Cunningham, 1996).

Having students generate new content is also supported by principles from cognitive psychology (Dunlosky et al., 2013). For example, psychologists have shown a generation effect whereby students better recall and remember information they generated themselves rather than information given by others (Slamecka and Graf, 1978). Moreover, it has been shown that asking questions that relate to one’s prior knowledge and experiences can help support complex learning beyond asking questions related to course content (King, 1994). Having students explain the relationship of found content to the ideas of the course also builds on the idea of self-explanation, a well-documented method for improving learning by elaborating on content information (Chi et al. 1989; Rittle-Johnson, 2006).

Understanding the relevant educational and psychological theories can help realize how to most effectively crowdsorce the creation of new content, not just for the sake of creating content for others, but, perhaps more importantly, for enhancing the learning experience of the students engaged in generating new content.

References


Affordances of Digital, Textile and Living Media for Designing and Learning Biology in K-12 Education

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Abstract: In this symposium we are examining the affordances that particular materials hold for supporting learning biology inside and outside of school along three dimensions: (1) digital materials that encompass screens and software through which students can interact, (2) textile materials that allow students to wear bodysuits that can help them visualize physical movements on interactive displays, and (3) interactive materials that allow students to interact with living microorganisms through games in science museums or through computational models that students design and test against the real data in science classrooms. Panelists will discuss how affordances of tinkerability (messing around), perceptibility (seeing results), expressivity (customizing experiences), and usability (using outcomes) entered into their considerations when designing and studying of environments, games, and design activities for interacting and learning with biology.

Overview
In this symposium we want to turn our attention how affordances of different media—digital, textile, and living—can be leveraged for learning and teaching about biology using participatory simulations, gaming environments, or design activities. The concept of affordances, first introduced by Gibson (1977) emphasizes that objects in the world are not just perceived in terms of their shapes and spatial relationships but also in terms of their possibilities for interacting with them. Later work by Norman (2013) applied the concept to technologies and interactivity. Considerable research has extended affordances into design of educational construction kits and tools to make games, robots, wearables and many other artifacts, on and off the screen (e.g., Blikstein, 2015; Resnick et al., 2008). More recently, the development of synthetic and DIY biology has made many new tools accessible and affordable for non-professional biologists and anyone interested in “hacking and tinkering with biology” (p. 258, Kuznetsov, Taylor, Regan, Villar & Paulos, 2012). However, the affordances of playing and making with biology are quite distinct from those with digital or textile materials and challenge many of the insights that have been gained in previous research, especially those that consider the quality of hands-on activities, processes of making, and the sharable, usable and personally meaningful artifacts key in generating interest and motivating learning (Peppler, Halverson, & Kafai, 2016 a and b):

Tinkerability is characterized as playful, experimental iterative style of engagement in which learners are continually reassessing their goals, exploring new paths and imagining new possibilities—or as having a conversation with the material. In these definitions, tinkering is often seen in opposition to planning (top down instead of bottom up). However, many activities with living cells are distinct from the ‘typical’ contexts of digital
or textile creation since these processes are time-dependent: they require a full run of the entire lab procedures before one can see the expected result. In other words, whereas tinkering in engineering, crafting, and coding contexts can occur because individual processes are discrete—iterating on a gear mechanism or developing a specially defined procedure—in biology they occur in a holistic fashion—fixing a ‘mistake’ means doing a lab procedure all over again and waiting for the result. Additionally, tinkering with living cells involves liquids rather than the discrete solid parts seen in ‘typical’ electronic making, something that makes the process of tinkering inherently more difficult.

**Perceptibility** illustrates how designs can yield immediate feedback to users either on the the progress or results of their interactions. For instance, a coder can instantaneous see the result of a bug they fixed in a program whereas in biology this process is slowed down because of the requirements of the living organism. While microorganisms grow quite rapidly, it often takes twelve hours or more for any genetic transformation to yield an outcome. More importantly, due to scale and colorlessness of the microorganisms, makers often cannot see the outcomes of their designs or their changes at first.

**Expressivity** because processes are not yet as customizable and personalizable as seen within digital or textile making. In many maker activities, the notion that individuals can make personal artifacts or designs that are based on their interests, desires, or needs, is considered one of the driving motivations for student engagement and learning in maker activities. But due to the nascent state of biosigns along with the available tools and processes on the market, this individualization is often not easy to accomplish. Whereas consumer-grade electronics kits have created opportunities for lay people to create personalized computational designs, people with limited biological knowledge and background are not yet as able to produce biosigns that fulfill their individual goals and purposes. Instead, they must depend on existing protocols and materials developed by experts.

**Usability** captures the dimension that many designs that can be used by themselves or others for play, learning, or work. In biomaking, usability of created products comes with different affordances and constraints. Because living designs can perish at some point, careful thought must be paid into designing settings that either keep them alive (e.g., enough nutrients, correct temperature) or develop everyday applications that fully make use of their products (e.g., transferring color into textiles). From this perspective, typical making affords numerous ready-made situations for usability (e.g., kits, everyday applications), while biomaking has not yet reached this point of development in its short history.

This symposium brings together researchers from the learning sciences, human-computer-interaction, and computer sciences, and science education to discuss how these affordances featured into their design and research of learning and teaching biology within K-12 education inside and outside of school. The first group of studies has focused on tangibility by using textile materials in new ways to introduce students of elementary and middle school ages to interacting and understanding complex systems. In BeeSim, Joshua Danish and colleagues will present their efforts of designing bee costumes and flower environments that let second grade students model bees by acting as bees in a mixed reality simulation

Modeling bees by acting as bees in a mixed reality simulation
Joshua Danish, Megan Humburg, Xintian Tu, Bria Davis, and Chris Georgen, Indiana University, and Noel Enyedy, UCLA

Advances in mixed-reality and augmented-reality technologies, which allow students to engage with computer models and simulations using their bodies, have great potential for supporting cognition and learning (Lindgren and Johnson-Glenberg, 2013). Research in this area has been particularly focused on the value of embodied
cognition, recognizing how moving one’s body can provide unique insights into complex phenomena, particularly when coupled with computer simulations that help students to make sense of their movements. However, much of the work in mixed reality learning environments has focused on non-biological concepts such as physics and chemistry, and frequently focuses on individual learners or dyads. In contrast, the Science through Technology Enhanced Play (STEP) project has explored how larger groups of students (ranging from 4-12 at this time) afford unique opportunities for engaging with complex science phenomena in early elementary classrooms Danish et al., 2015). We report on a recent implementation of the STEP: Bees software and curriculum where students take on the roles of honeybees to understand how bees collect nectar, and how this supports the growth of the hive, as well as leading to pollination in the local flower population.

In designing and refining the STEP environment, we have developed a sociocultural framework for embodied cognition (Danish et al., 2017) which aims to couple prior efforts at understanding the role of the body in learning with attention to how the interactions between participants and their peers, teachers, and technology all play a unique role in supporting cognition and learning. In the STEP: Bees environment, students engage in a number of participatory simulations (Colella, 2000) where they take on the role of honeybees foraging for nectar. To do this, they physically play the role of honeybees moving around within their classroom (figure 1, right). The STEP software uses Microsoft Kinect cameras to track their motion and feed their movement into a computer simulation which is projected at the front of the room (figure 1, left). Thus as students take on the roles of bees, they see bee avatars moving within the computer simulation, responding to their motions. As a result, students receive information and feedback from both their peers and the computer simulation as they embody the roles of honeybees.

To describe the unique affordances of the biological subject matter in this design, we present and contrast new analyses from two prior studies. First, we report on an implementation where 16 children ages 7-8 participated in the STEP: Bees curriculum with two teachers at a public elementary school in a small city in the midwestern United States. Previous analyses of the STEP: Bees Environment (Danish et al., 2017) focused on the role of embodiment in their learning. The present study focused instead on the unique affordances of the biological context, and of the role of our design for supporting learning within a biological context. To this end, pre-post interviews and drawings were used to measure changes in students conceptual understanding as a result of the intervention, and video analysis was used to document the process through which students learned the content. Video analysis will demonstrate the unique affordances of small group, embodied mixed reality simulations for helping students engage with these complex biological phenomena. In particular, we will show how the body provides unique opportunities for tinkerness, while also supplementing the affordances of the computer simulation for enhanced perceptability. Using one’s body also provides unique opportunities for both usability and expressivity. In particular, we have found that students move their bodies quite spontaneously, and often express their understanding both in ways that are interpreted in unique ways by the simulation (e.g., their movement in space moves their avatar) and by their peers (e.g., gesture, running, and jumping to convey ideas). Finally, we will provide a contrast with our STEP: Particles environment (Danish et al., 2015) to discuss how
explorations within this biological context led to new affordances and constraints that differ from the previous physics context. In particular, students’ ability to take on a first-person anthropomorphized perspective appears to have led to unique forms of engagement with the content. This will allow us to discuss the unique affordances of both using one’s body to study complex science, and using one’s body to study biological concepts where there is a one-to-one mapping between one’s body and an agent in the system being studied, as well as differentiating between the role of biological contexts of study on student learning in this kind of mixed reality environment.

Real-time play in microscopic worlds
Engin Bumbacher, Paulo Blikstein, Peter Washington, and Ingmar Riedel-Kruse, Stanford University

The microscopic world of biology is full of wonders to be explored, and that informs our understanding of life at all scales. Children in schools predominantly access this world through static observational microscopy. Observational microscopes open a window into that world, with limited possibilities to manipulate it. Other media such as robotics construction kits, programming languages for children, and videogames have demonstrated the educational potential of interactivity (Kim et al., 2016); and academia and industry have been developed ways to interact with microscopic worlds for decades. Our interdisciplinary research groups have explored two ways of bringing interactivity into biology: real-time interactivity through technology that is in the same physical space as the user, or remote interactivity through cloud-based systems (see Figure 2). An essential principle to developing this form of interactivity is to digitize the biological signal, e.g. with computer vision algorithms that track microbiological organisms and processes, and augment and enhance it for use in a variety of ways (see “Data augmentation,” Blikstein, 2014).

Real-time interactivity lends itself particularly well to ways of playing with the microscopic world. The Riedel-Kruse Lab built two systems that exploit intuitive notions of interactivity through tactile experiences (i.e. Human-Biology Interaction; Lee et al., 2015): Trap it! (Lee et al., 2015) and LudusScope (Kim et al., 2016). These systems use touch screens, microscopes and augmentation - either through projections or through mobile devices, to create biotic games, i.e. games that operate on the biological processes and allow children to interact with these processes to play games like virtual soccer or maze-based games (Riedel-Kruse et al., 2011). The core biological process in both systems is the phototactic behavior of Euglena, i.e. the real-time reaction to light in form of changes to movement direction. In Trap it!, users can interact with living cells by drawing patterns on a touchscreen displaying the microscope view of the cells. These drawings are projected onto the microscopy field as light patterns, prompting observable movement in phototactic responses. In LudusScope, a smartphone microscopy platform, users can interact with individual Euglena cells by digitally selecting them via the phone touch screen, and then influencing their swimming direction via a joystick that controls four directional LEDs arranged around the microscope. Both systems have been used in various informal contexts such as museums. In the user studies, the fact that the interaction involved real and not simulated organisms was particularly intriguing for children, and researchers observed intuitive and playful interactions with the system (Kim et al., 2016; Lee et al., 2015).

Beyond just playing with, interactivity is also powerful for learning about biological phenomena through authentic inquiry, enabled by remote laboratories. Remote laboratories consist of physical laboratory equipment, e.g. microscopes or other tools, that is accessible over the internet: But these interactive cloud labs (Hossain et al., 2017) enable multiple users at the same time to execute real biology experiments, in real-time or asynchronously, and to get that data for further analysis. Our labs developed and used two remote laboratories:
the physarum lab for remote asynchronous experiments on a slime mold (Hossain et al., 2015); and an interactive cloud lab for both real-time and asynchronous experiments on Euglena (Hossain et al., 2016). These systems remove crucial access barriers for schools, such as safety concerns, maintenance costs, and logistical requirement, that have impeded inquiry-based approaches in biology classrooms. Furthermore, they are versatile and flexible: by centralizing the core technology, and digitizing the data, they can be implemented in large online courses (Hossain et al., 2017), or in classrooms (Bumbacher et al., 2016).

By embedding these core technologies in web applications, we can create systems that enable rich ways of doing inquiry not possible otherwise - instead of having to combine different systems for modeling and for experimentation, we can integrate affordances for modeling and experimentation into one system. This is in line with the bifocal modeling framework that brings simulated and real-world data into the same representational space for simultaneous, real-time comparison (Blikstein, 2014).

Using the Bifocal Modeling framework, we developed a Lab in the Cloud that includes the biological data from the remote lab into a simulation environment; a classroom study using an earlier version of this web-application showed that students productively engaged in science inquiry (Bumbacher et al., 2016). We are currently developing and testing the next iteration of this technology (see Figure 2 right) that has increased experimentation, modeling and data representation capabilities. A major focus of this technology is to enable students to seamlessly create explicit comparisons between multiple experiments, experiments and models, and multiple models. We hope that this work will contribute to a theory-driven design framework for technologies designed to engage students in the relevant discursive and reasoning processes of science inquiry that integrate practices of modeling, experimentation and argumentation.

**Physiological investigations with live physiological sensing and visualization tools**

Tamara Clegg, Virginia Byrne, Leyla Norooz, Seokbin Kang, University of Maryland and Jon Froehlich, University of Washington

Wearable sensing technologies enable new forms of scientific inquiry experiences that enhance learners’ personal connections to inquiry processes (e.g., asking questions, planning investigations, collecting data, making claims) (Chinn & Malhotra, 2002; Bower & Sturman, 2015). Fitness trackers that learners wear on their wrists, for example, allow children to capture data about their everyday activities (e.g., steps taken) and vitals (e.g., heart rate) that can be analyzed later on mobile or desktop devices (e.g., Lee & Dumont, 2010). In this paper, we present the BodyVis project in which we take a textile and digital approach for helping elementary-age learners understand living data generated from their own physiological functioning (see figures 3a and b). Unlike other wearable approaches, we leverage the affordance of perceptibility to provide real-time model-based and analytic visualizations of learners physiological functioning.

We have developed a set of Live Physiological Sensing and Visualization (LPSV) tools that leverage the body as a platform for inquiry (Clegg et al., 2017). LPSV tools sense and visualize learners’ physiological functioning (e.g., heart rate, breathing rate) in real time. BodyVis (Norooz et al., 2015), senses and visualizes a wearers’ heart rate and breathing rate in real-time on an e-textile shirt that displays a model-based representation of learners’ upper respiratory organs (Figure 3-left). SharedPhys (Kang et al., 2016) allows up to six wearers to project their heart rate in real time on a large-screen display (Figure 3, right).
Growing and designing biosensors in high school classrooms
Justice T. Walker, University of Pennsylvania; Debora Lui, University of Pennsylvania; Emma Anderson, Massachusetts Institute of Technology; and Yasmin Kafai, University of Pennsylvania

The Maker Movement has had an increased presence in educational settings as researchers have demonstrated how these hands-on activities can exist in traditional disciplinary areas (Halverson & Sheridan, 2014). While making has become popular within computing and engineering (Berland, 2016; Martin, 2015), it has been less emphasized within life sciences. This is partly because maker activities typically involve materials that can be handled and repurposed in flexible ways. Life sciences, on the other hand, often involves living organisms or compounds that must be handled in particular ways, which are predefined and rote. Here, we argue that design thinking may be a useful frame within which to investigate how life science activities could exist within maker contexts. As defined here, design thinking can be understood as the way that people integrate useful knowledge from different disciplines with the goal of creating an artifact that addresses concrete needs (Buchanan, 1992). One promising context for highlighting design in biology is the rapidly growing field of synthetic biology, which looks at how living organisms can be manipulated to serve societal purposes and desires (Kuznetsov et al., 2012). In this study, we highlight an approach toward teaching biology which is situated within design thinking, something we call biomaking.

We implemented these tools in two iterations of a four-session activity sequence in three elementary school classrooms that progress from expiration of the LPSV tools and developing questions, to semi-structured inquiry activities, and finally planning and implementing learners’ own choice-based investigations. Our analysis of this sequence of activities in a first, second, and fourth grade classroom first in 2016 and then in 2017 includes video data of learners’ choice-based investigations, interviews with teachers, focus groups with learners, and participatory design with teachers between iterations. We draw themes from an Activity Theory analysis of the LPSV classroom ecosystem in 2016 and a case study of learners’ investigations in 2016 and 2017 to understand ways the affordances of LPSV tools influenced children’s scientific inquiry experiences.

Co-designing the BodyVis and SharedPhys tools and activities with children revealed that children wanted more and more opportunities to play and tinker with the BodyVis shirt. Each iteration of BodyVis has thus provided increasing tinkerability (e.g., ability to remove and replace organs). Learner surveys, focus groups and video observations show that the perceptibility of LPSV tools’ live visualization was deemed motivating and enjoyable by learners. However, learners need opportunities to pause visualizations and to observe the tools being used by others to promote analysis and reflection on results. We found that with additional scaffolds, even early elementary learners leveraged affordances for expressivity to create novel, personally relevant questions. However, more support is needed for fostering creativity for investigation questions more systematically among elementary learners of all grades. Finally, our study identified some usability issues that must be considered for broader use of LPSV tools in the classroom (e.g., rules and norms around touching and sensitive topics that may arise from live personal health data).
or not thus indicating a high or low arabinose concentration. Furthermore, the usability of their product was arguably high within the context of the class since it fulfilled a definite function (i.e., to test for the presence of the sugar). However, opportunities for tinkering and personal expression were severely limited within this phase due to the inherent constraints of wet lab activities in terms of how quickly microbes can respond to genetic or design changes and the general irreversibility of these kinds of processes.

The imagination phase, on the other hand, provided different affordances for students. While groups were pre-assigned to environmental sites, they each proposed diverse biodesign solutions, which were developed through several rounds of critique from other students and the teacher. For instance, projects ranged from genetically modified seaweed that would change color to indicate high petroleum concentration in the Gulf of Mexico to mechanical-biological hybrid buoys that would light up in response to high toxic algae levels in Lake Erie. In this way, students were provided extended opportunities to tinker with their ideas and express themselves creatively—affordances not seen within the lab phase of the workshop. From this perspective, the imagination phase addresses the gap between the available resources and opportunities within synthetic biology and students’ interest in actualizing personal designs. As biomaking progresses further as a viable classroom activity, there is a need to develop ongoing supports and scaffolds that allow students to simultaneous engage with hands-on wetlab activities in synthetic biology and to develop their design thinking sensibilities within this burgeoning field. In this way biomaking can reach its potential in engaging students as a true maker activity.

References


Attunements to the Ethical in Design and Learning

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Abstract: Within the learning sciences, conversations around the political dimensions of learning and design are growing, with implications for research epistemologies, approaches to social change-making, and possibilities for impact in the lives of children and communities. This symposium seeks to explicate, amplify, and further theorize ethical dimensions of human learning that orient our thinking towards what could or ought to be and sensitize us to the ways ethics, like politics, are always mediating learning. We explore these questions: In what ways do attunements to the ethical dimensions of learning, teaching, and design evolve in activity to expand opportunities for children and youth to grapple with the world as it is and imagine how it might be? In what ways does relationality shape and become shaped by emergent ethical attunements in learning environments? How might research and design that center the ethics of learning shift how “impact” is defined and assessed?

Keywords: ethics and politics of learning, geographies of responsibility, relationality, epistemic heterogeneity

The 21st-century marks a critical time in human history, one that demands the re-mediation of social structures of human communities towards more sustainable and just assemblages of forms of life. While the complexity of the task before us is stunning, we argue that a pivotal dimension of change rests on the remaking of relations between humans and more than humans, that is, the natural and material worlds of which humans are a part (Tallbear, 2011; Latour, 2013). Implicitly or explicitly, human activity draws together epistemic, ontological, and axiological commitments that vary across cultural communities and places, even as they traverse global and local trajectories. Importantly, this activity is constructed relationally, and, as such, as Massey (2005, p. 10) argues, poses challenging questions about the politics of the geography of those relations as well as the ethics of our relationships to and responsibility for those relations. Designing learning for expansive relationality attuned to these questions requires, we suggest, axiological innovations (Bang et al., 2016) beyond the normative forms often manifest in learning environments characterized by human domination and entitlement (Cajete, 2000; Wildcat, 2009). A focus on axiological innovations entails attention to the values, ethics, and aesthetics – that is, what is good, right, true and beautiful – that shape possible meanings, meaning-making, positioning and relations in the design and implementation of expansive learning ecologies.

Within the learning sciences, conversations around the political dimensions of learning and design are growing, with important implications for research epistemologies, approaches to social change-making, and possibilities for impact in the lives of children, families and communities. In a special issue of Cognition and Instruction, Bang & Vossoughi (2016) featured research aimed at making power, history, relationality and epistemic heterogeneity explicitly engaged aspects of designing for social change-making. Similarly, the Politics of Learning Writing Collective argues:

...to embrace learning as situated means to conceptualize it as inherently political: It is always embedded in and articulated through hierarchies of power and tied to particular visions of possible futures...we know that at minimum our efforts ought to resist the tendency to depoliticize the situated nature of learning and withstand the inclination to ignore the always-present historical and ideological dynamics and contexts (2017, p. 5).

In a resonant vein, Esmonde and Booker’s (2016) edited volume Power and Privilege in the Learning Sciences brings together sociocultural theories of learning with different strands of critical social theory in the effort to engender concepts and lenses adequately sensitive to the “always-present” political and ethical dynamics of learning and teaching. Building on the powerful ways sociocultural and cultural historical theories...
have intervened to widen and deepen the study of learning beyond individualism and ethnocentrism, these recent interventions assert that learning is always cultural and political. Further, they embody a critique of normativity and the ways learning is entangled with oppressive political and economic systems, as well as a call for critically imagining, designing and closely studying learning as relationally responsive ways of being, knowing and acting (Shotter, 2006). Though not always explicitly stated, both of these moves involve fundamental questions of ethics and values.

Importantly, attention to the political is not new to studies of learning; rather, the terms of engagement with the politics of learning are taking new forms. Situating ourselves within both the sociocultural and political turns in the learning sciences, this symposium seeks to explicate, amplify and further theorize the ethical dimensions of human learning, those that orient our thinking towards what could or ought to be, and sensitize us to the ways ethics, like politics, are always mediating learning.

The papers in this symposium explore how new “geographies of responsibility” (Massey, 2004) emerge when ethical attunements in learning and design become an explicit focus of attention. We explore these questions: In what ways do attunements to the ethical dimensions of learning, teaching, and design evolve in activity to expand opportunities for children and youth to grapple with the world as it is and imagine how it might be? In what ways does relationality shape and become shaped by emergent ethical attunements in learning environments? How might research and design that center the ethics of learning shift how “impact” is defined and assessed?

We will engage the audience in considering ways in which attention to politics implicates ethics (e.g., in future-makings), how politics and ethics mutually constitute one another, and how these dynamics shape what we might call theoretical-, design- and construction-oriented dimensions of impact.

“(If we can prepare ourselves to ‘think-with’ living things to guide us in our thinking...then not only will that change everything that in the past we have thought of as being well-known to us -- the nature of reality; knowledge and knowing (epistemology); the nature of communication and language; meaning and understanding; ways of being (ontology); and our everyday ways of relation to others and ‘othernesses’ around us (attitudes, orientation, and ethics) -- but it will also lead us into recognising the influence of factors to which, in the past, we have given no attention at all. (Shotter, 2015, p. 8)

**Embodied pathways and ethical trails: Attuning to the relational and axiological dimensions of learning**

Shirin Vossoughi and Ava Jackson, Northwestern University

In *Talk and Social Theory*, Erickson argues that “social changes of a deep-rooted kind, by their very nature, involve alterations in the character of day-to-day social practices” (Erickson, 2004, p. 160). This paper is part of a larger project that both draws from and widens this argument by paying close attention to the role of embodiment and relationality in the moment-to-moment and day-to-day development of learning environments that aim to enact educational dignity (Espinoza & Vossoughi, 2014). We define embodiment as the physical, gestural and artifact-mediated dimensions of human learning, as well as the kinds of ethical and pedagogical values embodied in talk and interaction (Vossoughi, Escudé, Kitundu & Espinoza, Under Review). Thus far, this work has looked closely at the kinds of embodied assistance that mediated rich forms of joint activity within an after-school setting focused on making/tinkering (the “Tinkering Afterschool Program” or TAP), as well as the ways adult and young adult educators’ analysis of photographs and audio-video recordings led to deeper forms of co-presence and relationality with young children.

Taking up questions of ethical attunement and relationality, this paper asks: how do relational histories and salient moments of embodied assistance mediate future action and meaning? Through a systematic analysis of ethnographic and interactional information spanning three years of programming in TAP, we found that particular forms of assistance and relationality across participants created embodied pathways that others then took up, plied and re-created in future moments. We define embodied pathways as courses of possible action involving participants’ voices and bodies that both represent and open up particular kinds of relations (ethical, intellectual, political). We argue that the felt experience of salient instances of assistance imprints (leaves an impression of) such pathways within memory, creating resources for possible action in the future. We substantiate this finding through three distinct and complementary cases: 1) a five-minute interaction wherein careful forms of embodied assistance used to support one child to learn how to use a hot-glue gun were immediately used by that child to guide her friend’s learning in both resonant and novel ways; 2) a case in which two children were deliberately supported to learn how to collaborate or form a “we” within a marble
Across distinct time-scales, these cases evidence the ways movements that are improvised within the flow of pedagogical activity can create resources for future activity in ways that illuminate local processes of cultural production—in this case, the shift from normative, individualized forms of education towards a model of joint activity built on the notion of people becoming keepers of one another’s learning. The term “cultural production” amplifies the improvisational dimensions of this shift, as well as the aesthetic dimensions of pedagogical activity. In this case, the shift towards joint activity was also aimed at surfacing and addressing the re-emergence of racialized and gendered inequities with regards to who received different forms of assistance within the setting (who was more likely to have an artifact taken out of their hands, or who was trusted to use a tool, etc.).

The notion of “pathways” is germane to the study of gesture and embodied interaction because there are literally paths through the air that may be seen as “marked” or accentuated by participants in ways that create potential openings for others to utilize, explore, and reshape. Though research on embodied cognition tends not to foreground the relational histories among participants within a focal interaction, analyzing these pathways has helped us to see learning as both deeply historical and radically future-making. In a genetic sense, we might say that participants “re-trace” prior moments with their bodies/hands, or that future moments carry the trace of prior relations and systems (Bakhtin, 1984; Gordon, 2008; Wolfe, 2016). Looking forward from present moments, we argue for the salience of interactional “firsts”—the initial turns within an exchange, or the initial moments and days of a program or setting (Hansen, 1989)—as creating value-laden movements or “substrates” (Goodwin, 2017) that can linger in the air.

We conclude with a discussion of key pedagogical and theoretical implications. First, our analysis of gestural pathways offers one way to see learning (shifts in participation, new relations with others, with materials and tools) through the movements of the body, and to conceptualize collective learning as tied to the live choreography of activity within a setting over time. Understanding design as a kind of compositional activity, this lens can support educators in being reflective and intentional about the pathways we are enacting in the moment. In other words, making the ethical explicit engenders new responsibilities and domains of consideration for design. Our findings also attune us to the ways pedagogical movements are always ethnically and politically laden (Bang, et. al., 2016), enmeshed with processes of social reproduction, contestation and transformation (Erickson, 2004). Orienting towards present action as always holding the potential to create expansive meanings that can shape future moments in unanticipated ways offers a way of perceiving real-time activity that is sensitive to the “ethical trails” we are etching in the air. On a small but significant level, we see in such everyday moments how settings come to be, and children, youth and adults make decisions about who they want to be in the world, what kind of thinker, teacher, or friend.

The Hummingbird story: Navigating ethical multiplicities of heterogeneous nature-culture relations in learning environments

Megan Bang, University of Washington

In this paper I explore the axiological engagements and possibilities that are designed for and enacted in a STEAM learning environment focused on forest ecology and climate change with 1st-12th graders. Axiological positionings of self and others with respect to knowledge, knowing, and human activity are routine parts of interaction (Lemke, 2002). This study is part of an iterative community-based design project which involved community members, researchers, and graduate students to design and implement land-based learning programs that facilitate and support Indigenous ways of knowing and western science. The program was designed to focus on nature-culture relations and learning about complex ecological systems through relational ont epistemologies and mobile pedagogies of walking, talking, and storying the land (Bang & Marin, 2015; Bang & Medin, 2010). The framing question for the STEAM camp was: How can we live in respectful, reciprocal, and responsible relations with our lands and waters? In this paper, I analyze the ways in which these forms of relations were explored and enacted and the kinds of affordances or constraints they placed on learning and teaching about nature-culture relations and, more specifically, complex ecological systems.

The data for this paper come from four sources. The research team collected video and audio recordings of the program that included 30 youth and 4 educators as well as additional community members, artists, and scientists who also co-taught in these environments. The video data included both panoramic video of the activity as a whole as well as 5 students who wore point of view cameras during activity. Audio was also collected of all of the teachers in learning environments so that we could ensure the capturing of all of their
Microbe-human relations: Imagining new geographies of responsibility through artsience
Beth Warren, Boston University, and Ann S. Rosebery, TERC

In U.S. schools, intellectual traditions rooted in Cartesian influences selectively shape the aims, practices and phenomena highlighted as central to disciplinary learning. This “form-shaping ideology” (Bakhtin, 1984) structures a particular conceptualization of the relations between natural and cultural (or human) worlds in disciplinary learning. At its core, this conceptualization positions humans as distinct from and apart from the natural world in relations of mastery and entitlement (Latour, 2013). This form-shaping ideology continues to dominate disciplinary learning, functioning as a tacit and pervasive form of settled expectation (Harris, 1995) that restricts the scope of possible meanings and meaning-making in classrooms, i.e., how students and teachers imagine, come to know, and attend to relations between natural and human worlds (Bang & Marin, 2015; Bang, Warren, Rosebery & Medin, 2012; Warren & Rosebery, 2011).

In its orientation to human entitlement, the dominant conceptualization of nature-culture relations stands in stark contrast to cutting-edge research in a variety of disciplines (e.g., ecology, geography, oceanography, anthropology), which is re-conceptualizing relations among human and more than human forms of life in new “geographies of responsibility” (Massey, 2004). In these disciplines, complex socio-ecological futures are being re-imagined through relations of reciprocity, humility, responsibility, and sustainability (Cajete, 2000; Hulme, 2009; Massey, 2005). In this work, we connect these disciplinary developments to educational designs that engage epistemic heterogeneity not as a problem to repair or overcome but as foundational and generative in learning and teaching (Bang & Vossoughi, 2016; Rosebery et al., 2010).
In this paper, we share findings from a collaborative research endeavor to design an “artsscience pedagogy” that aims to cultivate youths’ attunement and involvement with complex ecological phenomena, specifically the emerging interdisciplinary field of the human microbiome. Over three years, a design collective of learning scientists, high school arts and science faculty, microbiologists, and local independent artists worked together with two main design goals in mind and in hand. One goal was to build from the microbial turn in recent biology to desettle dualistic structures of nature-culture relations rooted in Cartesian and colonial logics. As understood by anthropologists Heather Paxson and Stefan Helmreich,

(t)he microbial turn marks the advent of a newly ascendant model of ‘nature’, one swarming with organismic operations unfolding at scales below everyday human perception, simultaneously independent of, entangled with, enabling of, and sometimes unwinding of human, animal, plant, and fungal biological identity and community…Microbes are not tokens…of the ‘age of biological control’…. but are rather pointers to a biology underdetermined and full of yet-to-be explored possibility. (Paxson & Helmreich, 2014, pp. 166-167)

A second design goal, resonant with these shifting dynamics in biology, was to open up more relationally responsive, epistemically heterogeneous, participative modes of thinking, feeling, being, and making (Shotter, 2006) than are conventionally made available in high school science to youth from historically non-dominant communities. Taking seriously the heterogeneity of human sense-making, the artsscience pedagogy was designed to engage youth in exploring and creating “narratives of life” (Heath, 1986) imagined through relations of reciprocity, humility, responsibility, and sustainability (Cajete, 2000; Hulme, 2009; Massey, 2005; Shotter, 2006) rather than human domination and entitlement.

Students at a public high school with an arts focus were invited to explore microbe-human relations through engagement with multiple, narrative-centered practices of art and science. The idea behind this artsscience repertoire is that multiple, narrative-centered engagements would bring to life the ordinarily invisible presence of microbes on the human body, making them newly legible as forms of life of varying color, shape, contour, texture, and growth, and making them newly speakable as a part of “a world around us ‘here’” (Shotter, 2006, p. 112). Working with practicing artists and scientists over four weeks in the official space of a biology class, students cultivated microbial communities living in and on various parts of their bodies (e.g., the palms and fingers of their hands, forehead, armpits, belly buttons) and then explored possible meanings of microbe-human relationships through varied artistic and scientific forms of engagement. They choreographed movement phrases to experience microbial ubiquity and scale. They sculpted imagined microbial worlds with wood reeds. They musically scored microbial growth as it unfolded in Petri dish cultures of their skin microbiomes. They painted expressive portraits of microbe-human relationships. They scripted and dramatized microbe-human encounters. They engaged with emerging findings and open questions in human microbiome science. Towards the end of their inquiry, the students created and shared an “artsscience story,” defined as an artistic and scientific expression that a) explored an aspect of the human microbiome or their own process of inquiry that had become important to them, and b) creatively communicated this to people they care about.

In this paper, we draw on data that includes the artsscience responses of three students and their narrative accounts of their responses in individual interviews. Two students co-created a hip-hop song (“Bacteria At Its Finest”). In the lyrics, they riff on the genre of a love song by counterposing third-person negative societal narratives about bacteria with a first-person bacterial point of view. Another student created facial body art, which she entitled “False Expectations vs Reality,” to express “the drastic difference there is between what people think (about bacteria) and what it actually is.” Using narrative and discourse analytic methods, we are exploring the ways in which the students conceptualized, expressed, and evaluated microbe-human relations in their artsscience stories. Preliminary analyses show the students narrating their growing attunement to microbes and humans as being in a “we” rather than an “other” relationship, answerable to each other. In their lyrics and narration, the students creatively used the meaning-making resources of their art forms to move between points of view and layer multiple voices to chart new geographies of responsibility linking humans and microbes in withness-relations, e.g., of mutual care. They spoke of human cultural practices as creating vulnerabilities for both humans and microbes (e.g., hand sanitizers, wide-spectrum antibiotics, consumer capitalism), and emphasized their growing sense of responsibility to educate others into new understandings of microbe-human relations. They expressed an ecological sensibility toward microbial ways of being and living, which they marked aesthetically (“the true beauty behind our microbiome”) as well as politically (“this doesn’t stop at just me”) in a new ethical formation of relational involvement.
Building on Shotter’s work, we suggest that, in an artscience pedagogy of the kind we have been exploring, transdisciplinary practices of attending, thinking, feeling and making support expansive ethical engagements with complex socio-ecological phenomena. Learning becomes the cultivation of new possible “responsive living relations” with phenomena, relations that emerge in and through participative modes of inquiry (Shotter, 2006). We see high school youth, virtually none of whom identified with school science, responding to this vision, imagining themselves into new geographies of responsibility as they engage creatively with the complexities of socio-ecological future-making.

References


Life-long Life-wide Learning Within and Beyond the Disciplines

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Abstract: Does the learning sciences community need to question its epistemic values and reconceptualize its stance on the content and structure of formal schooling? Many researchers in the learning sciences investigate learning environments that center on disciplinary practices. Yet, professional settings often involve the meeting of minds and of expertise that require the ability to shift between perspectives. Is a disciplinary focus a good model for preparing learners for these roles? How well does a disciplinary apprenticeship prepare learners for their everyday lives? This symposium includes theoretical, methodological and design presentations that set the stage for engaging the audience in a conversation over a number of overarching questions that include: What motivates broadening our gaze beyond the disciplines? What methods can help us understand the meaning of a beyond the disciplines perspective? How might subject-matter learning be reconceptualized to adopt a beyond the disciplines approach? What costs are involved in adopting such an approach?

Overall focus
Is the existing disciplinary focus of K-12 and Higher Education still an apt model for formal education? In what ways does this focus prepare learners for a multitude of vocations, for the future of work and for their everyday lives? In this symposium, we aim to understand the role that K-12 and Higher Education might play in enabling learners to pursue both personal and professional goals. Specifically, we examine whether and how disciplinary learning may need to be reconceptualized. We invite the audience to join us in this process. To this end, we include three presentations to set the stage for this discussion, and allocate a large part of the session to a structured and moderated discussion with the audience. One presentation is devoted to a retrospective and prospective framework of research on learning in the disciplines in the learning sciences. A second presentation offers a novel reflexive methodology for studying mixed expertise that can be used to identify knowledge and skills that are involved in team encounters that transcend disciplines, and that can be used to study learning environments that might emulate such encounters. A third presentation proposes design principles for designing disciplinary curricula that cultivate practices that can serve professional as well as everyday goals. Against the backdrop of the possible framework, methodology and design offered in these presentations, we will consider, with the audience, how aspects of disciplinarity, inter-, trans- multi-disciplinarity, multivocality and multiliteracy, which were raised in the presentations, coalesce with changing views on the roles of K-12 and Higher Education.

Motivation and major issues addressed
Characterizing the nature of knowledge and practice in a discipline, and designing learning environments that are sites of apprenticeship into these respective sets of disciplinary practices are hallmarks of research in the learning sciences (Bransford, Brown, & Cocking, 2000; Bransford & Donovan, 2005; Bruer, 1993; Collins & Kapur, 2014; Herrenkohl & Polman, in press; Sawyer, 2014 [Part V]). These foci arose in part as a challenge to formal learning environments in which school subjects seemed to consist of a set of knowledge and procedures that learners should master but that bore loose ties to professional values and practices. Regardless of how well the knowledge and practices of school subjects cohered with professional practice, the set of underlying values and purposes of these practices were rarely shared with learners. The idea was that making these values and purposes explicit, and orchestrating classroom activities around practices that cohered with these values and purposes would enable learners to take an intentional stance to their learning that would have both cognitive and affective learning benefits (Berland & Hammer, 2012; Lampert, 1990). Learning a discipline was seen as learning about the nature and professional practice of the discipline as much as it was about acquiring specific knowledge and skills.
This approach seems most beneficial when there is a clear and continuous trajectory (Wenger, 1998) from formal educational settings to more advanced educational settings or to professional practice (Roberts, 2011). However, few learners follow such trajectories. Learners face a multitude of possible paths. In addition to pursuing different career paths, projections concerning the future of work suggest that pursuing any career path will involve collaboration with different multi-professional teams, as well as mobility between different forms and topics of expertise (Gratton, 2010; Malone, 2004). A disciplinary focus may provide opportunities for team work and argumentation that draws on perspectives within the discipline (Osborne, 2010), but does not require communicating underlying assumptions across perspectives, and considering shared information in light of multiple perspectives. Moreover, K-12’s and Higher Education’s ability to adequately prepare learners not only for the future of work, but for the knowledge and skill demands of everyday life is increasingly questioned (e.g., Feinstein, Allen, & Jenkins, 2013). For example, the public is unlikely to design and execute a scientific experiment in order to understand the factors that underlie a natural phenomenon, but is likely to seek information online in order to decide whether to get vaccinated (Tabak, 2016). It is not clear whether learning science from a disciplinary apprenticeship perspective prepares learners for such everyday practices.

Working, playing, or learning in groups or teams where participants have different types of expertise, but a common goal begins early in school and continues through adulthood, yet K-12 and Higher Education rarely specifically teach the skills that are needed for participants to function well in groups. Particular attitudes and skills are needed in order to benefit from being in a team, but there are also challenges, some of which are specific to context, others which are generalizable (DeHart, 2017; Rosé & Lund, 2013). In addition, the transfer of the different types of knowledge gained from working in one group to another group, or from one type of stakeholder to another is a practical as well as a methodological challenge (Adler, Hirsch Hadorn, Breu, Wiesmann, & Pohl, 2017).

Learners should be able to understand why common disciplinary practices such as argumentation are important and how this practice might be similar and different across disciplines and problem-based contexts. Learners should also be able to appreciate the different values and stances, or what’s worth knowing or doing, that disciplines bring to shared problems and then learn to select the most vital approaches or synthesize across perspectives in order to offer productive solutions or explanations to particular problems. In addition, learners should understand that the knowledge they gain rests upon assumptions that are made about what knowledge is, but also about what kinds of evidence are acceptable, and this may depend on the discipline (Stevens, Wineburg, Herrenkohl, & Bell, 2005). And since this is also the case for others with different knowledge and expertise, it follows that working well in groups entails that collaborators make their assumptions clear. In order to understand the knowledge of others, one must understand the assumptions others make about the world.

Here, moving from multi-disciplinary perspectives and practices to inter- and trans-disciplinary ones can sometimes be productive; Stember (1991) describes multi-disciplinary work as involving people from different disciplines collaborating, with each drawing on their disciplinary knowledge; inter-disciplinary work as involving knowledge integration and synthesis and methods from different disciplines; and trans-disciplinary work as creating unified frameworks transcending disciplinary perspectives. This approach suggests that cultivating an anchoring in particular disciplines should be accompanied by opportunities for different forms of encounters across disciplinary boundaries. Yet, other takes on these constructs carry alternative instructional implications. For example, some see inter- and trans-disciplinarity as a new thought style, moving further away from the disciplinary anchors and including elements such as modes of interaction, and a pluralism of actors that challenges traditional power structures (such as symmetrical collaborations between scientists and the public) as defining elements in these constructs (e.g., Darbellay, 2015). Such definitions might carry different instructional implications, and might offer greater continuity between preparing for work and preparing for life.

Increasingly, different strands of research in the learning sciences (Herrenkohl & Polman, in press; Lund & Suthers, in press) recognize that a disciplinary approach intended to apprentice learners into academic research-oriented work in a single discipline does not respond well enough to the full range of current K-12 and undergraduate learning needs. However, it not clear whether abandoning disciplinary foci as a driving curricular structure is the solution. There are also many open questions concerning the nature of disciplines and of inter-, trans- multi-disciplinarity (Lund & Frandji, 2017). We need to engage with these questions in order to reconceptualize how disciplinary learning is contextualized within a broader scope.
In this symposium, we seek to discuss how we may think about learning within and beyond the disciplines, as well as define and support pedagogical tasks that create conditions that correspond to these emerging pedagogical visions. We consider:

- What motivates broadening our gaze beyond the disciplines?
- What methods can help us understand the meaning of a beyond the disciplines perspective?
  - How is this anchored in differing views on multi-inter-trans-disciplinarity (MITD)?
  - How can novel ways of studying teams help us converge on pedagogically productive views of MITD?
- How might subject-matter learning be reconceptualized to adopt a beyond the disciplines approach?
  - How can we create conditions for learners to gain competence in working together in groups where participants have different expertise?
  - How can we create conditions for learners to be able to connect the underlying values, stances, and professional practices of particular disciplines to purpose-driven action in the world?
- What costs are involved in pursuing these reconceptualizations?

**Symposium session structure**

The session is designed to devote equal time to presentation and to discussion with the audience:

- 10-minutes introduction and overview of the session. (Session moderator; Adi Kidron).
  - In addition to presenting the key issues and motivation for the session, each presenter will contribute questions that arise from their presentation and that concern broader implications or controversies. These questions will be presented in the introduction, prior to the presentations, in order to set the stage for the subsequent discussion.
- 45-minutes individual presentations (12-minute presentation; 3-minute clarifying questions).
- The remaining 35 or so minutes will be devoted to a discussion with the audience.
  - The session chair will present the set of discussion-prompting questions, and the discussion will follow these questions as well as questions and issues raised by the audience. With the audience’s permission we will record the discussion, in order to maximize the future knowledge construction potential of the session. We will also make use of social media tools in order to incorporate the audiences’ thoughts and considerations, as they arise and are shared digitally throughout the session, into the discussion.

**To the disciplines and beyond: Shifting epistemic stances and values in learning sciences research**

Leslie Rupert Herrenkohl, University of Washington, and Joseph L. Polman, University of Colorado Boulder

This presentation briefly explores the history and fruitfulness of learning sciences research on learning in the disciplines. It also explores how recent and emerging work in both formal and informal settings indicates the importance and promise of moving beyond strictly disciplinary boundaries. The field has and continues to shift toward a more human science view (Flyvbjerg, 2001; Penuel & O'Connor, 2010) where the values, purposes, and goals of learning as well as who has the power to decide such matters are critically important to examining and understanding learning. Borrowing the concept of phronesis, or wise action, from Aristotelian philosophical thought (Nussbaum, 1997; Toulmin, 1992; Flyvbjerg, 2001) and the practice of improvisation from Holland (Holland, Lachicotte, Skinner, & Cain, 1998), we argue that learning scientists are increasingly emphasizing the role of everyday individuals-operating-with-mediational-means (Wertsch, 1998) as a way to understand personal learning and development as well as cultural change. This stands in contrast to earlier research in the learning sciences that emphasized understanding the development of expertise and then applying this knowledge to create opportunities for non-experts to learn and ultimately approximate expert performances (Bransford et al., 2000; Dreyfus & Dreyfus, 1986; Perkins & Salomon, 1989). We offer examples from our own research in journalism (Polman & Hope, 2014; Polman, Newman, Saul, & Farrar, 2014) and science learning (Herrenkohl & Mertl, 2010) as well as emerging research from scholars in the field (Peppler, 2010, 2013; Shapiro, Kelly,
Ahrens, & Fiebrink, 2016; Taylor, 2017) to surface epistemic values and stances at the heart of contemporary research in the learning sciences.

Proposed discussion questions: (1) How do equity-oriented and emancipatory values play into decisions about designing learning environments “beyond the disciplines”? In other words, what are the potential advantages and disadvantages to learners of taking a view that emphasizes agency and action over predefined disciplinary learning goals? (2) How can we as researchers and designers understand enough about emerging practices and communities to harness their potential in a rapidly changing world?

**Integrating aspects of disciplines through multivocal analyses of group interactions**
Kristine Lund, University of Lyon, Ecole Normale Supérieure de Lyon, and Dan Suthers, University of Hawai`i at Manoa

In this presentation, we describe a collaborative approach to analysis of interaction in which analysts from multiple traditions dialogue to achieve not only a richer understanding of the data, but also to understand how their methods construct the object of study and provide alternate ways of producing evidence for arguments about analytic claims (Suthers, Lund, Rosé, Teplovs, & Law, 2013). We begin with a brief review of a selection of analytic traditions that offer alternative perspectives on understanding interaction, and that researchers have used to focus on the study of learning in groups. Illustrating the diversity of traditions allows us to make the case for countering tendencies towards fragmentation and for working toward some level of coherence across traditions that study group interactions. In doing so, we define what constitutes a discipline, as well as multi-inter- and transdisciplinarity (Lund & Frandji, 2017; Darbellay, 2015; Klein, 1990), addressing the debate that exists around these constructs. We then present the origins and tenets of multivocal analysis, and summarize ten practical strategies for achieving productive multivocality. Discussion will center on how our own insights (Suthers, Lund, Rosé, Teplovs, & Law, 2013; Rose & Lund, 2013) as well as research from the Science of Team Science (e.g., Fiore, 2008) can be leveraged to reconceptualize K-12 and undergraduate teaching and learning.

Proposed discussion questions (1) As a researcher, what are the benefits in venturing outside of disciplinary boundaries? What are the drawbacks to doing so? How is our understanding of the nature of knowledge influenced if we take a multi-inter, or transdisciplinary stance? (2) How do we go about teaching the skill of making connections between broad areas of inquiry — at different age levels — and why is this viewed as having more or less value than digging deeply into a single area?

**Multiliteracies within and beyond the disciplines**
Josh Radinsky, University of Illinois – Chicago, and Iris Tabak, Ben-Gurion University of the Negev

In this presentation, we broach the tension of learning within or beyond the disciplines from a design perspective. We consider how higher education instructors, charged with teaching a particular discipline, might redesign their courses to provide functional as well as disciplinary literacy in undergraduate education. In using the term *functional literacy* we refer to the knowledge, skills and dispositions that people might use in their everyday lives (e.g., Burgess & Hamilton, 2011; Nutbeam, 2008; Ryder, 2001). In using the term *disciplinary literacy* we refer to the knowledge, skills and dispositions that approximate those that are used by professionals in the discipline (Bransford & Donovan, 2005; Goldman et al., 2016; Herrenkohl & Polman, in press; Moje, 2007). We focus in particular on the interpretation and sensemaking of multimodal texts (e.g., prose, images, graphs, and dynamic displays). There seems to be a false assumption that contemporary multimodal networked resources can be straightforwardly interpreted by individuals with at least rudimentary competence in reading texts and graphs (for a similar argument see: Wineburg & McGrew, 2016). However, we contend that the public encounters numerous complex data representations in a variety of everyday information contexts, such as entertainment, real-estate, weather, health and general news reports that have literacy demands that are not readily addressed through most existing K-12 and undergraduate curricula. Thus, existing curricula may privilege disciplinary literacy at the expense of adequate preparation for civic participation. Yet, we suggest that there is often an overlap between disciplinary and functional literacy, and that disciplinary learning can be redesigned to cultivate both disciplinary and functional literacy. We propose a set of design principles for such curricular redesign. We first present a critique of the presumed facility of contemporary networked resources. We then present our proposed principles, as well as an example illustrating how they can be used to design
activities within a social science discipline. We conclude with a discussion of the promises and pitfalls of this approach.

Proposed discussion questions: (1) Delving deeply into a discipline and understanding its values and standards of evidence can provide broader insights into the nature of knowledge. Is this an important learning goal and do we run the risk of not meeting this goal if we shift our focus away from disciplinary apprenticeship? (2) Teaching as disciplinary apprenticeship is not a simple feat, and even after much research in this area we have many open questions. What type of supports will instructors need in order to not only consider disciplinary practices, but also the points of contact between disciplinary practices and purpose-driven action in the world?

References

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Assessing Prerequisites and Processes of Self-, Co- and Shared Regulation During Collaborative Learning

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Abstract: To conceptualize regulation processes that may occur within groups, a differentiation between self-regulation (i.e., individual members regulate their own learning during collaboration), co-regulation (i.e., single learners regulate the learning of one or more of their learning partners), and shared regulation (i.e., the whole group regulates its learning) has been proposed. This symposium assembles four papers that offer various ways regarding the measurement of prerequisites and processes of such regulatory efforts during group learning. The presented methods range from Likert-scale self-report questionnaires over video case vignettes towards an analysis of real group processes by aid of logfiles and discourse coding schemes. These methods will be critically discussed, especially in terms of their transferability to studying collaborative learning in diverse educational contexts, both formal and informal. That way, the symposium will significantly expand previous methods for the assessment of self-, co- and shared regulation during collaborative learning.

The importance of regulation processes during collaborative learning
Collaborative learning is often described as an ideal context for individuals to engage in high-level cognitive processes that are closely related to knowledge acquisition. Examples for such high-level cognitive processes are asking and reacting to thought-provoking questions (King, 2007) or exchanging arguments and counterarguments with learning partners (Vogel et al., 2016). Activities like these occur almost naturally once students learn together. Not surprisingly, positive effects of collaborative learning on knowledge acquisition have been reported (Springer, Stanne & Donovan, 1999). However, research has also shown that learning in groups is not always superior to learning individually. For example, in a study by Weinberger, Stegmann and Fischer (2010), students were asked to analyze three problem cases by aid of a psychological theory. While some students worked individually on this task, others collaborated in groups of three. Results showed that – at least when groups were not appropriately scaffolded – students who had learned individually outperformed students who had learned in triads on a subsequent domain-specific knowledge test. As possible reasons for such suboptimal effects of collaborative learning, both motivational (e.g., social loafing effects; Karau & Williams, 1993) as well as (meta-)cognitive issues (e.g., a lack of cognitive and metacognitive learning strategies; Wang, Kollar & Stegmann, 2017) have been discussed. Thus, to make collaborative learning a successful endeavor, groups need to be able to effectively regulate such problematic processes.

Self-, co-, and shared regulation: Three levels of regulating collaborative learning
To conceptualize regulation processes within groups, Järvelä and her colleagues (e.g., Järvelä & Hadwin, 2013; Järvenoja, Järvelä, & Malmberg, 2015) suggested a theoretical model that distinguishes regulation processes at three social levels: First, at the “self”-level, individual group members may regulate their own learning, e.g., by setting goals for what they would like to learn by collaborating with their partners or by mentally monitoring their understanding of the subject matter during collaboration. Second, at the “co”-level, an individual group member may regulate the learning of one or more of her learning partners, e.g. by asking probing questions or by telling them what content to repeat for the following collaborative learning session. Third, “shared
regulation” happens when the whole group more or less deliberately engages in regulation processes, e.g. by jointly discussing what content to learn in and what order or by setting up time plans for the whole group.

**Goals and structure of the symposium**

Whereas theoretical models on self-regulated learning are well established and validated by an abundant of empirical studies over the past decades, theorizing social forms of regulation has only recently gained momentum (Panadero & Järvelä, 2015). Previous studies in this respect are mainly focused onconceptually differentiating individual versus social forms of regulation and at identifying the latter in collaborative learners’ (online) discussions. Empirically validating the theoretical constructs of self-, co- and shared regulation, however, unraveled methodological questions on how to assess social forms of regulation in an objective, reliable, valid, and economic way. Optimizing collaborative learners’ regulation behavior furthermore demands for correlational studies unraveling facilitating conditions towards students’ adoption of self-, co- and shared regulation. The symposium makes an important contribution to both aspects. First, it provides insights into the effects that different kinds of prerequisites have on the employment and selection of different strategies for self-, co- and shared regulation. In this realm, the paper by Williams, Seufert and Weinberger specifically looks at prerequisites on the learners’ side (i.e., their competence to co-regulate learning processes) and reports on the development of a self-report questionnaire to measure learners’ co-regulation competence. They also provide information on the validity of the instrument: co-regulation competence as assessed by aid of their CRCQ demonstrated to be predictive for achievement as well as learners’ goal orientations. The paper by Melzner, Greisel, Kollar and Dresel investigates the effects of different characteristics of the situation (i.e., whether the group currently exhibits motivational or cognitive problems) on how individuals intend to engage in self-, co- and shared regulation processes during collaborative learning. Their results show that groups seem to react differently to different regulation problems, and that – at least when it comes to exam preparation – students put more emphasis on regulating their own learning than the learning of other group members or of the group as a whole. Second, the symposium offers insights into the methodological challenges and requirements when studying social forms of regulation, given that the different papers make use of different assessment methods, allowing for a critical methodological discussion. In this respect, the paper by Kielstra and Molenaar describes the development of an app that provides learners both with guidance on how to engage in task-oriented reading in individual and collaborative learning settings and with an automated way of measuring students’ use of task-oriented reading strategies, based on logfile data. First results indicate that groups can successfully be scaffolded with the app, and that the app holds large promise for an in-depth assessment of regulation processes at the individual and the social level. The paper by De Backer, Van Keer and Valcke provides an in-depth look into time-bound evolutions in students’ regulation behavior as well as in the quality (instead of only the kinds) of collaborative learners’ regulation strategies. The results demonstrated that collaborative learning particularly evokes co-regulation but that truly sharing regulation is rather challenging for students. They need time and practice before they demonstrate sharing regulation. Findings further revealed qualitatively different types of shared regulation. Overall, all four papers offer valuable contributions especially regarding the question how to assess and manipulate (individual and situational) prerequisites and/or processes of self-, co- and shared regulation within groups. The availability of such assessment methods is of utter importance for the investigation of further research questions on self-, co- and shared regulation, especially regarding the effectiveness of self-, co- and shared regulation for successful collaborative learning and the question how to scaffold these social forms of regulation. Furthermore, the results of the four papers will spark further theoretical discussions and enable elaborating and refining current theoretical models on self-, co-, and shared regulation. From this perspective, the papers imply an important step forward in the emerging literature on self-, co- and shared regulation processes during collaborative learning. Their results show that groups seem to react differently to different regulation problems, and that – at least when it comes to exam preparation – students put more emphasis on regulating their own learning than the learning of other group members or of the group as a whole. 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**Are we closer? Measuring co-regulation competencies in collaborative learning environments**

Christopher Williams, Tina Seufert, and Armin Weinberger

Regulation research has seen a shift of focus from an individual perspective of self-regulated learning (SRL) to more emphasis on social modes of regulation (Panadero, Kirschner, Järvelä, Malmberg & Järvenoja., 2015). In the literature, the two social modes of regulation often discussed are co-regulation and socially shared regulation. Hadwin, Järvelä and Miller (2011) claimed co-regulation is the temporary coordination of self-regulation amongst self and others” (p. 68). With the increased importance of investigating social modes of regulation like co-regulation, the question of how to properly measure this phenomenon also follows.
There are several self-evaluated learning strategies assessments, like Pintrich’s (1991) Motivated Strategies for Learning Questionnaire (MSLQ), but there have been few attempts to measure co-regulation with questionnaires. Schoor, Narciss and Koerndle (2015) argued that even though researchers possess an in-depth understanding of methods to investigate self-regulation, co-regulation is a separate phenomenon and requires suitable method consideration. In our studies, the Co-Regulation Competencies Questionnaire (CRCQ) was developed and tested. The development of CRCQ aims to complement other qualitative methods. Moreover, the development of our multi-dimensional framework for coding co-regulation manifestations provides a specific approach to evaluate co-regulation.

Our research questions were: (1) Are we able to reliably measure co-regulation competencies and its sub-facets using a questionnaire? (2) Are co-regulation competencies measured with the CRCQ related to learning performance in a collaborative learning task? (3) Can the CRCQ be validated by qualitative measures of the learning process?

To answer our research questions, we conducted two studies. In the first descriptive study, the CRCQ was developed and analyzed with respect to the reliability of its subscales (N=212). Based on these results, we conducted a second study where 34 participants learned in a collaborative group setting. Their task was to understand biochemical concepts by integrating multiple representations learning materials that were distributed amongst the learners. The learning process required shared knowledge construction and hence, co-regulation. With this sample, we addressed the second research question and relate learners’ co-regulation competencies – measured with the CRCQ – to their individual learning outcomes after the group learning process. Additionally, to answer the third research question, we analyzed group discourse by using our coding scheme to categorize actual co-regulation manifestations (up to now with N=9).

In the first study, the participants (N=212) were between 18 and 74 years old (M=35.88, SD=10.89). The CRCQ contains 84 items and aims to measure the learners’ co-regulatory competencies by asking learners to assess the sharedness of their strategies: cognitive (e.g. rehearsal, organization, elaboration, critical thinking, collective efficacy), metacognitive (e.g. planning, monitoring, goal setting), and motivation (e.g. intrinsic/extrinsic motivation, task value, control beliefs). Participants rated statements, which assessed their learning strategies, by asking to what extent do they share their strategies either at all (e.g. self-regulation), with either one group member (e.g. co-regulation) and/or with the whole group (e.g. socially shared regulation). An example of a CRCQ survey statement assessing motivation strategies was “My expectations that we will do well.” The study revealed, that 15 out of 17 CRCQ scales had an α > .72, which made us confident to use the questionnaire further on with slight amendments.

In the second study, participants (N=34) were between 20 and 43 years old (M=27.56, SD=6.00). A week before the learning activity, they completed several online questionnaires including the CRCQ and MSLQ. Before the learning activity, participants completed the CRCQ, and a biochemistry pre-test. In the learning phase, participants were presented with six different inter-linked representations in the domain of biochemistry. Each representation contributed vital information to understand the whole subject matter. After the learning activity, the participants completed a biochemistry post-test. Participants were encouraged to think aloud during the learning phase. They were also recorded and an observation protocol was implemented.

To answer RQ2, a regression analysis was applied for the biochemistry post-test (e.g. performance) as dependent variables with the following predictors: cognitive, motivational, and metacognitive competencies from the CRCQ and MSLQ. The regression model for co-regulation motivational competencies was significant (F(6, 27)=2.74, p=0.05, adjusted R²=.24). Co-regulation intrinsic goal orientation (β=.53, t(13)=2.82, p=.01) and co-regulation control belief (β=.62, t(13)=−2.05, p=.05) were significant predictors of performance. The cognitive and metacognitive predictors showed no significant influence on learning outcomes.

To answer RQ3, we coded up to now two groups based on our multi-dimensional framework for coding co-regulation. Participants (N=9) were between 22 and 33 years old (M = 25.2, SD = 3.38), and were categorized as either 1) high (N = 3) or 2) low co-regulators (N = 6) based on a median split for their CRCQ score. The raters were trained (Vogel & Weinberger, in press) and obtained a significantly high level of agreement with a Kappa of above .95. The individual learner’s co-regulation competency score was calculated by combining the raters’ scores for each of the learners based on the 4 subcategories of the COPES model: operations, product, standards, and evaluation (Hadwin, Järvelä & Miller, 2011). The individual learner’s total score was divided by the total maximum point available. The individual co-regulation score ranges from 0% (e.g. self-regulation) to 100% (e.g. socially shared regulation). A median split was conducted to create an independent categorical variable identified as co-regulation score. The dependent variables were (a) biochemistry post-test performance and the (b) co-regulation score. Concerning (a) the biochemistry post-test performance, we found differences between high and low-regulators (high: M = 9.75, SE = 1.75; low: M = 10.38, SE = 1.42). Regarding (b) the co-regulation score, we discovered no effect for metacognitive or cognitive
learning strategies (metacognitive high: $M = 30.89, SE = 24.19$; low: $M = 19.78, SE = 17.52$; cognitive high: $M = 28.92, SE = 6.05$; low: $M = 22.54, SE = 7.56$), but we did find a meaningful difference for extrinsic goal orientation (high: $M = 11.60, SE = 10.54$; low: $M = 27.37, SE = 6.17$).

Considering the first research question, the CRCQ and sub-facets’ alpha scores displayed a positive sign that the questionnaire has potential to reliably measure co-regulation competencies. The sharedness of one’s motivations showed a positive effect on the learners’ performance. Similar to the CRCQ initial study, the high inter-rater reliability with our multi-dimensional framework for coding co-regulation is another encouraging sign for future research and fairly validates the initial CRCQ results. Furthermore, the effects of high co-regulators on their external goal orientation is evidence that sharing one’s motivations can have positive influences on performance but also is potentially a defining characteristic of high co-regulators.

**How different regulation problems influence self-, co-, and shared regulation in student groups**

Nadine Melzner, Martin Greisel, Ingo Kollar, and Markus Dresel

Research revealed that learning collaboratively may positively impact knowledge acquisition (Kyndt, Raes, Lismont, Timmers, Cascallar & Dochy, 2013). Therefore, it is not surprising that students often meet in groups voluntarily, for example when comes to preparing for important exams. Nevertheless, research has shown that groups often struggle during collaboration, especially when they experience motivational (e.g., a low interest in the learning material) and/or knowledge-related problems (e.g., little understanding of the subject matter at hand). To effectively regulate their learning when being faced with such problems, groups need to select and employ effective regulation strategies. Yet, an open question is how an adaptive choice of strategies would look like with respect to the social level on which these strategies operate. In this respect, Järvelä and Hadwin (2013) suggested to differentiate between strategies at (a) the self-level, at which group members regulate their own learning, (b) the co-level, at which they regulate the learning of other group members, and (c) the shared level, at which they jointly negotiate regulation processes within the group. In other words, it is unclear at what social level(s) groups mainly regulate motivational and knowledge-related problems that pop up during collaboration. By using a video-vignette paradigm together with open-ended questionnaires, this study therefore aims to elucidate the effects of present vs. absent motivational and/or knowledge problems in student groups (1) on the extent to which (individuals within) groups apply cognitive learning strategies and (2) on the extent at which they show these learning strategies at different social levels (self-, co-, and shared level).

Subjects were $N=197$ university students $(M_{Age}=22.14, SD_{Age}=4.33)$ from educational science and from a pre-service teacher education program. On average, participants were in their 2nd semester of studies $(M_{Study}=2.27, SD_{Study}=1.72)$. They watched four videos that presented groups preparing for an upcoming exam. Videos were shot from a first-person view perspective to increase the level of participants’ immersion. Across the four videos, we varied the presence vs. absence of the two problem types (motivational and knowledge problems). Presentation sequence of the videos was randomized and balanced. After each video, participants were asked to write down what they would do in each situation to guarantee a high-quality learning process (separately for the self-, co-, and shared level). To that end, an open-answer format was used. First, all student answers were segmented into single idea units. Reliability of segmentation as the relative portion of two independent coders’ overlapping sequences (Strijbos, Martens, Prins, & Jochems, 2006) was sufficient (82.2% vs. 85.1%, calculated from both coders’ perspectives). Next, we coded the social level at which the mentioned strategy operated (Cohen’s $\kappa = .78$). After that, we applied a self-developed coding scheme to capture the kinds of strategies participants mentioned (six categories; Cohen’s $\kappa = .87$). For the purpose of this paper, we only focus on cognitive strategies such as elaborating or organizing the learning material.

To answer our research questions, we ran a 2x2x3-factorial ANOVA with the within-subject factors ‘motivational problems’, ‘knowledge problems’, and ‘social level’ and the frequency of cognitive strategies as dependent variable. Regarding RQ1, we found a significant main effect for ‘knowledge problems’, $F(1,196) = 30.451$, $p < .01$, $\eta^2 = .134$, and for ‘motivational problems’, $F(1,196) = 62.813$, $p < .01$, $\eta^2 = .243$: With both problem types present in the group, participants mentioned more cognitive learning strategies than when these problems were not present. The interaction between knowledge problems and motivational problems was not significant ($F(2,392) = 0.034$, n.s.). Concerning RQ2, we found a significant main effect for ‘social level’, $F(2,392) = 21.851$, $p < .01$, $\eta^2 = .100$. Bonferroni-corrected post-hoc comparisons revealed that participants mentioned significantly more strategies at the self- than at the co- and shared level $(p = .00)$. The difference between strategy use at the co- and at the shared level was not significant $(p = .42)$.

The results seem to indicate that once students experience any kind of problem (be it motivational or be it knowledge-related), they react with a reduction of their use of cognitive learning strategies. With motivational problems being present, a reason for this might be that the application of such strategies itself is dependent on
students’ motivation (as suggested for example by Boekaerts, 1997). Watching an unmotivated group and imagining being a member of that group might reduce one’s own motivation as well and that way cause a lower use of cognitive learning strategies. In turn, when knowledge problems occur, students may switch the kinds of strategies they are currently using in the direction of applying more metacognitive strategies, in order to search for reasons for the current problems and to update the plans for the subsequent learning phase. Further analyses are necessary to test this assumption. Interestingly, at least when it comes to exam preparation, students seem to be mostly concerned with regulating their own learning (rather than the learning of other group members or the group as a whole). This may be specific to the particular situation we chose: Since exams typically are taken individually, students might regard a possible engagement in social regulation processes as an unnecessary burden. At least, students do not seem to expect to get a lot out of an engagement in such processes. This is unfortunate, given that prior research has particularly underscored the importance of socially shared regulation to promote individual learning outcomes (Järvelä, Volet, & Järvenoja, 2010). Future research should investigate to what extent these results can be transferred to other, possibly less externally-regulated learning situations.

An app to measure self- and shared regulation during task-oriented reading
Jolieke Kielstra and Inge Molenaar

Task-oriented reading involves reading with the purpose of processing information for the execution of a specific task (Anmarkrud, McCrudden, Bråten, & Stromso, 2013). Research shows that task-oriented reading is influenced by how students apply reading strategies (Vidal-Abarca, Mañá, & Gil, 2010). For example, Rouet, Vidal-Abarca, Erboul, and Millogo (2001) show that application of reading strategies during task execution explains differences in students’ reading comprehension. Although this provides evidence for the importance of reading strategies during task-oriented reading, it does not inform us how students regulate during task-oriented reading. A number of elements are put forward as important. Prior to reading, a task can act to signal relevance, allowing readers to understand which sections of the text are relevant for a task (Anmarkrud et al., 2013). Thus, task representations play an important role in strategy application as they allow students to select a reading strategy that supports successful task accomplishment (Rouet, Britt & Durik, 2017). Also, proficient readers tend to use reading strategies more frequently compared to less proficient readers and also use more diverse strategies (De Milliano, van Gelderen & Sleegers, 2016). The above indicates the need for a more profound understanding of how less proficient readers regulate their task-oriented reading. Moreover, this group seems to need additional regulation support. We hypothesize that reciprocal peer tutoring can improve collaboration, students’ understanding of a task and the usage of appropriate reading strategies (De Backer, van Keer, Moerkerke & Valcke, 2016) and that it can enhance less proficient readers’ regulation of task-oriented reading.

To examine this hypothesis, we first need to develop a measurement instrument to assess how students regulate their task-oriented reading both in individual and collaborative settings. We performed a literature research to examine current methods to measure students’ regulation of task-oriented reading. Current methods focus on task performance and strategy execution (Vidal-Abarca, Mañá, & Gil, 2010). As discussed above, we expect that a student’s regulation is dependent on the students’ task representation, their ability to select an appropriate strategy and to reflect on their strategy use. Therefore, we included these elements in a newly developed scaffolding and measurement app. Moreover, the app also has to be used to measure shared regulation in collaborative settings. We developed a macro script directed at supporting shared regulation on the specific elements of task-oriented reading during reciprocal peer tutoring. To the best of our knowledge, this app is the first measurement tool to measure self- and shared regulation in this way.

The app measures the interrelated aspects of task-oriented reading in individual and collaborative settings. Students’ self-regulation of task-oriented reading is measured through a) the indicated task complexity, b) the selected reading strategy, c) the applied reading strategy, d) the execution of the task and, e) the reflection on the applied reading strategy. We trace a students’ use of reading strategies with blurring. The text is masked except for the sentence the student deblurs, which allows us to capture the students’ reading process. The log data from the app are used to measure self- regulation of task-oriented reading.

Students’ shared regulation during reciprocal peer tutoring is scaffolded by including the five steps in a macro script to guide the groups’ interaction around shared regulation of task-oriented reading. The groups’ task representation, their strategy selection, their collaborative reflection on strategy execution as well as their individual reading, task performance and reading strategy awareness are included in the script. The script is designed to enhance group interaction by creating interdependency among the group members. Each member is provided with different information in the App which is necessary to fulfill the task. Students are assigned to different roles, i.e. tutor, task guard, text guard and writer. The tutor guides the shared regulation with a number of questions about task perception and reading strategies. The task guard has access to the task and explains the task to the group. The text guard has access to the text and describes layout of the text. The writer writes down
the groups’ answers to the questions. Under guidance of the tutor, the group discusses the task representation and the appropriate reading strategy. After this collaborative stage, each member continues to individually read the text and complete the task. Upon completion, each student indicates which reading strategy s/he applied. After all group members finish, the tutor again guides the collaborative discussion reflecting on the application of the reading strategies. The groups’ answers are recorded in the logs as a measure of their shared regulation.

To validate the measurement instrument, audio recordings record the interaction between the group members. The dialogue is analysed to validate the app’s measurements by aligning the logs with the groups’ discussion of their shared task representation, strategy selection and reflection on their strategy use after task performance. Existing coding schemes from Molenaar, Sleegers and Van Boxtel (2014) will be used to analyse the groups’ interactions.

Currently, 45 students in two classes of grade 4 in vocational secondary school are using the App. The students first completed 9 task-oriented reading tasks individually, after which they engaged in four reciprocal peer tutoring lessons in which they collaboratively engaged in 3 task-oriented reading tasks using the macro-script in the app. First results indicate great diversity in all elements of self-regulation of task-oriented reading. The macro script indeed supports reciprocal peer tutoring during the lessons and students indeed engage in shared regulation of their task-oriented reading.

Overall, this contribution introduces an App that is developed to measure how students regulate task-oriented reading both in individual and collaborative settings. In this way, we aim to better understand how shared regulation during reciprocal peer tutoring influences students’ individual regulation during task-oriented reading. As such, the development of this tool is of essential importance to further our understanding how students enact regulation and how shared regulation can influence self-regulation.

A process-oriented analysis of peer tutoring participants’ shared regulation behavior

Liesje De Backer, Hilde Van Keer, and Martin Valcke

The metacognition research recently shifted the focus from individual to social forms of regulation for there is consensus that collaborative learning not only encourages self-regulation, but shared regulation at interpersonal levels as well (Panadero & Järvelä, 2015). Socially shared metacognitive regulation (SSMR) refers to a joint engagement of multiple learners operating on each other’s metacognitive contributions when regulating the group’s cognition (De Backer, Van Keer, & Valcke, 2015; Iiskala, Volet, Lehtinen, & Vauras, 2015). Although SSMR is expected to advance collaborative learning, empirical evidence in this respect is limited and sometimes inconclusive (Panadero & Järvelä, 2015). This inconclusiveness raises theoretical questions regarding the existence of different types of SSMR, as well as methodological questions on how to measure utterances of shared regulation. It could be that not all of students’ shared regulation benefits collaborative learning to the same extent and, consequently, that more fine-grained analyses are needed to enable the identification (and measurement) of these possibly different types of shared regulation. The present study investigates the existence of qualitatively different types of SSMR, demonstrated by higher education students collaborating in a peer tutoring context. Peer tutoring (PT) is a type of collaborative learning characterized by specific role taking: the more knowledgeable tutor supports the learning of less experienced tutees. The present study opts for a micro-level, process-oriented analysis of PT-participants’ shared regulation. Its aims are twofold, directed at unravelling time-bound evolutions in students’ SSMR and at identifying quality differences in the acts of SSMR demonstrated by the PT-participants.

A semester-long PT-intervention was implemented as part of the curriculum of freshmen in the Educational Sciences program. Sixty-four students weekly tutored one another in small groups of six. All PT-sessions of five randomly selected PT-groups were videotaped (70 hours of video recordings). The PT-intervention consisted of eight weekly face-to-face sessions (2 hours each). PT-interactions were structured by weekly session-specific tutor manuals. Students participated in a compulsory preliminary training to master tutoring skills and received ongoing support through interim feedback. During the PT-sessions, students worked on authentic assignments, demanding high levels of cognitive processing and directed at co-constructing domain-specific knowledge on “Instructional Sciences”.

Students’ shared regulation was assessed through systematic observation of the video data by means of literature-based coding instruments (De Backer et al., 2015), allowing process-oriented study of self-, co- and shared regulation. Coding the video data and analyzing PT-participants’ shared regulation followed subsequent steps. First, statement coding was used to identify utterances of metacognitive regulation in students’ verbalized interactions (n=14968). A statement referred to a single thematically consistent verbalization of a single metacognitive action by a single student. Second, metacognitive statements were reanalyzed through interaction coding to check the regulatory agents involved and the reactions following the statement, aimed at identifying
utterances of SSMR ($n$=397). A unit of SSMR encompassed interdependent regulative actions, represented by a sequence of reciprocal conversational turns reflecting a particular regulation skill, proceeding through at least three PT-participants’ metacognitive statements. Third, mixed models for logistic regression allowing change points were run to unravel time-bound evolutions in PT-participants’ adoption of SSMR. Fourth, all identified SSMR-units were analyzed in more detail to unravel possible quality differences. The latter were coded based on the following parameters: (a) the number of students’ involved in a SSMR-unit (Iiskala et al., 2015); (b) level of (dis)agreement with peers’ regulative thinking; and (c) the level of elaboration in the regulative reactions to peers’ regulative contributions (Näykki, Järvenoja, Järvelä, & Kirschner, 2017). Fifth, a two-step cluster analysis was run to identify variations in the quality of segmented SSMR-units, based on the cluster variables (i.e. parameters a-c). Akaike’s Information Criterion (AIC) was adopted as a measure of fit for the clustering, whereas Euclidian distance was adopted as a measure of similarity.

Despite a limited adoption of SSMR, the findings reveal an evolution towards increased SSMR from the starting (2.04%) to the closing PT-session (8.06%). During the second intervention half, SSMR is increasingly adopted during orientation and monitoring in particular. Whereas the odds of SSMR do not change during the first intervention half ($p$=.185), they increase 2.58 times ($p<.001$) during the second half. A significant change point was revealed at PT-session 5, implying a considerably larger evolution towards SSMR upon completion of the PT-intervention. It should be noted, however, PT-participants’ engagement in SSMR is much more limited as compared to their involvement in self- (24.71%) and co-regulation (70.11%).

Further, results reveal the existence of variations in the quality of segmented SSMR units, based on the cluster parameters taken into account. More particularly, a two-cluster solution was revealed. After examination of the subscale means in both clusters, two types of quality were defined: surface-level SSMR ($n$=1489; 49.9%) and in-depth SSMR ($n$=1494; 50.1%). Surface-level SSMR, is characterized by the involvement of a rather limited number of students ($M$=4.03), who mainly react to each other’s regulation with paraphrasing comments ($M_{level\ of\ elaboration}$=1.65) and who mainly confirm or only shortly discuss peers’ regulative thinking, aimed at quick consensus-building ($M_{level\ of\ disagreement}$=1.65). In-depth SSMR is characterized by the involvement of a large majority of students ($M$=4.93), who react to each other’s regulation with elaborative comments ($M_{level\ of\ elaboration}$=2.55), and who mainly question and challenge peers’ regulative thinking during SSMR ($M_{level\ of\ disagreement}$=2.98).

The study’s process-oriented scope on time-bound evolutions in SSMR enhances our theoretical understanding of SSMR but also provides instructors with input on when to scaffold SSMR. Acknowledging qualitative variations in SSMR further allows refining current theoretical models, as well as validating the differential impact of SSMR-acts on collaborative learners’ outcomes in future studies.

References


The State of the Field in Computational Thinking Assessment

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Abstract: While interest in computational thinking (CT) education has grown globally in the past decade, there lacks a single unified definition of CT. This can pose significant challenges for researchers, teachers, and policy makers trying to decide which assessment methods are appropriate for their specific CT interventions. Rather than trying to create a single unified definition of CT, this symposium brings together a broad spectrum of leading CT researchers to share what CT means for them, how it influenced their learning designs, and the methods for assessing CT learning. This interactive session will showcase these different views of CT in a single place and serve as a rich opportunity for comparison and discussion.

Introduction

The learning sciences community has shown considerable interest in the role that learning to code should play in preparing students for the 21st century workforce. However, within computing education, there is a growing chorus of researchers, administrators, and policy makers who are advocating for inclusion of a broader set of computational skills, often referred to as computational thinking (Wing, 2006). Still, developing computational thinking curricula and assessing computational thinking learning is a persistent challenge. In part, this is because the broader community does not have a common definition of computational thinking (National Academy of Sciences, 2010). In some cases, definitions of CT focus on key concepts such as abstractions, algorithms, and conditional logic (Grover & Pea, 2013; Brennan & Resnick, 2012). Other definitions have focused on learners' developing their sense of belonging as members of the broader computational community (Erete, Martin & Pinkard, 2017), or feeling empowered to develop solutions to problems in their daily lives (Tissenbaum, et al, 2017), yet others on using CT to engage with powerful ideas in scientific disciplines (Wilensky, Brady & Horn, 2014). This also raises critical questions for researchers, teachers, and administrators about the appropriate methodology for assessing CT learning, given each group’s particular goals.

The current global landscape of computational thinking education offers us an ideal opportunity to bring together leading researchers in the field to critically discuss current approaches for assessing computational thinking. To this end, this symposium brings together a spectrum of learning sciences researchers investigating
CT learning. In particular, the presenters in this symposium will provide detailed examples and insights into 1) what computational thinking means to them and how these varied definitions have informed their research; and 2) the methods and assessments they use to evaluate changes in learners' computational thinking.

Objectives
Together, these contributions aim to provide a single venue for advancing understanding of the range of methods available for assessing changes in computational thinking. These include interactive online assessments (Weintrop et al.); evidence-centered design (Basu et al.); "systems of assessment" (Grover); portfolios (Lui et al.); triangulating data mining and qualitative measures (Tissenbaum et al.); digital ethnographies (Pinkard et al.); incremental problem-solving strategies (Mustafaraj & Sorensen); and utility-based assessments (Temple & Shapiro). While all the contributions will emphasize their assessment approaches, the design and context of each intervention will provide added insight into researchers’ assessment decisions. This symposium will provide opportunities to examine similarities and differences in perspectives on CT, theoretical and methodological frameworks, and pedagogical goals for assessing CT learning.

Session format
To promote active and productive discussion, the symposium will be conducted as an interactive demonstration. Following brief teaser introductions on each project, attendees will be invited to explore stations at which presenters will have posters showing their respective works around computational thinking assessment. This will provide attendees ample opportunities to examine and discuss the methodological decisions made by the presenters, and how they may be adapted for attendees' own designs in a way that traditional talk do not allow. The symposium will close with an open discussion period.

Implications
Given the increased interest in K-12 computing education, this symposium comes at an important time for the learning sciences. Around the world, governments and businesses are realizing the importance of teaching computing to students, which has resulted in a wave of new pedagogical approaches and computing curricula. Despite this growth there have been too few discussions about what the learning is that we are looking for in these interventions, and more importantly how we can reasonably assess if such learning is taking place. This symposium brings together researchers with a diverse set of approaches that tackle this challenge head-on, from a variety of perspectives and with methods that are grounded in real-world contexts. As a result, this symposium provides an important collection of exemplar cases to inform the broader learning sciences community's own research into computational thinking education.

Assessing computational thinking embedded in mathematics and science contexts
David Weintrop, Kemi Jona, Michael Horn, and Uri Wilensky

As we seek to provide opportunities for all learners to engage with computational thinking, we face a number of challenges. Computational thinking, if it is taught explicitly at all, is conventionally embedded in computer science classrooms. This means students at schools that do not offer computer science classes (often due to a lack of resources, infrastructure, or qualified teachers) and learners without access to or interest in computer science courses never learn these important 21st century skills. This situation perpetuates existing inequalities in computing. The strategy we pursue for addressing these challenges is to integrate computational thinking into existing mathematics and science classrooms (Weintrop et al., 2016). Given that all schools teach these subjects and all students are enrolled in these classes, this integrative approach reaches a much greater range of learners (Orton et al., 2016). Further, computational thinking and high school disciplines can be mutually supportive: computational thinking can deepen content learning (Wilensky, Brady, & Horn, 2014) and high school disciplines can offer meaningful contexts for situating computational thinking concepts (Weintrop et al., 2016). Additionally, given the growing role of computing in contemporary mathematics and science, this approach better prepares learners to be scientifically literate citizens. Our conceptualization of computational thinking is based on Weintrop et al.’s (2016) Computational Thinking in Mathematics and Science Practices Taxonomy.

To evaluate students’ emerging computational thinking abilities in math and science classrooms, we developed a series of interactive, online assessments (Weintrop et al., 2014). In the creation of these assessments, we followed two central design principles. First, each assessment is situated in a mathematics or science scenario so as to be authentic with respect to the nature of the computational thinking practices students are being evaluated on while also not being dependent on specific domain content knowledge. For example, our assessments include
Evidence-centered design: A principled approach to creating assessments of computational thinking practices
Satabdi Basu, Daisy Rutstein, Eric Snow, and Linda Shear

Computational thinking (CT) refers to the thought processes involved in expressing solutions as computational steps or algorithms that can be carried out by a computer (Wing, 2006). CT is increasingly being recognized as an essential form of literacy for informed citizens, not just for computer scientists, so that they feel empowered to leverage the power of computation to solve problems in their daily lives. This viewpoint initially motivated a body of research on CT assessments that measure students’ interests in computing and their likelihood of pursuing CS courses in the future (Basu et. al, 2016).

While measuring the extent to which students feel computationally empowered and interested is important, our research on creating CT assessments has focused on designing ways to measure student behavior and thought processes while engaging in CT practices. In creating measures of CT practices, we try to move away from the assessment of factual knowledge about CS concepts, and toward applying the knowledge to solve problems (Snow et al., 2017). Our approach for developing assessments that measure CT focuses less on programming syntax and constructs and more on foundational problem solving skills that transcend disciplines. For example, choosing appropriate representations for problems, modeling relevant aspects (and ignoring irrelevant aspects) of problems to make them tractable, and using different levels of abstraction for problem solving are all examples of CT practices that are useful across disciplines.

We employ a principled approach to systematically produce the required evidence of students’ CT practices. Evidence-Centered Design (ECD) is a systematic design process that improves the coherence of assessments by explicitly linking task features, the evidence of student performances generated by the tasks, and the knowledge and skills implicated by the evidence (Mislevy & Haertel, 2006). The ECD process typically starts with a domain analysis to identify and analyze the domain, constructs, and underlying skills of interest. For domain analysis of CT practices in the context of a specific curriculum, we refer to our CT practice design patterns from prior work (Bienkowski et al., 2015), review the learning objectives and lesson activities specified in the curriculum, and obtain input from the curriculum design team, experienced teachers, and experts in Computer Science, Learning Sciences and assessment design. The results from the domain analysis give us the information we need to specify the focal knowledge, skills and abilities (FKSAs) in the ECD domain modeling phase. While CT practices can be instantiated in different contexts, the knowledge and skills at the curriculum unit level are at a finer grain size and are related to the particular learning objectives of the unit. Along with articulating FKSAs, we also specify characteristic features that the task must contain and features of tasks that can be varied to make new, related tasks. A “task” refers to an authentic scenario with a related set of questions. Additionally, we also create examples of the types of responses students might produce and what quality of their response will be used to score the response. Once the task features are specified, we develop tasks to assess CT practices using these as a guide. We make sure the tasks comprise a mix of programming-construct-independent ones, and ones that are in the context of the programming language used in the curriculum. During our presentation, we will describe how ECD principles were used to design assessment tasks for CT Practices that are being used in a pilot program (CoolThink@JC) for upper primary students in Hong Kong.

Multifaceted views on CT learning through “Systems of Assessment”
Shuchi Grover

“Deeper learning” (Pellegrino and Hilton, 2012), seen as an imperative for helping students develop robust, transferable knowledge and skills for the 21st century, acknowledges the cognitive, intrapersonal, and
interpersonal dimensions of learning. Barron and Darling-Hammond (2008) contend that robust assessments for meaningful learning must include: (1) intellectually ambitious performance assessments that require application of desired concepts and skills in disciplined ways; (2) rubrics that define what constitutes good work; and (3) frequent formative assessments to guide feedback to students and teachers’ instructional decisions. Conley and Darling-Hammond (2013) assert that in addition to assessments that measure key subject matter concepts, assessments for deeper learning must measure both higher-order cognitive skills and abilities such as complex problem solving, planning, reflection, collaboration, and communication. These assertions imply the need for multiple measures or “systems of assessment” for CT (Grover, 2017) that are complementary, encourage and reflect deeper learning, and contribute to a comprehensive picture of student learning.

This presentation describes the systems of assessment for assessing algorithmic thinking and CT skills designed for an introductory computer science course for middle school students. These include open-ended and directed programming assignments with accompanying rubrics, innovative programming exercises inspired by Parson’s puzzles (Denny et al., 2008), low-stakes quizzes for formative assessment (targeting individual concepts and constructs) with auto-grading and feedback, a summative assessment with MC and open-response items, final project of students’ choosing, final project presentation to the whole class along with individual written student reflections and a shared “studio” of students’ final projects, “artifact-based interviews” (Barron et al., 2002) around their final projects, and open-ended responses to questions related to identity and interest.

This presentation also follows on work that represents a refinement of how we can design programming tasks specifically aimed at measuring CT Practices or CT (Grover, Basu, & Bienkowski, 2017). For this we are guided by assessment design patterns of CTP as mapped out by Bienkowski, et al. (2015) that employ Evidence-Centered Design (ECD; Mislevy & Haertel, 2006), a principled framework for assessment design. In particular, we designed assessment tasks to elicit evidence about the specific CTP such as (but not limited to), the ability to— use predefined methods to achieve a goal, create a generalized solution to a problem (as opposed to hard coding to meet a very specific case), identify the appropriate place in code to modify given a new specification, design an abstraction to represent a problem or solution, implement testing and debugging methods to test and fix a computational solution, use programming constructs including conditionals, Boolean logic expressions, loops, parallel execution in algorithmic instructions. We will describe the design of two such tasks and findings from our empirical studies involving their use in three high school classrooms using the Exploring CS curriculum.

Assessing youth’s computational thinking in the context of modeling and simulation
Irene Lee and Eric Klopfer

Dave Moursund (2009) suggests that “the underlying idea in computational thinking is developing models and simulations of problems that one is trying to study and solve.” At the MIT Scheller Teacher Education program we examine how these ways of thinking take shape for middle school youth specifically in the context of modeling and simulation. The terms of abstraction, automation, and analysis (Cuny, Snyder, and Wing, 2010) are useful for understanding how youth approach novel problems using Computational Thinking (CT) in modeling and simulation. While we adopt these principles, we adapt them to this context. Abstraction is “the process of generalizing from specific instances.” In modeling and simulation abstraction is a necessary process for working from a specific example to building a more general model. Automation is a labor saving process in which a computer is instructed to execute a set of repetitive tasks quickly and efficiently compared to the processing power of a human. In this light, computer programs are “automations of abstractions.” In modeling and simulation this takes the form of being able to rapidly run many iterations of a model. Analysis is a reflective practice that refers to the validation of whether the abstractions made were correct. In modeling and simulation one needs to think about how to collect and analyze the data that comes out and what are the right comparisons from real data to make against the data.

This paper aims to contribute to the discussion and development of tools used to assess youth’s computational thinking by sharing methods including an exploratory method used in Project GUTS: Growing Up Thinking Scientifically. We present a method to assess near transference of computational thinking as an approach to problem investigation and problem-solving when faced with a new scenario.

Supporting metacognitive awareness of the process of making: Portfolio assessment in high school e-textiles classrooms
Debora Lui, Gayithri Jayathirta, Mia Shaw, Yasmin B. Kafai, and Deborah A. Fields

In recent years, the Maker Movement has drawn much attention from educators and policy makers because of its potential for rich learning in solving problems that arise throughout the process of digital fabrication. Yet assessing
learning in making has proven a challenge, in part because student creations are inherently personal and distinct. Researchers have taken several different directions to assess student learning in making, each with affordances and limitations. Content tests and surveys allow documentation of learning or interest development across multiple classrooms (Tofel-Grehl et al., 2017) but tend to limit what counts as learning to standards-based content, discounting the ongoing processes of learning. In contrast, case studies of student design processes and clinical interviews (e.g., Lee & Fields, 2017) show depth of learning and students’ uptake of process-based practices but are time-consuming and limit student agency in shaping their own narratives of learning.

Here we share our initial efforts to develop assessments authentic to the context of making e-textiles but scalable to multiple classrooms. In 2017, we piloted an eight-week curriculum where students created e-textiles (programmable circuits sewn with conductive thread) as part of the year-long Exploring Computer Science course. The unit included a final portfolio assignment where students reflected on and presented their own learning. The portfolio assignment served two main goals: 1) study student learning in a manner authentic to the creative making process, 2) support students’ metacognitive awareness as a type of equity-based learning (Darling-Hammond, 2008). Portfolios included three elements: a video summarizing how the final project worked, a reflection on a challenge or revision in making the final project, and a reflection on learning in the e-textiles unit as a whole.

Three teachers from diverse schools in an urban center of California piloted the unit. Data consisted of four types: portfolio collection, interviews with select student focus groups, interviews with teachers reflecting on the portfolios, and observation of two portfolio-creation days in each classroom.

Our analysis revealed the types of problems students identified in their portfolios as well students’ reflections on their own learning. We identified the degree to which students were explicit (versus generic) in discussing the problems they faced. Further, students’ reflections on creating the portfolios revealed a new cognizance of their own learning process, pointing to the potential for the portfolios to support metacognitive awareness, though this was not universally present. Finally, teachers’ reflections demonstrated different interpretations of the value of portfolios for students’ learning and as a classroom tool to assess their learning. In the full presentation we consider the utility of the portfolio assignment to students, teachers, and researchers as well as the potential of this type of process-based portfolio to other types of making scenarios.

**Combining data mining and qualitative analysis to reveal learners' computational practices in open-ended student-driven curricula**

Mike Tissenbaum, Mark Sherman, and Josh Sheldon

There is increasing advocacy for the need to emphasize the processes of learning and creating in addition to final products (Vossughi et al., 2013). This is particularly true in computing education, as learners’ growth as computational thinkers often occurs during the processes of thinking and designing. The environments in which learners write their code offer a unique opportunity for understanding the processes, as many can capture traces of student program development through their incremental edit operations.

Learning analytics and data mining have been shown as fruitful for unpacking this progression, providing insight into computational thinking education and problem-solving approaches (Berland et al., 2013). While learning analytics and data mining can help reveal these patterns in student learning, they cannot detect what is happening "above the screen", meaning that inferences drawn can miss many of the important causes of these patterns. On the other hand, qualitative approaches have been successful in revealing nuanced computational thinking patterns that learners engage in "off of the screen,” particularly in collaborative settings (Bienkowski et al., 2015; Grover & Pea, 2013). Yet, these approaches can require intensive labor and may miss commonalities in student programming. In particular, they cannot capture differences in “off of the screen” enactment patterns.

Such differences could help us to understand the variations between groups of learners.

This paper offers an approach that combines these two methods for assessing learners’ computational thinking practices in open-ended learner-driven computing curricula. We looked at a group of 23 youth (ages 15-19) engaged in a 5-week summer camp to build solutions that solved personally relevant problems using MIT App Inventor (a blocks-based programming environment for building fully-functional mobile apps). Using two data mining approaches- block selection mining and moments of flailing (Sherman, 2017), we highlighted moments in the learners’ app building for analysis to understand their computational thinking practices. We then applied a coding scheme derived from the computational thinking practices framework developed by Bienkowski et al. (2015) to analyze discourse among group members. Using this analysis, we can discuss the affordances of blending learning analytics with qualitative coding. This helps us understand the nuanced ways students engage in collaborative computational thinking during open-ended projects.
Valuing and revealing networks of engagement around computational making
Nichole Pinkard, Caitlin K. Martin, and Sheena Erete

Multidimensional views of computational thinking (e.g. diSessa, 2001) that pay attention to the larger learning ecology (Barron, 2006) and social networks are especially relevant to encouraging and supporting participation from underrepresented groups, such as women and non-dominant populations. Repeated studies have found that pervasiveness of social orientations, including negative stereotypes about girls and non-dominant students’ STEM abilities and interests and a lack of sense of community and belonging within STEM classrooms and fields (e.g. Margolis & Fisher, 2002) impact interest, engagement, and ultimately participation.

In this presentation, we share strategies for assessing computational thinking within Digital Youth Divas, an out-of-school program for middle school girls designed to build and support a social ecosystem of computational making in communities that have been underrepresented in engineering and computing fields.

There is a growing understanding that supplementing traditional approaches to STEM assessment with socially-grounded strategies is critical, especially to better understand and design for unique populations of learners. These strategies include biographical and narrative approaches as well as social network representations. In addition to traditional pre-post knowledge measures, we look deeply into the two environments girls inhabit in the program, across different levels of analysis. In the online space, where girls access activities, submit work, and give and receive feedback, we conduct digital ethnographies to qualitatively document online activity and interactions to better understand social learning analytics of platform user trace log data representing all girls in the program. In the face-to-face space, where they work through projects together, we document a focal classroom through field notes and photographs and engage in artifact-based reflection interviews with individuals in that classroom using projects as shared references to discuss work process, connections to people or practice in and out of the program, and plans for learning more.

Our findings indicate that girls connected aspects of their computational projects with people in their networks at home and school, and shared, designed for, and taught peers, siblings, and younger members of their community. These moves engaged family members in the computational activities the girls worked on, playing roles of audience, learners, and collaborators. This internal advocacy could serve to broaden participation in communities as these young girls from underrepresented populations take on the role of visible computational makers in their personal networks.

A case study of observing and identifying computational thinking practices in the wild
Eni Mustafaraj and Clara Sorensen

Many researchers have proposed computational thinking frameworks composed of different components. One such example is that of (Brennan & Resnick, 2012), who identify concepts, practices, and perspectives as possible components. How these components interact with one-another is an area of active research, but one credible hypothesis is that learners are engaged simultaneously in a kind of feedback loop that encompasses all these components. Concretely, when they are learning about specific concepts, such as expressions and statements, they are also learning about the practices of testing and debugging.

Given that this is a continuous feedback loop that leads to deeper understanding of concepts and practices, it is important to study the learning trajectories as students move from one level of understanding to another. One would typically expect that middle school students who are learning how to solve problems through computation are at a very different level of understanding than college students who have completed two programming courses. But college students are also still learning, and although they know how to program, they struggle considerably when asked to solve real-world problems through computation. These struggles point to gaps in their computational thinking, which need to be exposed and recognized, in order for them to deepen their understanding. Our research interest is in studying whether we can observe and capture “in-the-wild” gaps in computational thinking of advanced learners, so that such gaps can be made explicit to learners. With “in-the-wild”, we mean the everyday learning process that happens in the classes that students take.

This presentation will discuss findings from studying the learning of college students in a data science class. Data science, with its current focus on large amounts of automatically captured data, provides a rich context for observing computational thinking in practice, because it offers a wide range of problems that are new and challenging, but also meaningful to explore, something that motivates learners. For example, one of the datasets used in the course were the personal email inboxes of students (each student analyzed her own inbox). When dealing with this dataset, students were motivated by the curiosity about what it can reveal about their habits (e.g., am I contacting my professors more from one year to the other?), but also by the potential for changing their habits (can I build a model that it will predict the rate of incoming emails, so that I don’t constantly check my email).
Finding answers to these questions is not trivial. Students have to learn new libraries to become efficient in data analysis, and because there is no given algorithms for each problem, they need to be creative, work incrementally, and iterate often, all practices inherent to computational thinking. The computing environment that they were using, the Jupyter notebooks, allowed us to capture automatically and without any instrumentation cost, practices of incremental and iterative problem solving. A quantitative analysis of the notebooks from their class projects revealed two distinct patterns of learners: “explorers” versus “goal accomplishers”.

Computational rethinking – Applying CT in new contexts
Will Temple and R. Benjamin Shapiro

The emergent computational landscape is inhabited by large-scale communications systems that students interact with \textit{constantly}. In response, we need how new paradigms for Computer Science that expose networked communications technologies to students as platforms for play, exploration, and learning. Within these new systems, basic assumptions about what’s important for beginning students to learn (e.g. loops in Brennan & Resnick, 2012) diverge from the platforms of yesterday. Our own BlockyTalky project shows that students, even at a young age, reason competently about networked systems when provided appropriate abstractions (Shapiro et al., 2017). Online systems such as MIT App Inventor empower many students—even those with minimal experience—to create complex mobile technologies that enhance their lives and communities.

In an interdisciplinary context full of new notions about which computational ideas are the most powerful, \textit{how will we know if our students are learning CS?}\ When we apply CT to other disciplines, we ought to orient our assessments towards the application domain, as conventional ideas about the necessity of particular concepts in fundamental CS may not suit the modern, diverse applications of CT. For example, our BlockyTalky WeJam music toolkit does not include generic looping constructs, since they are not generally useful in the design of distributed computer-music. An assessment in that context might examine how students create different topologies of networked systems and then use computational constructs such as message passing to explore the computer-music domain, to synchronize rhythms and melodies, and to support real-time control over musical parameters through tangible interfaces. In other words, we expect students to reason in the application domain using whatever computational constructs serve them.

The application of CT to music, as suggested above, affords an opportunity to assess the way that students model and implement musical phenomena in terms of computational processes. Using our BlockyTalky toolkit, students design musical compositions as a system of networked instruments. In this environment, we can assess students’ uses of computational models and ability to design effective synchronization strategies by analyzing their output: a musical composition. Our toolkit deliberately requires students to organize their music into a networked system, allowing us to observe properties of the resulting music (do the notes play in the desired order or tempo, and at the same time?) and thereby learn about how our students built an understanding that utilizes the underlying CS as a model for their creation. By redefining our assessments of CT to emphasize utility to the application domain, we will empower students to construct the CT skills that are relevant to their creative goals.

References


Community-Based Design Partnerships:
Examples from a New Generation of CHAT/DBR

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Abstract:
There has been great interest recently, across research communities, in the intersection of formative interventionist methodologies (originating in cultural-historical activity theory, or CHAT) and design-based research (originating in the learning sciences). A recent special issue of the Journal of the Learning Sciences was dedicated to exploring “CHAT/DBR” from multiple perspectives (Penuel, Cole & O’Neill, 2016). Beyond the similarities and differences between these methodologies, this scholarship also imagines new possibilities and orientations drawing on the two traditions – new roles for researchers and collaborators, alternative “argumentative grammars” (Kelly, 2004) underlying these approaches, and even new conceptions of learning itself. This symposium highlights the work of emerging scholars whose research employs variations of CHAT-inspired DBR in collaborative, community-grounded work oriented toward social change. The session offers innovative perspectives on how we conceptualize learning; rethinking design in our methods; what constitutes a learning environment; and rethinking relationships among researchers, partners, learners and interventions.

Focus of the symposium
There has been great interest recently in the intersection of formative interventionist methodologies (originating in cultural-historical activity theory, or CHAT) and design-based research (originating in the learning sciences). A recent special issue of the Journal of the Learning Sciences was dedicated to exploring “CHAT/DBR” from multiple perspectives (Penuel, Cole & O’Neill, 2016). Beyond the similarities and differences between methodologies, this scholarship also imagines new possibilities and orientations drawing on the two traditions – new roles for researchers and collaborators, alternative “argumentative grammars” (Kelly, 2004) underlying these approaches, and even new conceptions of learning itself.

The JLS special issue offered case studies of CHAT-DBR projects that, while diverse in methods and theoretical framing, suggested a set of “family resemblances.” For one thing, the learning environments tend to be removed from the familiar learning-sciences context of the classroom. In the words of Cole & Packer (2016), “although the learning sciences may have escaped from the laboratory, it has not escaped very far. Rather, it has escaped to the school classroom, a (very) artificial setting that gave shape to laboratory procedures in the first place” (Cole & Packer, 2016, p. 505). By contrast, the CHAT/DBR cases in the special issue moved notably farther from the “container” of the classroom (Leander, Phillips & Taylor, 2010), out to urban gardens, flooding favelas, programs for migrant youth, and other complex and evolving contexts. With this “escape” came more diverse conceptualizations of learning itself, decoupled from the strictures of curriculum and assessments.

Also, as noted in the introduction to the special issue, another common feature of CHAT/DBR work is “a concern with praxis, or practical human activity to transform the world” (Penuel et al, 2016, p. 490). While DBR has always had an intent to effect change in real-world learning environments (Brown, 1992), the concept
of praxis moves further from a linear model of (for example) researchers effecting change in teachers’ and students’ environments. Instead, it is concerned with the ways learners identify contradictions between the realities of their lives and the imagined futures they desire (Freire, 1970); collaborative design becomes a means of internal transformation of the activity system that has both theoretical and practical implications (Gutierrez & Vossoughi, 2010). Rather than assume that transformation must be positive or “successful” in obtaining predetermined outcomes (cf. O’Neill, 2016), this stance offers lenses for examining the ways tensions and contradictions in activity systems evolve with change, potentially both transforming and reproducing issues of equity/inequity and agency/oppression.

These features of CHAT/DBR projects – engagement with more diverse learning environments, and a focus on praxis or expansive learning – point to some fundamental theoretical and methodological shifts that were evident in the case studies and the commentaries in the JLS special issue, and extend through the papers in this symposium. We use the symposium to explore a handful of these issues more deeply, through the lenses of emerging scholars whose research employs variations of CHAT-inspired DBR in collaborative, community-grounded work oriented toward social change.

By highlighting the work of junior scholars, the symposium provides a window on directions this work is moving in the learning sciences community. The Discussant role in this symposium will be played by an intergenerational pair of scholars with intimate knowledge of these research traditions: Drs. Susan Jurow and Rogers Hall. The discussion will be in the form of a conversation about the ways these papers advance the exploration of CHAT/DBR in the learning sciences; trends that are visible in the work of these emerging scholars; and challenges for the LS community in moving this line of research forward.

Major issues illustrated by the collective work
The issues arising from the JLS special issue that organize this symposium are:

1. Re-conceptualizing research-design partnerships – who designs, who researches, who learns
2. Re-examining the research endeavor itself, including the life cycles of research projects and designs
3. Studying learning processes at different scales of time, space, social organization, and units of analysis
4. Historicizing learning processes and design work
5. Embracing power struggles as central to learning and research

In this section we review some of the key implications of each of these interconnected issues, and preview how they are illuminated in the papers in the symposium. Descriptions of the individual presentations follow.

Re-conceptualizing research-design partnerships
In the studies shared in this symposium, the term “participants” refers to a collective whole that includes community members, organizational representatives, educators and researchers (including those who engage in multiple capacities, e.g. participant action researcher). Community residents and others are not differentiated in their capacity to enact change in their communities, while researchers are not positioned as external entities coming to a community to provide answers or solutions. Key defining features of these projects are the way collaboration is structured, the way divisions of labor are negotiated, and the way designs for learning are co-created. This is the central focus of the paper by Meléndez & Radinsky, and is addressed in different ways in each of the papers.

This process of co-design and co-research inevitably surfaces tensions and contradictions. The exercise of agency by one partner can elicit push-back or resistance from another. The insights afforded by CHAT/DBR include revelation of underlying relationships of power, and opportunities to re-mediate these relationships (#5 below). Importantly, the division of labor – who designs, who constructs goals – is explicitly negotiated, as part of the design itself. This is a focus of the paper by Phillips et al, through the lens of “mutual appropriation.” The assumption is that hierarchies of power and agency are to be confronted and negotiated, with a focus on the needs, histories, and possible futures of members of historically disenfranchised communities.

Re-examining the research endeavor itself
This focus on collaborative design and shared ownership of the three key aspects of any DBR project – research, design, and learning – upsets some of the traditional underpinnings of university-based research projects. For example, grant cycles, generally channeled through a university (with indirect costs accruing to the university partner), lock into place a number of constraints on collaborations that tend to disempower partners outside the university. Processes of expansive learning and iterative co-design may take many years to evolve, and so may not fit neatly into these funding cycles, as is the case for the design circles discussed by Marin, Bang & Nolan.
The nature of academic publications and conferences can reinforce assumptions that the important intellectual work of the project resides with academics, undervaluing the contributions of community partners. The assumption that published research should reflect “successful interventions” can distort the narratives that are produced from a project (O’Neill, 2016).

Each of the projects here struggles to re-mediate and reconfigure these assumptions and norms of research. The languages of CHAT and DBR offer different affordances for constructing practices that afford longer-term and more equitable collaborations around research and design. The projects seek to identify the longer histories and trajectories of each of the learning environments engaged in the partnership, beyond an individual design that may emerge within a given project -- an explicit focus of Vossoughi’s “sister-spaces,” which evolve from project to project, extending the life cycle of particular concepts, ethical groundings and analytic foci. Each paper in the symposium reveals the ways multiple voices are brought to bear, and the ways the structures of the partnership mediate these negotiations.

**Studying learning processes at different scales**

As noted above, researchers have highlighted the need for analytical approaches that take into account different scales of time to study learning in practice (e.g., Engeström, 2011; Lemke, 2000; Sannino et al., 2016). These researchers have made the argument for longer scales of time in studying learning in analytical units beyond the individual – collective- and system-level learning that opens up new possibilities of what the learning processes themselves can be. Supra-individual units of analysis are found in each of the papers here.

As the learning sciences branch out into more naturalistic and less formalized settings, some of the distinctions between teaching and learning break apart. In these settings, the collaborative design process includes a negotiation of what is to be learned -- a conceptualization that can shift during the life of a project, across cycles of design and analysis. Participants from different communities bring different assumptions about learning, such that initial intentions and goals are subject to change: “[t]hese intentions … are seen as only the starting point, which a truly expansive learning process typically confronts and deviates from if the learners are to produce their own collective designs”, with their own learning goals (Sannino, et al, pg. 3).

This “deviation,” as learners collectively come to new awareness, facilitates participants’ agentic engagement in activity, producing collective-level learning (Roth & Lee, 2007). Changes to practices are conceived of as learning processes, entailing an “expansion in the object or subject … of activity” (Greeno & Engeström, 2014, p. 5). Rather than documenting the attainment of pre-existing objectives, “[e]xpansive learning is a creative type of learning in which learners join their forces to literally create something novel, essentially learning something that does not yet exist” (Sannino et al., 2016, p. 5). These processes are seen in symposium papers by Meléndez & Radinsky (as system-level learning), Vossoughi (as evolving subject-subject relations), and Phillips et al (as learning on the move).

**Historicizing learning processes and design work**

The papers in this symposium, in different ways, attempt to meet the challenge of more deeply historicizing the learning processes and designs at the heart of each project. One way in which this is accomplished is in attending to learning phenomena not just as present-day challenges, but as grounded in longer-term historical processes: settler-colonial epistemologies and work to desettle those conceptions (Marin, Bang & Nolan); movements for critical literacies and political education (Vossoughi); and participatory budgeting as a movement for democratic empowerment (Meléndez & Radinsky).

Another aspect of historicizing this work is in extending (and attending to) the histories of the design processes themselves. Longer term engagements with co-designers require “a degree of knowledge and legitimacy” among the partners (O’Neill, 2016, p. 499) that is beyond what has often been the norm in learning sciences work in the past. Shared histories of collaborators plays a key role in establishing deep levels of trust, reciprocity, and local knowledge of practices and context (Penuel, Cole & O’Neill, 2016). In these more extended histories of co-design, learning scientists, along with other participants, engage in “joint learning activity to identify and refine the goals of the intervention and make visible the historical dimensions of a community’s practices” (Guttierez & Jurow, 2016, p. 5).

As such, the emphasis is on how participants engage with history not as disjointed events of the past, but as “resources and understandings of the past into the future” which support new forms of learning, agency, and imagined possibilities (Guttierez & Jurow, 2016, p. 7). This involves attending to complex relationships among present, past and future. In Vossoughi’s paper, a critical lens is brought to the analysis of histories to provide structural critiques of normative hierarchies of power and imagined possible futures, while taking a prefigurative stance that attends to consequential impacts in the here and now (Bang & Vossoughi, 2016).
Meléndez & Radinsky’s paper, learning outcomes include a hybrid space where political imaginaries of the future emerge alongside critical reflections on the past.

**Embracing power struggles as central to learning and research**

Research incorporating the political realm is a relatively new focus for the learning sciences (Radinsky & Tabak, 2017). The Politics of Learning Writing Collective calls for more explicitly political theorizations of learning (Philip et al, 2017), to “address the powered and politicized contexts and consequences of learning in ways that make it possible for children, families, and communities to create thriving, self determined lives” (p.4). There is a need for research not only that attends to power as an abstract term, but more importantly, that shows how it manifests itself in practice, in relationship to learning. The papers in this symposium document a variety of contexts where questions of “diversity, inequality, conflict, complementarity, cooperation, and differences of power and knowledge are socially produced, reproduced and transformed” (Lave, 1988, p. 10).

The papers in this symposium study designs from the perspective of how they engage power relations, including ways that they perpetuate or transform these relations. The papers dialogue with the concept of historical agency (Gutierrez & Jurow, 2010), illustrating the ways in which agency is at the heart of designing learning environments where equity and social justice are front and center (Philip et al, 2017). Recognizing the power relationships inherent in the practices of research, the papers in this symposium use CHAT-DBR to trouble those relationships, aiming to re-mediate hierarchies of epistemology and pedagogy.

One way to operationalize power is through identifying tensions and contradictions in the activity for which we design. “Historically formed contradictions” (Sannino et al, 2016) necessitate historical analysis of these tensions. Yet, even when tensions and contradictions are resolved, if we take an activity system to be an evolving and complex unit, new crystallizations of practices and innovative pathways of participation should be expected to yield new tensions and contradictions in future design cycles. The papers in this symposium all cast a different light on contradictions that emerge and evolve over the course of collaborative design partnerships.

**From stunted limitations to awakened imaginaries: Expansive learning among Latino immigrant participants in participatory budgeting**

José W. Meléndez and Josh Radinsky

The authors provide a three-year case study of the Participatory Budgeting Process in the 49th ward of Chicago. Since the 1970s, local demands for more direct and meaningful participation in government processes that have direct impact on communities and individuals’ lives have been growing. The communicative turn in participatory planning (Habermas, 1996) and the rise of social movements pushing for re-definitions of citizenship identity (Dagnino, 2003; Ellison, 1997; Flores, 2003) have resulted in a growing number of participatory, deliberative, democratic processes. The focus of this paper is one example of this movement, called participatory budgeting, originating in Brazil and studied here in Chicago’s 49th Ward (PB49), the first ever PB process in the U.S. Processes such as PB49, which can have meaningful impact in communities, often are not representative of all constituents who are impacted by the decisions, either in participation levels or in who is at the decision making table. This study examined three iterations (which we positioned as designed) of the PB49 process to investigate contradictions in how democratic practices (both direct and representational) played out in situ for a historically under-represented community: Latino immigrants.

Using a CHAT/DBR approach, the study revealed expansive learning related to civic engagement, and the development of civic capacities. As a case of praxis, the enactment of (and reflections on) designed innovations to PB49 over three years led to changes in the structures of participation, as well as new political imaginaries of future possible selves for members of the ward’s predominant-Spanish speaking Latino immigrant community. These expansive learning processes were documented at the collective and systems levels: at the collective level participants demonstrated qualitative changes in their agency, both over their involvement with the PB49 process but also over the designed interventions that were being created in the name of; for, and by participants. Evidence of collective learning also included figuring out how the city bureaucracy works; conceptualizations of the needs of the Latino immigrant community; and emergent political imaginaries.

At the system level of learning, this was noticed through changes in practices (new language and tools), activity structures, and greater incorporation of new participants - not just in numbers, but also in a change in the object of activity. Three distinct system level learning findings were: the inability to support predominant Latino immigrants participants involvement in the first iteration; the expansion of the object of activity in the second iteration, resulting in the creation of new activity structures; and the eligibility of predominant Latino immigrants participants to join the leadership committee. With the push to expand participatory processes, this
CHAT-inspired community-based design research partnership is an example of how a democratic process itself is up for re-designing for social justice and equity learning environment.

Sister-spaces: Participatory design research as a tool for studying learning as collective, historical and prefigurative activity
Shirin Vossoughi

Participatory Design Research (PDR) refers to a family of interventionist methodologies that include formative interventions (Engeström, 2011), Social Design Experiments (Gutiérrez & Vossoughi, 2010), and Community Based Design Research (Bang, Medin, Washinawatok, & Chapman, 2010). Methodologically and conceptually, PDR works to interweave structural critiques of normative hierarchies of power with imagined possible futures, taking a proleptic or prefigurative stance that attends to consequential impacts in the here and now (Bang & Vossoughi, 2016). This paper aims to further theorize the collective, historical, and prefigurative dimensions of learning within PDR through an analysis of sister-spaces.

Sister-spaces are educational contexts separated by physical space and/or historical era that embody parallel values (Espinoza, Vossoughi & Rose, Under Review). Sister-spaces can also be thought of as the settings that grow from settings, often through individuals who experience possible forms of activity and then draw from that experience as a resource for design within a distinct context (what Zavala [2016] refers to as the repetitions of practice across space that embody developmentally new activity).

The sister-spaces that form the primary objects of analysis in this paper include: a summer academic program for high school-aged migrant students (The Migrant Student Leadership Institute, or MSLI), which understood itself as a student of historical models of political education and critical literacy, and two recent cases in which core principles from MSLI served as guides in the development and study of an after-school tinkering setting and a summer bridge program. Information sources include key design documents, participant reflections, and ethnographic and interactional analysis of teaching and learning across the three settings.

Findings elucidate the three dimensions—collective, historical and prefigurative—introduced above. One way of conceptualizing collective learning within DBR/CHAT projects is to move beyond individual views of subject-object relations to treat the community or collective itself as the subject who designs, iterates and studies a given setting. Recent work on PDR has also argued for foregrounding subject-subject relations as a domain of learning in itself (Bang & Vossoughi, 2016). Building from these perspectives, I consider how relations across activity systems may constitute a distinct realm of learning and resource for pedagogy and design. As Gutiérrez and Arzubiaga (2012) argue, “the relations among and contradictions that exist between activity systems are central to the analysis of human activity” (p. 205). Studies of multiple activity systems often consider how people move and participate across distinct settings (home and school, for example), or analyze object-oriented activity across two or more settings to develop more adequately complex views of human activity, and to identify transformative potentialities.

Taking a slightly different lens, I foreground the dimension of time, and consider what it means to treat particular settings as learners in relation to other settings, be they present or past. This historical dimension of learning raises new questions: how is learning mediated across time and space? If settings can be learners and teachers, what kinds of collective zones of proximal development might emerge between and across activity systems? How might attention to longer time-scales productively shift how we define the “outcomes” or “fruits” of learning? What role does memory play in the ways individuals and collectives draw from past experiences to design present and future activity? Lastly, prefiguration refers to forms of social change-making activity that seek to enact or inhabit the kind of future they are working to bring into being, to express the political ends of their actions through their means (Yates, 2015). To better understand the prefigurative qualities of designed sister-spaces, I argue that we need views of present activity that account for historical traces (echoes of principles and practices in other times and places), and views of activity systems past that attune us to the ways they sowed seeds for future action and possibility.

Community based place designing: Innovations in design practices for expansive science education
Ananda Marin, Megan Bang, and Charlene Nolan

The socio-ecological challenges of the 21st century will mark an important time in the evolution, adaptation, and reimagining of human communities and our relations with more-than-human life and the natural world - what we call nature-culture relations. Developing forms of education that prepare children to engage in problem solving that also cultivate decolonial social and ecological justice is critical. In our work, we have engaged and

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explored the heterogeneity of human-nature relations that structure forms of learning with young people, their families, and communities as the central object of inquiry in the design and implementation of learning. Increasingly scholars are studying the ways in which constructions of relations between humans and the natural world shape cultural practices and impact knowledge, reasoning, and learning about, in, and with the natural world in cultural ecologies (e.g. Bang, 2015; Medin & Bang, 2014; see also: Lee, 2008; Rogoff; 2003). We have focused on the relational construals between natural and human worlds, and have broadly referred to this orientation as relational epistemologies. We suggest that observing and creating human-nature relations (e.g. relations with land, water and more-than-human life) is a routine, though deeply under-explored, part of human learning and activity that impacts what is learned, how learning happens, and why it is consequential.

In this paper we present findings focused on designing early science learning environments for Indigenous children and their families. This study is part of an iterative community based design project which involved community members, researchers, and graduate students to design and implement land-based early science learning programs that facilitate and support Indigenous ways of knowing and western science. Land-based science education refers to science learning that is designed in places with critical historicity, engages Indigenous ways of knowing and responds to the affordances of such places. The program was committed to employing and reinforcing relational epistemologies (Bang & Marin, 2015; Bang & Medin, 2010). A foundational activity in the program was remaking plant and animal relatives, by which we mean youth learned about culturally salient plant and animals as well as the cultural practices, histories and stories about them.

The data for this study included 12 design meetings and 24 implementations in which community members and scholars came together to design early science learning environments which we called “Little Ones.” Each of the design sessions and implementation were audio and video recorded. Field notes were taken as well and facilitator debrief meetings were audio recorded as well. This data was content logged and thematic analyzed across all data sets. Drawing from this broader analysis this paper focuses in on how design practices evolved over the course of the project and how it expanded core understandings of culture, learning, and teaching practices across the practice.

Overall we find that designers developed Indigenous pedagogies of walking, reading, and storying land (Cajete, 2000; Kawagley, 2006) through what we call place designing practices. Walking, reading, and storying land was comprised of at least three dimensions: coordinating attention and observation, generating explanations and finding evidence, and creating a story about the perceptual field. Importantly, these dimensions are all assembled through the layering of discursive, embodied, and ambulatory micro-practices (questions and directives, pointing gestures, shifts in movement) that involve a kind of onto-epistemological navigation where participants weave their way through emergent understandings of local phenomena. In this paper we trace how these pedagogical foci came to be and how design practices took shape as this pedagogical vision solidified. For example, we trace the evolution of design practices that began inside buildings in which the content and practice of learning was talked “about” to a shift in which designers and teachers engaged in place designing in which they were both engaged in the learning activities they were planning with young people and their families as they were planning – what we call withness planning (see Shotter, 2012). Importantly we trace how critical decolonial reflections on meanings of culture, learning, and land led to innovative design practices and ultimately learning and teaching practices. These practices enabled transformative learning and ecological systems in ways that were culturally robust. We draw implications from this work for how place based designing practices made new semiotic landscapes (e.g. Goodwin, 2013) and specifically geo-semiotic (Scollon & Scollon, 2003) landscapes, available to educators in ways that expanded opportunities for learning and could be utilized across other teaching and learning contexts. Further we draw implications about how the innovating design practices may be a critical site of innovation to create more equitable and just learning opportunities.

Migrations, persistence, and mutual appropriation: Research/practice on the move

We report on an ongoing research-practice partnership among university-based researchers and community partners from museums and cultural institutions in Chicago. We draw on ethnographically-documented shared experiences researchers and community partners have had over four years as we have worked to develop and distribute tools for documenting, assessing, and reflecting on “learning on the move” (Taylor, 2017). We continue to design and iterate tools/activities intended to be easily implemented by both novice and experienced educators to guide program participants, educators, and staff in educational settings (e.g., zoos, schools, museums, after-school programs) in identifying their own learning on the move, reflecting on that learning, and
considering implications and intersections of learning taking place everyday across people’s lives with learning from/in formalized settings.

Our approach to partnership and collective design and iteration is one of “mutual appropriation” (Downing-Wilson, Lecusay, & Cole, 2011), in which concepts, curricular materials, and activities take root within the communities of our partnership but also within organizations outside of our partnership as we share and distribute them. We view our partnership as both focused on better understanding and reflecting on teaching and learning “on the move” but also recognizing that, simultaneously, the objects, structures, curricula, and concepts created by/in the partnership are also mobile. The movements of initial innovations can be described as “migrating and persisting over time, but participants appropriate these ideas and concepts, reshaping and deploying them in unpredictable ways through personal interpretation and experience” (Downing-Wilson et al., 2011, p. 658; emphasis original). We view this as productive and healthy mutual appropriation, as all participants “are doing their best to achieve the common goals that anchor [our] continued interactions, while staying focused on [our] individual activities, which may or may not mesh perfectly with those of the other participants” (Downing-Wilson et al., 2011, pp. 658-659).

In this paper, we explore intersections of CHAT and DBR in the context of this particular research-practice partnership, highlighting voices from across our partnership. We approach this analysis of distributed means and meaning making through the lens of transliteracies (Stornaiuolo, Smith, & Phillips, 2017) to observe and account for the ways that research-practice partnerships construct meaning and practice that migrates, persists, and is mutually appropriated at various scales of (time, participation, organizational structure) and along (sometimes) intersecting trajectories with participants and practitioners.

Our findings include the following: With respect to migration, conceptual movement is central to the project’s goals, but we have found that migratory pathways, destinations, and adaptations are challenging to track especially as generations of sharing spreads. With respect to persistence, we have found that some ideas, concepts, and activities do persist across scales of time and space. As some ideas migrate and assimilate to new contexts, other ideas retain their character as they are taken up by new participants in new places for new purposes. In our partnership, we have been purposeful about attending to persistence, consistently (re)calibrating around our emerging understandings of learning on the move. With respect to mutual appropriation, we have found that sharing our appropriations openly with each other has led to succeeding cycles of appropriation. We have found that openness around mutual appropriation does not mitigate frustration, disarticulations, and questions around commitments to persistence amidst migration but rather that openness allows us to better understand each other’s’ positions, commitments, and values with respect to key concepts in ongoing iterations and cycles of conceptual production and meaning making.

Significance of the contributions

The papers in this symposium offer a coordinated attempt to move the conversation about CHAT/DBR forward in our field. By focusing on the work of junior scholars and their collaborators, the symposium offers a view not only of the state of the field, but of the near horizon of work that engages these methodologies and concepts. The five threads identified, running across the papers, offer a framework for engaging with the affordances, possibilities and challenges of CHAT/DBR. The great diversity of the learning contexts, designs for collaborative work, and critical questions across the papers offers a promising opportunity to explore the boundaries of where CHAT/DBR might take us as a field.

References


Unpacking ‘Signs of Learning’ in Complex Social Environments: Desettling Neoliberal Market-Driven Educational Methodologies, Epistemologies and Recognitions of Learning

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Abstract: This structured poster session examines the design and study of meaning making in and across multimodal contexts, exploring how recognition of new signs of learning, in new ways, might enter into the reconfiguration of educational practices and institutions. We expand on recent work in the learning sciences that challenges prevailing power structures and the ways that they are produced by existing ways of recognizing learning. The presentations build on the work of sociocultural and semiotic theories to challenge current neoliberal ideals about what counts as knowing, learning, and becoming, as well as who can come to know.

Introduction
Contemporary educational institutions are, as Gunther Kress (2013) has noted, in an unsettled state brought about by broken linkages among school, society, and economy. “The social,” Kress argues, “is marked by multiplicity, diversity, fragmentation, fluidity, provisionality, by far-reaching changes in distributions and assignation of power, which affect the agency and the potentials of individuals” (2013, p. 120). This opens up a need for reconsidering learning, in particular for understanding how recognizing new “signs of learning” might enter into the reconfiguration of educational practices and institutions. The Learning Sciences (LS) have of course for some time been engaged in this project. Like Kress, some in LS have called for a move beyond understanding learning research as an “administrative science” (Stevens, 2010) that identifies learning through the use of “metrics of achievement” (Kress, 2013) with origins and interests exogenous to learning contexts and ultimately grounded in “the power of an institution and conformity to convention” (Kress, 2013). In other ways, Kress’s call for “a re-calibration of pedagogic relations congruent with contemporary social givens” not only resonates with contemporary LS work, but also holds promise for the continuing development of the field. Kress emphasizes that learning researchers’ practices of recognition must remain attuned to the semiotic work of learners and teachers, to how they “realize meaning” through producing and using signs, in multiple modalities, within and across contexts. In so doing, learning researchers, he argues, are better able to attend to the agency involved in learning contexts, and thus to meet the challenge posed by Stevens (2010), who calls for LS to be an endogenous science, that is, to look “from within” at the work being done in and across learning contexts.

The papers in this session are tied together through an interest in the design and study of meaning making in and across multimodal contexts. We draw on existing work in the learning sciences and also explore new ways of understanding signs of learning. We engage with creative, agentic aspects of learning, and attend to sociomaterial practices that function as “pedagogical pivot points in enabling critical learning and social change” for learners often forgotten about in the current market driven education system (McKenzie & Bieler, 2016, p. 16). We attend to the multimodal and multisensory and how they mediate the production of learners and learning, and to “the agency evident in semiotic work” that offers new possibilities (Kress, 2013, p. 129).
The papers explore different research sites and imaginaries, marked in different ways by globalization, mobility, diversity, and inequity. Gutiérrez’s (2014) metaphor of “learning as movement” helps us ask new questions about “what takes hold as people, tools and practices travel across activity settings of everyday life, and on how individuals develop, repurpose and reorganize repertoires” (p. 48). We document learning of “border crossers,” who must learn “to negotiate the power, violence, cruelty of the dominant culture” through their “own lived histories, restricted languages, and narrow cultural experiences” (Giroux, 2012, p. 13). Hence, we not only unsettle learning but its grounding in Western and Indigenous epistemologies and methodologies. We address issues of design, expanding on issues that Bang and Vossoughi (2016) judge to be essential to “create sustainable and transformative change.” Building on the work of sociocultural and semiotic theory and challenging current neoliberal ideals about what counts as knowing, learning, becoming and who can come to know, we aim to engage in a dialogue with the audience about new ways to recognize and engage with learning.

Identity, agency and subjectivities of Afro-diasporic teachers in STEM classrooms
Jennifer Adams

Introduction
This presentation describes “signs of learning” in relation to the emerging professional identities of new teachers of colour. It is a part of a larger study that articulates relationships between science teacher identity and learning to teach with an emphasis on informal science teacher education. Responding to calls for greater collaboration between science-rich informal institutions and teacher education programs, this research focuses on exploring aspects of teacher identity that related to their learning to teach experiences with informal science institutions.

The study is situated in a large, diverse urban public school district that has long-standing issues with science teacher recruitment and retention and student performance in STEM, especially that of racialized, minoritized and economically marginalized students. In this paper I examine the lived experiences of three female new teachers (within their first three years of teaching) of colour in science classrooms as they navigate their identities and subjectivities of teaching and learning to teach vis-à-vis the racialized storylines around schooling in general and STEM education specifically. I unpack the discursive fields in which they exist, particularly the narratives around disparities of Black and Latinx people in STEM how their own racialized subjectivities shifted and responded to these discourses, and the ways that they adapted meanings of informal science learning in these enactments.

Theoretical and methodological approach
Nasir et al. (2012) frame relationships among race, racism and learning through racial storylines—pervasive narratives about race in social discourse that get enacted in schools and other settings. Racial storylines make identities available to learners (and teachers) in learning contexts, in turn influencing how people are positioned and position themselves. With learning, goals, and identity being “three prongs of a triangle, with bidirectional arrows between each two points” (p. 294), evolving together in social practice, racial storylines offer spaces where learners could resist, articulate new goals and take up new identities.

In learning settings, teachers are both subjected to the racial storylines as individuals while also shaping learning experiences for their students, often in response to these narratives. Agency describes how one accesses and appropriates resources in a given field in order to meet goals (Adams & Gupta, 2017). Teacher agency is the belief that the teacher-self is capable of making the right instructional decisions, knows how to acquire and use resources to teach, and confident about creating and maintaining a safe and effective learning environment for all learners to meet instructional goals. For science teachers, agency also means confidence in content knowledge and ability to motivate and sustain science learning in all students. Racial storylines present a challenge in that it often positions people of colour counter to positive science achievement. Therefore how a teacher learns to respond to the racial storylines in practice, with equitable science learning central to being an effective science teacher, contributes to agency and subsequently identity.

This study draws from two and a half years of data from a group of science teachers who met bi-monthly as a collaborative teacher inquiry group. The teachers are middle and high school science teachers in a large, public, urban system. The meetings were structured around co-generative dialogues—structured dialogues around shared events or practices—that aim to generate new understandings, meanings and practices (Martin, 2006). During these meetings teachers shared experiences and artifacts (lesson plans, pictures, videotapes, etc.) for group analysis and discussion. Three participants emerged for analysis in this paper because of their identities as Afro-diasporic teachers coupled with their enactments of teaching. Individual interviews and one-
on-one informal dialogues also informed this study. I am also a Black woman who taught high school science in the same public system. Engaging in reciprocal vulnerability (Kohli, 2014) I shared my experiences of learning to teach, teaching, and educating teachers as well as my experiences with race vis-à-vis these contexts.

Identities and subjectivities are made and remade through discourses, i.e., recurrent themes or storylines: “discourses…mark out identifiable systems of meaning and field of knowledge and belief that, in turn, are tied to ways of knowing, believing, and categorizing the world and modes of action” (Luke, 1995). During the analysis, I specifically looked for a) what storylines emerged, b) how they viewed themselves vis-à-vis these storylines and c) they ways that these storylines influence their becomings/identities as teachers.

Findings

Within the different contexts, teachers enacted teaching in different ways in relation to how they viewed themselves vis-à-vis their students. Their goals for creating STEM learning experiences were shaped and enacted around STEM futures that they imagined for their students and to counter the prevailing deficit discourses around students of colour and STEM. Teachers challenged and resisted storylines by developing structures that allowed their students to create alternative narratives and imagine a broader range of futures for themselves: weekend science-related field trips, interactions with graduate students and scientists of color, creating new activities and out-of-classroom learning spaces, etc.

The three teachers defined and redefined informal science teaching in ways that resonated with their identities as teachers and how they viewed themselves in relation to their students. In describing their identities as teachers, it is hard to separate their professional and social identities as they are both present and continuously influenced the other, thus “I am a black teacher, and because I am a black teacher I function in this way in this classroom.” This classroom speaks to the complexities of urban schools and classroom in that although all three teachers teach within the same public school system, each of their schools and classrooms diverge in the students and resources that structure them.

In dreaming of and creating possibilities for their students, these teachers engage in the emotional/psychological labor of the constant struggle to resist the racial storylines of people of color in relation to science and school, for themselves and their students.

Retracing the experiential trajectory of Science and Technology teachers’ as they change the pattern of their teaching practice and engage in curriculum development.

Sylvie Barma, Marie-Caroline Vincent, and Samantha Voyer

Introduction

The curricula of several Western nations have made a priority of improving the contextualization of Science and Technology (ST) education through the study of problems with relevance to the lives of students (Barma, 2011). Roth & Lee (2004) argue that teachers should avoid creating learning environments that funnel students into performance-based tracks and should instead offer students a broad variety of situations conducive to participation enabling them to make decisions in line with their own interests. ST education should be understood in terms of the definition provided by Fourez (2002, p. 198, our translation), for whom it is a “person’s capacity, in a sociotechnical society, to build for him or herself a field of autonomy, communication and negotiation with his or her environment”. Teachers are thus considered sense makers instead of grade makers. It challenges encapsulated forms of school activity (Engeström and Sannino, 2010). Our contribution documents the trajectory of the professional development of three science teachers engaged in designing a new form of practice for learning and expanding.

Context

In 2006, Quebec ST teachers were asked to integrate technological design of prototypes to support the appropriation of scientific concepts (MELS, 2006). However, after the implementation of the curriculum, there was a great lack of teacher training and tensions rose. From 2010 to 2017, we engaged in a school-university partnership with three ST teachers coming from different schools. They acted as collaborators and co-creators to co-model prototypes for workshop activities. Over the seven years, more than 165 teachers, lab technicians and pedagogical counselors coming from 15 school districts benefited from five workshops co-produced by the participants for their peers’ professional development. We documented the agency and actions of the three leading teachers as they engaged in the co-design of new curricular materials in the form of concrete artefacts to be presented to their colleagues as an opportunity to modify their practice. The results presented will describe
why, how and where ‘meaning-making’ took place and how, over the years, the individual and collective creativity changed the development of their professional practice. The participant teachers actively worked to shape their new form of practice and got involved.

**Theoretical framework**
We use the key concept of boundary to understand the activity under construction (teachers’ professional development). Boundaries are “established distinctions and differences between and within activity systems that are created and agreed on by groups and individual actors during a long period of time while they are involved in those activities” (Kerosuo, 2006, p. 4). The metaphor of “learning as movement” helps us ask new questions about “what takes hold as people, tools and practices travel across activity settings of everyday life, and on how individuals develop, repurpose and reorganize repertoires” (Gutiérrez, 2014, p. 48). According to Vooght et al. (2015), partnerships constitute a move from within, instrumental in exploring new ways of teaching and learning. Those ways take a variety of forms and shapes and involve boundary crossing as tensions arise and are overcome (Engeström, 2001). To document “what is not yet there” we adopted the theory of Expansive Learning, focusing on individual and joint agency to understand why and how participants collectively created new artefacts that revealed key boundary crossing instruments. We document how teachers created “sustainable and transformative change” that had an impact on their educational communities (Bang & Vossoughi, 2016).

**Methods**
We adopted a collaborative and interventionist methodology to document the co-design of the teachers’ professional development (Barma et al., 2017). Ethnographic data was collected over the seven years in the form of audio-video recordings of teacher training sessions, interviews and photographs during co-teaching sessions, and artefacts produced by the team (teaching documents, YouTube videos, prototypes, online resources, administrative documents, speaking turns, etc.). We pooled in (“bricolage’) all the data gathered over the seven years and analyzed them in keeping with the experiential trajectories of the participants (Kincheloe & Berry, 2004). Focusing on individual and joint agency allowed us to understand why and how participants engaged in expansive learning and came to collectively progress to create new tools that revealed boundary crossing objects and determined new roles to reconceptualised the object of their joint activity. The construct of a hybrid space in the form of a new activity implies that multiple levels of activity systems expand their own activity to establish a zone of proximal development and boundary crossers were identified as key players between activity systems.

**Findings**
Findings will be presented as a narrative, respecting the chronological development of the participants’ agency and creativity as well as the unfolding of the co-design of artefacts. As the participants reflected on their productions and experiences, their professional identities evolved and redefined the borders of their teaching activities. The data is still under analysis but, already, we are able to reconstruct an experiential trajectory of the reconfiguration of the teachers’ practice in response to their need for professional development. For example, different co-designed prototypes were presented during 6 teacher training sessions where 165 peer-teachers, student-teachers, lab technicians and pedagogical counselors of 15 different school districts participated. These prototypes were created to integrate several elements of the ST curriculum and implemented with high school students. We presented the prototypes to 124 university student-teachers during didactic classes and crossed another unexpected border. Quantitative data was also collected through seven online questionnaires. We obtained a total of 776 students’ responses and a total of 39 responses from teachers with relation to their own relationship to ST education. Three sections will orient the presentation of the narrative: 1) critical contexts, questioning and resistance to change; 2) contexts of discovery, creativity and modelling of new forms of practice and 3) contexts of practice and the social relevance of the integration of the tools produced in the community. The issues of teachers’ will to design for learning and expanding was traced back in their individual and collective agency as well as in the artefacts that acted as boundary crossing objects.

**Coding science as boundary Work: The role of publicness in scientific computing**
Pratim Sengupta, Marie-Claire Shanahan, Stephanie Hladik, and Dylan Paré

**Objective and theoretical background**
For Papert (1987), technocentrism was the fallacy of referring all questions about technology to the technology itself. Despite Papert’s call to action, educational computing has predominantly reified and perpetuated
technocentric images in which learning to code has become synonymous with the “proper” use and production of computational abstractions (Sengupta et al., 2018). In contrast, we argue that rather than viewing computing as regurgitation and production of a set of axiomatic computational abstractions, scientific computing using open source code in public spaces that invite playful engagement can be reconceptualized as boundary work.

We conceptualize science and computing as figured worlds (Sengupta & Shanahan, 2017). Holland et al. (1998) argue that individuals’ identities and agency both constitute and are constructed within cultural realms, or figured worlds, in which particular characters are recognized, significance is assigned to certain acts, and particular outcomes are valued over others. Gieryn (1999) defined “boundary work” as the continuous acts of figured world creation that scientists engage in when they frame their work through what it is not (“not-religion,” “not-mechanics,” “not this kind of research but that kind”).

Sengupta & Shanahan (2017) introduced public computing as a new form of open-ended, public learning environments, in which visitors can directly access, modify and create complex and authentic scientific work through interacting with open source computing platforms. Framed phenomenologically, technology should be viewed not only as ways and means of performing disciplinary work, but also in light of broader norms of participation in disciplinary and ancillary cultures developed around localized technological infrastructure. We posit that when placed in the public domain—both as a public space and in the form of open source code—where members of the public can freely access, alter and manipulate the code—scientific computing becomes freed from being beholden to narrowly forms of disciplinary authenticity. Scientific code, in such contexts, becomes a boundary object, their ill-structured nature allowing them to have different meanings in the different social worlds that they cross and therefore to be acted on in completely different ways.

Method
This paper presents ethnographic analyses of the experiences of teaching and learning coding across two different contexts of public computing: a science and technology museum (M), and a public space within a University (U). The participants include children 10 years and above and their parents (in settings M and U), museum facilitators who act as teachers (in setting M), students and pre-service teachers (who act as both teachers and learners in setting U). In each setting, we designed an open source, interactive exhibit allowing visitors to directly interact with open source simulations of complex systems. These simulations modeled how flocks emerge from simple rules of interactions between many individual-level virtual agents, allowing any visitor to modify the underlying open source code. We conducted participant observations over a period of 15 months in each setting.

Analysis and findings
We show that the experience of coding in these settings can be conceptualized as boundary work (Gieryn, 1999), i.e., continuous acts of creating “as if” worlds that learners jointly engage in along with their parents, teachers and facilitators, where they frame their work as “coding” through comparing with other disciplinary frames. These lateral frames are initiated by the interest of learners (and in some cases, parents and facilitators) in disciplines other than computing, and by their personal narratives and interpretations. Our analysis also illustrates how code fragments serve as pivots, artifacts that shift the frame of an activity and evoke or “open up figured worlds” (Holland et al., 1998, p. 61). Working directly with the code pivoted visitors partially and playfully into the designers’ figured worlds. We identify how specific fragments of the code may have served as pivots, allowing play between larger disciplinary cultures in which the designer’s and visitors’ figured worlds of the simulation were embedded. A final key finding is that teaching coding, in these informal spaces, often requires facilitators to step back and let these other disciplinary frames come in. The work of the teacher as designer can therefore be understood as facilitating back and forth movements between these frames, an image of reflection in action that further urges us to move beyond technocentric images of coding and teaching coding.

Significance
Our work challenges epistemologies of certainty (Dewey, 1929), in the context of democratizing disciplinary cultures of science and technology and suggests that an emphasis on publicness within the technological infrastructure, especially in the context of educational and scientific computing, can potentially create spaces for playful representational and epistemic uncertainties, which in turn can make it possible for science and technology to become public experiences.

Youths’ circulations in STEM networks of multiple scales: Case studies of agency and transformation of self and practice

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Jrène Rahm and Ferdous Touioui

Objectives
Studies of youth circulations within complex networks of STEM practices over time have led to the documentation of moments of youth agency and the temporary overcoming of injustice (Bang & Vossoughi, 2016; Bricker & Bell, 2014). Yet, we still need to better understand: 1) how youth engage locally in creative, agentive meaning making in science, 2) how youth address injustice as they enact agency through local and global meaning making, and 3) how adults may open up spaces for the development of critical agency and meaning making that challenge deeply rooted historicized oppression.

Theoretical framework
We invoke a conceptual reading of STEM practices as a complex matrix of practices (Leander et al., 2010). Imperative is a focus on relations among practices and the tracing of youths’ circulations, agency, and transformations within and across practices, next to implications for social justice in STEM. We juxtapose analysis of local meaning making and explore “signs of learning” as emergent from youths’ multimodal, multivoiced, embodied, and creative enactment of science. We rely on video analysis, attending to embodied action rather than just discourse or “the moving image” (de Freitas, 2016). We focus on the affective and emotional that transpires and constitutes the kind of complex dances of meaning making that we document.

Data sources
We present two case studies. Case 1 examines elementary children’s engagement with science in a space between school and out-of-school, a community organization offering access to meaningful activities in science, mathematics and robotics to enrich the education of children in schools in underserved communities. Case 2 draws from a multi-sited ethnography tracing a cohort of six girls for seven years beyond their participation in an afterschool program. The narratives of each case emerged from a bricolage (Kinchesloe & Berry, 2004) of multiple data sources (participant observation, video-ethnography, interviews, youth initiated joint productions).

Results
Case 1 tells the story of two teams engaged in two different science activities, one implying extraction of DNA from a strawberry, following a session on DNA and the creation of a DNA chain, while the second activity implied dissection of a plant. We noted an interesting tension between children’s engagement in “administrative science” and successful pursuit of the science protocol, and moments of “realizing meaning” made possible through the manipulation of the tools in creative ways owned by the children, supported by exchanges with each other and by positioning one another as doers of science. The case makes evident the value of analysing situated and practical experiences in which materials and selves are entangled in ways that make them pivots for learning and becoming in science. Case 2 explores circulations and learning on the move of Achyntia and Alana. We make evident the power of sisterhood and affinity that supported the girls’ circulation among diverse STEM practices beyond the afterschool program, into high school, and later, higher education. The case makes evident how the two girls became agents of circulation by opening up spaces of the STEM network for each other, as their paths crossed, and as they shared ongoing struggles as youth of color and insiders of STEM.

Significance
The cases offer rich insights into circulations of bodies, epistemologies of science, and identities in science. They challenge what it means to make meaning in science and the long-held vision of a linear STEM pathway. Both explore youth circulations, yet at different scales: one within a science project, the other across practices over time. Both point to social justice in STEM as emergent, as affectively charged, and as implying a sense of belonging, sustained by youths’ circulations, grounded locally and globally in supportive communities. The two cases raise methodological issues of scale, in particular the challenge of having others recognize these moments as signs of learning. Youths’ agency and transformations of learning environments in ways they valued remained marginalized and essentially unattended to by others in power. To conclude, we discuss the complex dynamic of oppression at work and its implications for social design based research but also methodology.

Learning that matters: Critical science agency in and through teen women’s film production
Rachel Chaffee, April Luehmann, Day Greenberg, Jessica Thompson, Sara Haganah, and Angela Calabrese Barton
Introduction

New ways of recognizing learning can aid in reconfiguring STEM learning opportunities and lenses whose current inertia cements an unwelcome environment for youth already marginalized in STEM. Working with teens engaged in out-of-school learning allowed us to investigate how three groups of teen women took up and re/shaped science for their own purposes through STEM film projects. We explored what aspects of filmmaking served as transformational pedagogical pivots for inviting teens’ Critical Science Agency (CSA), i.e., the ability to collectively leverage scientific understanding in conjunction with other forms of expertise to identify, investigate, and take actions on problems that matter within the community and that relate to justice-oriented issues. Here, we explore CSA as one expansive outcome promoting more equitable engagement and futures in science and engineering (S/E). CSA offers important pivots into deeper engagement with science knowledge and practice as well as into the contexts in which their science-related concerns take place. Pivots are “mediating or symbolic devices” not just to “organize responses, but also to pivot or shift into the frame of a different world” (Holland et al., 1998, p. 50). When youth leverage their funds of knowledge, they etch their insideness onto their work in ways that impact the design process, how/where it unfolds, and their roles in it. As pivots, these funds are not simply complementary to the youths’ investigations, but essential to who they are and their project work. We asked: 1) How and why did teen scientists develop and use repertoires of practices across their films?; and 2) How was power re/negotiated through youths’ acts of CSA, and what served as transformational pivot points for developing that agency?

Cross-site methods

We engaged in multimodal analysis of four films created by four sets of young women in three different out-of-school contexts serving low-income populations of color. Beginning with the construction of five transcripts for each film that documented interpretations of youth’s productions by foregrounding five unique lenses (auditory, visual, editorial, cinematographic, and background), we coded choices youth made in recruiting and organizing resources in particular arrangements within filmic episodes, across trajectories of episodes, and in overall film productions (Halverson, 2013). We repeated this process for all films before cross-analyzing the film data. This process of visual analysis allowed us to identify young women’s efforts to enact CSA through multimodal representations of themselves and the science in which they engaged.

Findings

Analysis across the four films revealed patterns of prioritizing issues of caring: for the local environment, for family and community members, for peers suffering with depression, for animals. Teen-developed repertoires of practice, emerging within and across films, consisted of repeated forms of framing, sources of motivations, and processes of meaning-making. First, each group of teen filmmakers constructed global narratives to sequence the film by introducing themselves as investigators, detailing a problem of significance to them, describing their varied S/E inquiry endeavors, and sharing their research findings with their audience(s). Second, teen women consistently acted and spoke as a collective “we” across episodes, centering their collective voices in the investigation, outcomes, and implications of the work. All four films evidenced teens’ overlapping attention to expectations of varied cultural memberships as they embodied S/E learning: addressing accountabilities of science while also attending to cultural expectations of being a teenager (music choices, cartoons), being a teen woman (removal of Hijab in all girl space), and a filmmaker (credits, transitions, candid and full-frontal shots). In doing so, S/E productions foregrounded the humanity of doing S/E work, thus recentering themselves in S/E.

Film production supported and reflected moments of developing and enacting CSA through dynamic and purposeful use of transformational pivot points. Teen filmmakers re/negotiated traditional STEM power structures by positioning themselves as authors and owners of STEM investigations and designers of socioscientifically informed solutions, leveraging funds of knowledge, and collectively making S/E contributions with implications for intended audience action. They capitalized on multimodal affordances of film production: text overlays for counternarration, coupling of moving and still images for representing multidimensional identity and skill development in-the-moment, full frontal shots with eye contact for claiming physical presence in STEM, dramatic role play as radical reenvisioning of scientific communication). Teens pivoted science and digital technology to merge personal stories with scientific understandings, to invite external expert perspectives while maintaining story ownership, and to simultaneously address diverse cultural expectations. Films documented the investigative process and taught the science behind the investigations through traditional artifacts like charts and graphs as well as through non-traditional methods of science practice and teaching. Filmmakers drew from community memberships while simultaneously leveraging the project to develop new social networks/coalitions to advance their work towards their goals of change.
Significance
The study demonstrates the power of youth-driven multimodal production to afford rich opportunities for CSA. Through the publication of their films, teen women challenged current conceptions of who can do meaningful science and engineering, in what ways, and toward what ends. The need for this work is underscored in the need to recognize diverse forms of participation and production for students who have been traditionally marginalized. Foregrounding the role of CSA in S/E shifts the process and outcomes of learning from a primary focus of developing and deepening practice-based S/E understandings to one of enabling and empowering individuals and communities to leverage S/E knowledge in ways that matter to them in the present.

References


Rising Above? Implications of Complexity for Theories of Learning

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Abstract: A recent article—Conceptualizing Debates in Learning and Educational Research: Toward a Complex Systems Conceptual Framework of Learning—analyzed the long-running cognitive versus situative learning debate and proposes that a Complex Systems Conceptual Framework of Learning (CSCFL) could provide a principled way to achieve a theoretical rapprochement. In this session, we bring together major educational and learning theoreticians to consider, debate, and perhaps “rise above” currently engaged major issues, debates, and disagreements that fundamentally influence educational research in a wide range of areas.

Session summary

The main objective of this session is to bring together major educational and learning theoreticians who generally conduct research from cognitive, situative, embodied, and socio-cultural theoretical perspectives to discuss and consider a Complex Systems Conceptual Framework of Learning (CSCFL) proposed by Jacobson, Kapur, and Reimann (2016). Their article argues that “current complexity perspectives might function best to inform a conceptual framework from which to view current and perhaps future theories of learning in terms of shared processes and conceptual dimensions,” such as complex collective behavior in a system (e.g., system levels, nonlinearity, emergence) and behaviors of individual agents in a system (e.g., parallelism, conditional actions, adaptation and evolution). The CSCFL is then used to analyze the cognitive-situative debate, noting “a number of theoretical components of both situative and cognitive theories of learning do align with several key CSCFL conceptual perspectives” but also that “the CSCFL … helped identify major omissions in both theories such as sensitivity to initial conditions and nonlinearity and emergence. (p. 217)” Their article notes the applicability of the CSCFL for new “debates” about the potential primacy (or not) of neuro-science over cognitive and situative perspectives and concludes with the hope that “principled theoretical considerations of learning as an emergent phenomenon in complex neural, cognitive, situative, social, and cultural systems will yield critically important insights of central relevance to our field that might not otherwise be possible with current perspectives and approaches (p. 217).”

The organizers of this session hope that bringing together these distinguished researchers for “principled theoretical considerations of learning” will help answer the question posed in the title of this session: Is a complex systems conceptual framework fundamental to theories of learning? If yes, then why; if no, then why not.

Scholarly or scientific significance

This session is significant because it will open a dialogue and exchange of ideas and perspectives by a distinguished group of researchers whose work has been influenced by different theoretical perspectives who will consider potential merits and limitations of the CSCFL proposed by Jacobson et al. (2016). Further, through their interactions, the participants and the audience can perhaps identify or articulate ways to advance thinking in the field of educational research broadly construed about issues of fundamental theoretical importance.

Structure of the session

This 90-minute session opened with comments by the Chair (5 minutes), followed by the five presentations (10 minutes each). The participants were asked to consider three main points in their presentations: (a) provide a brief overview of their main theoretical orientation, (b) discuss how their theorizing has informed their main research activities, (c) consider if the CSCFL (or some complexity-based variation of it) might or might not provide insights not otherwise possible with current theoretical perspectives in educational and learning research. The Discussant then provided comments for 10 minutes followed by 25 minutes for small group discussions and audience questions.
Methodological applications of the CSCFL: Quantitative and qualitative methods meet agent-based modeling
Michael J. Jacobson, The University of Sydney; Manu Kapur, ETH Zurich; and Peter Reimann, The University of Sydney

Our respective research activities have generally employed a range of quantitative methods (e.g., experimental and quasi-experimental designs, discourse analysis, data mining) and we have also used conceptual aspects of the CSCFL in our research, such as Kapur, Voiklis, and Kinzer (2007) (e.g., sensitivity to initial conditions) and Jacobson et al. (2017) (e.g., system levels, emergence). In this presentation, we propose to extend the applicability of the CSCFL from considerations of theory to another key issue in the field: methodologies for doing research and their suitability for studying learning as an emergent phenomenon. Our reading of the educational research literatures associated with cognitive and situative empirical studies is that researchers in these “camps” typically use different methodologies. In general, we find papers based on cognitive perspectives tend to employ quantitative research methods, whereas situative researchers tend to use qualitative and descriptive methods (i.e., design research), with some use of mixed methods (of course, we recognize there are exceptions).

Why is this important? There is an issue about whether either quantitative or qualitative methods are sufficient for explaining the emergence of learning. That is, we need to ascertain if and how these methods can deal with critically important facets of complex systems of learning such as emergence, the dialectical co-existence of linearity and nonlinearity, and issues of scale and hierarchical levels of systems. Unfortunately for quantitative approaches generally used in education, its major tools involve mathematical modeling (e.g., differential equations, statistical models) that are primarily (but not exclusively) linear tools to break a system into its components or parts, study the parts individually, and then add the parts together to form the whole. Unfortunately, emergent phenomena have important characteristics that are nonlinear and that cannot be analyzed by “adding up the parts” (Jacobson & Kapur, 2012). There also are limitations for using qualitative approaches to understand the emergence of learning. While qualitative methods have certain advantages over quantitative approaches (Firestone, 1097), we argue qualitative techniques still have certain limitations for understanding learning as an emergent phenomena. For example, the spatial-temporal scale of learning as it emerges from complex neural, cognitive, social, and cultural systems poses challenges for qualitative approaches that must focus on a humanly-manageable portion of the entire space and time over which a learning or educational phenomenon unfolds.

From the perspective of the CSCFL, a significant way to address these inherent limitations in the existing quantitative and qualitative approaches used in educational research is a hybrid approach that incorporates methodologies being used to study other types of complex physical and social systems (Jacobson & Kapur, 2012). We expect that research informed by the CSCFL would likely employ computer modeling methodologies such as agent-based modeling (ABM) and network models that are increasingly being used in the natural sciences (Holland, 1995; Mitchell, 2009) as well as in social science areas (Epstein, 2006), including economics (Arthur, Durlauf, & Lane, 1997), sociology (Elder-Vass, 2010), and organizational science (Carley, 2002). The symposium presentation discussed research employing such hybrid methods (Abrahamson, Blikstein, & Wilensky, 2007; Kapur, Voiklis, & Kinzer, 2008; Levin & Datnow, 2012; Maroulis et al., 2010), and considered challenges and issues for using such approaches.

Connecting the unit of analysis in learning research
Sten Ludvigsen, University of Oslo

Over the last three decades, the conceptualization of the phenomena of learning and cognition has been a hot topic. In the award-winning paper published in Educational Psychologist, “Conceptualizing Debates in Learning and Educational Research: Towards a Complex Systems Conceptual Framework of Learning,” a new conceptual turn is suggested (Jacobson, Kapur, & Reimann, 2016). I will take a socio-genetic (cultural) perspective on the problems of complexity raised in this symposium. “Socio-genesis” means understanding the multiple layers involved in activities when analyzing human learning. We thus need to avoid the fragmentation of the learning sciences in separate units of analysis and levels of descriptions. When the analysis of learning takes a starting point that involves social interaction and artifacts in complex systems, the question of connecting layers and the unit of analysis becomes urgent.

In most stances in learning theory, the unit of analysis mainly focuses exclusively on the individual within an environment. The socio-genetic perspective, however, provides an analytic stance that encompasses
three layers (social interaction, the individual in interaction, and social practices) that we must view as interdependent (Ludvigsen & Arnseth, 2017).

When taking socio-genesis as a premise, understanding learning starts with an analysis of micro-interactions. The study of micro-interactions implies a detailed analysis or measurement of how students engage in reasoning and problem-solving in specific knowledge domains or in themes that cross areas of disciplinary knowledge. Social interaction is crucial because it is here that history, tools, and human action come together and mutually shape one another. This is the first layer in the analysis. The second layer focuses explicitly on how students make their cognitive, social, and emotional competences relevant through a series of actions in interaction with others (process analysis). This layer gives insight into how students manage to interact with others and into their mastery of specific forms of knowledge. The third layer focuses on the institutional and historic dimensions that create affordances and constraints for students’ actions (the social practices). Institutions will always involve a degree of complexity and emerging phenomena that requires a broader historical and institutional analysis using a variety of methods.

The socio-genetic (cultural) stance includes the complexity that creates the foundation for learning and the kinds of concepts that the field needs to progress. It makes it possible to work with different types of analysis rather than with only one analytic layer. We need to recognize that multiple layers influence participant’s processes and performance. This will give us a more robust, nuanced, and sophisticated understanding of human learning and cognition. In modern society, this often involves the use of computational artifacts.

**The cognitive-situative divide and the perspective of a complex systems framework**

Stella Vosniadou, College of Education, Psychology and Social Work, Flinders University

I am a cognitive developmental psychologist who works in the area of conceptual development and conceptual change. From my perspective, I find that the attempt on the part of the situated perspective to capture the dynamic and social nature of learning is in the right direction. However, I also consider that treating knowledge entirely as a process “an activity that takes place among individuals, the tools and artifacts that they use, and the communities and practices in which they participate” (Greeno et al., 1996, p. 20) is problematic, particularly for a theory of learning that needs to explain phenomena like conceptual change. Nevertheless, I believe that it is possible to soften the boundaries between the cognitive and situative perspectives and to allow for conceptual change, by accepting that humans are processors of symbolic structures and that knowledge is something that can be acquired and change, while also accepting that this acquisition happens through participation in socio-cultural activities (Vosniadou, 2007). In other words, there is no need to see a conflict between learning as acquisition as opposed to learning as participation if we consider that knowledge structures exist in the form of symbolic representations, but also accept that these symbolic representations were acquired through participation in socio-cultural activities. Conceptual change in this system is the result of a complex process of interaction between individuals and the world through a rich variety of mediated symbolic structures. Further, it is proposed that teaching for conceptual change cannot rely on the implicit methods of cognitive apprenticeship, but must aim towards developing in students the metacognitive awareness required for explicit and intentional belief revision through the appropriate use of socio-culturally based practices and carefully designed research-based curricula.

Jacobson, Kapur and Reimann (2016) propose a conceptual framework of learning based on the study of complex systems—physical or social—arguing that such a framework can provide a theoretical rapprochement to the cognitive versus situative learning debate. Although I am not sure that the complex systems framework can indeed provide such a rapprochement, I do agree that learning occurs in complex social and cultural contexts and that a perspective which examines it as an emergent phenomenon brings to the study of learning and of conceptual change theoretical constructs and methodologies that have the potential to yield new and innovative insights.

**The art and science of impact: Unlocking human potential from a dynamic systems perspective**

Sasha Barab, Anna Arici, and Earl Aguilera, Arizona State University

We are arguing for a paradigm shift in the ways we think about unlocking human potential, one that sees content as fundamentally linked to practice, people as having rich potential, and technology as one component of an empowered ecosystem.

While unlocking human potential is clearly a complex endeavor, many of us working to innovate and positively impact this area have been operating under the wrong paradigm for creating sustainable growth. We
have created an artificial divide among the **content** what one needs to know, the **context** in which it has value, and how it transforms the **person** who is doing the learning (Engeström, 1987). Quite problematically, we have allowed for human capacity to be treated as a “commodity” that, in the form of knowledge, can be converted into some “technological fix” and transmitted into the mind of a passive learner.

From this starting point, too many efforts have failed to recruit the everyday individuals whose potential we are invested in catalyzing (Engeström & Saninno, 2010). Rather, many approaches to learning position them as objects to be changed (problems to be solved) rather than as change agents (problem-solvers) themselves, passionately invested in expanding their own ability to do great things (Barab, Cherkes-Julkowski, Swenson et al., 1999). When a design is focused on content transmission with an assumption of fixed and isolated minds, we devalue the capabilities learners bring to the process and undermine those we are working to empower.

In contrast, we are arguing for an ecological and optimistic perspective of learning that considers one’s motivation for learning as a key component of the complex learning ecosystem. More importantly, clearly there are problems that are amenable to “technological fixes” (Sarewitz & Nelson, 2008) in which the solution is bound up within the technology itself; for example, the use of antibiotics to fight an infection. However, even in the most direct causal relationships of biochemistry, there is still a wide variability in how each person will respond to the same treatment, with many contextual factors and complex interactions involved in the successful administering of medication (e.g., getting a correct diagnosis, affording the cost, finishing the treatment, experiencing side effects, or over-prescribing that leads to drug resistance).

Naturally, these variations are even less predictable when applying innovations to complex issues like unlocking human potential. It is here, that complexity theory is essential to conceptualizing how one leverages innovation for impact. In creating innovations to address literacy, discrimination, health, or unlocking human potential more generally it is unlikely that any designed product alone, whether a pill or a technology, will prove sufficient for achieving meaningful impact; too many other factors interplay. Instead, in this presentation we will draw from complexity theory to offer a complicated and more optimistic view of how we leverage innovation to help people grow.

When we shift from overly deterministic and mechanistic perspectives of how innovation can support human growth we begin to look not at technological fixes but at empowered ecosystems (Barab & Arici, in press). Empowered ecosystems involve interpretive space where learners, technologies, and enabling resources can come together to produce solutions. They have elements of dynamic systems, especially in terms of the solutions living in the dynamic interactions among the various components, but we will also argue for the investment of the learner. Any intervention that does not leave room for interpretive space and allow for agency is unlikely to cultivate the necessary energy for growth to emerge (Engeström & Saninno, 2010).

We view complexity theory as essential to accounting for the success of the platform revolution where the focus of the innovation is to connect consumers and producers who bring and create value—in contrast to pipeline solutions that disseminate value (Choudary, Van Alstyne, & Parker, 2016; Van Alstyne, Parker, & Choudary, 2016). Pipeline technologies are based on linear cause-effect relations with the solution residing within one component and the innovation focused on most effectively dispensing these solutions. A platform perspective, coupled with complexity theory, positions “solutions” as distributed among multiple interacting components with the goal being to empower and catalyze dynamics (see Figure 1). In this way, we argue that innovations for impact should be conceptualized, designed, and researched as complex ecosystems—not isolated technologies.

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**Figure 1.** An Ecosystem-Based Framework for Characterizing Innovation for Impact.
Do the merits of the complex systems conceptual framework of learning extend to design-for-learning guidelines?
Mitchell J. Nathan, University of Wisconsin

My scholarship in STEM education is influenced by a theoretical perspective that characterizes learning and development as emergent phenomena that arise from interactions between processes that operate at a wide range of scales (Figure 2). In addition to this theoretical perspective, methodologically, I distinguish between systemic and elemental approaches to learning research (Nathan & Sawyer, 2016). Elemental approaches assume aspects (such as context) can be “factored out” and analyzed independently (Greeno & Engeström, 2016). Systemic approaches reject this “factoring assumption.”

For example, I am intrigued by ways that fine-grained processes of embodiment operating at the level of neural, perceptual, and motoric systems, contribute to, or supervene on, complex cognitive processes such as conceptual learning, inference making, teaching, and educational policies that operate at greater time scales (e.g., Nathan & Martinez, 2015; Nathan & Walkington, 2017). This also motivates my use of a systemic perspective on classroom learning by studying both learning/learners and teaching/teachers, and their interactions. These systemic studies of situated learning and instruction combine with elemental investigations into potential mediators of the complex behaviors of interest. Information from systemic and elemental studies each inform early stages of design based research on learning environments as experienced by teachers and students.

One central outcome is that teachers are highly responsive to students’ in-the-moment learning needs, and that teachers and students each employ physical enactment of their thoughts, levels of cognitive development, and social communication along with spoken language to make sense of new ideas, be understood by one another, and manage the complexities of the environment to foster learning and engagement (Alibali et al., 2014; Nathan & Kim, 2009; Nathan et al, 2015). These studies demonstrate that much of what we know, as well as how we teach and communicate what we know (and what we think we know about what others know), is embodied, as exhibited by behaviors such as gesture and movement, the use of objects and space, and metaphors linking abstract ideas to concrete experiences. This seemingly formative role embodied processes have on complex cognitive behaviors has significant implications for learning environment design and for formative and summative assessment, which I would discuss during the presentation.

Fit of CSCFL
In my view, learning, and behavior more generally, is a complex system, with many processes and subsystems interacting dynamically to produce the emergent phenomena that we observe. My questions enter on how to use complex systems theory to advance our understanding of learning and produce effective learning environments.

Figure 2. A Log10 time scale of human learning. Systemic (above) and elemental (below) research methods are placed in approximate scale.
First, we need to move beyond what Cognitive Science has achieved in defining and measuring initial conditions and constraints in areas such as attention, perception, and memory, to tackle the question of supervenience: How do the processes operating at different scales interact to produce observed and intended behaviors? Second, we must also acknowledge that studies of learning always under constrain the design guidelines needed to create and implement effective learning environments. I would push the panel to weigh in on whether and how CSCFL can bridge the design-for-learning question.

References


Abstract: In this symposium, we ask what mathematical engagement looks like in the context of play, focusing on contexts designed to support mathematical thinking through open-ended activity, and looking at ages that are traditionally overlooked in studies of play. We heed Dewey’s admonition to look beyond sugar-coating: we do not seek to claim that “play is a good method for supporting traditional mathematics learning,” but rather, to explore the ways that mathematics is engaged through play, and how such different engagement with mathematics might transform students’ relationships with the domain. Taken as a collective, the papers in this symposium address this issue by looking across technical and physical contexts, using different lenses on play, and studying different experiences of play. Despite these contrasts, we jointly ask questions about what mathematics thinking and learning could look like if we changed the rules of the game.

Keywords: play, mathematics education, informal learning

Everything is made play, amusement. This means over-stimulation; it means dissipation of energy. Will is never called into action. The reliance is upon external attractions and amusements. Everything is sugar-coated for the child, and he soon learns to turn away from everything that is not surrounded with diverting circumstances.

John Dewey, Interest and Effort in Education, pp. 4-5

There is widespread agreement about the importance of play in supporting learning. Early childhood education has a long tradition of play-based curriculum, with significant evidence demonstrating how children substantively engage the world through play. Some play scholars demonstrate the ubiquity of play as a developmental strategy, extending this lens into the animal kingdom, and developmental theorists often articulate how different kinds of play develop over childhood (Piaget, 1932/1965; Vygotsky, 1967). Studies of children as they move into formal schooling consider the role that play takes in supporting development of social-emotional skills, in providing exercise, and generally allowing for periods of focus in the classroom. However, little research investigates the role of play in learning mathematics in older children.

Indeed, once children enter school, discussions of learning almost never reference play, and work investigating the design of learning environments has seldom explored whether or how play might be involved. And yet, much of what is considered to be sophisticated disciplinary engagement involves many of the same features as play, including exercising personal agency to set and reach goals, exploration, imagination, and joy. Thus, it seems likely that there is quite a bit of play involved in learning in the later years, and the field could benefit from better understanding how and when play is involved in disciplinary engagement.

In the mathematics education community, the context for this symposium, there is a significant history for studying students’ mathematical problem solving (Schoenfeld, 1985), and how their engagement with tasks...
might extend to their relationships to the discipline (Boaler & Greeno, 2000). Most of this work has taken place in the context of formal schooling, which is often sufficiently constrained so students have few opportunities to engage in the kind of open exploration of ideas foundational to mathematical problem solving. In settings less pressed by time and uniformity, mathematical problem solving can involve visualization and imagination, exploration and play, and investigating what if questions—all elements of engagement that are very much like play (Sutton-Smith, 1997; Gray, 2015). However, little is known about students’ engagement in such spaces, what is playful or enjoyable, and what mathematical ideas students think about when playing therein.

Thus, in this symposium, we ask what mathematical engagement looks like in the context of play, focusing on contexts designed to support mathematical thinking through open-ended activity, and looking at ages that are traditionally ignored in studies of play (that is, children who are in elementary and middle school). We heed Dewey’s admonition to look beyond sugar-coating: we do not seek to claim that “play is a good method for supporting traditional mathematics learning,” but rather, to explore the ways that mathematics is engaged through play, and how such different engagement with mathematics might transform students’ relationships with the domain.

Specifically, Paper 1 considers how a teacher’s’ use of a multi-touch app called *TouchCounts* and a collection of web-based Dynamic Geometry sketchpads help create propitious conditions for mathematical play in K-7 students. In exploring the relations between mathematics and play, they consider what children were aiming to do, how those aims emerged, and how the aesthetic features of their activity shaped their play. Paper 2 investigates middle school students’ engagement in a large-scale number line activity called *Secret Pattern*, where students performed a walking pattern along a giant number line on the floor for others to guess. They consider how this activity became a kind of socio-dramatic play as students explored the tension between wanting to develop and perform a pattern difficult for the other team to guess while also producing a good performance, and how this tension supported the flexible and creative recruitment of existing mathematical understandings in the service of meeting the challenge. Paper 3 explores how children’s self-chosen and self-directed play with mathematically structured objects creates opportunities for spontaneous mathematical sense-making. Specifically, they reveal that as children persisted in their attempts to repair trouble, they often became increasingly systematic in their efforts. This systematicity involved careful exploration of objects’ properties and relations between them, which, by design, were also mathematical properties. Finally, Paper 4 explores what play can mean in the context of an educational videogame, and asks what students might be playing at. The paper explores how a gamer initially set aside the game goal according to the game narrative and took a playful, explorative stance toward the game, and in doing so, he began to uncover and question the underlying mathematical structure of the game world.

Taken as a collective, the papers in this symposium address this issue by looking across technical and physical contexts, using different lenses on play, and studying different experiences of play. Despite these contrasts, we jointly ask questions about what mathematics thinking and learning could look like if we changed the rules of the game.

**Designing intellectual playgrounds for mathematics learning**

Nathalie Sinclair and Victoria Guyevskey

Drawing on the work of historian Johan Huizinga, Featherstone (2000) argues for the central importance of what she calls *intellectual play* in mathematics learning. She draws many parallels between the characteristic features of play and mathematical activity as it is described by mathematicians. These characteristic features include: stepping outside of ordinary or “real” life; being orderly and, in consequence, beautiful; being governed by rules; creating social groupings; and, being voluntary. Featherstone does not argue that play and mathematics are identical, nor that teachers should include play periods as part of their mathematical lessons; instead she is interested in “the ways in which ‘play’ might expose children to aspects of the discipline that may not ordinarily be visible to them” (p. 16).

In this paper, we explore some of the features of environments in which Featherstone’s intellectual play can emerge. We do so in the context of elementary school mathematics, because we are particularly interested in the way that play might free children “from the dictatorship of concrete objects,” as Vygotsky (1967, p. 19) writes, and enable them to “develop the capacity to behave in accordance with meaning.” This is all the more pertinent in the primary school grades, where the emphasis on the concrete — through manipulatives and real-life situations — may in fact delay children’s mathematical development.

In addition to these characteristics, Featherstone underscores the fact that play is not an aimless, spontaneous activity, but it instead, always has an aim: “The player wants something to ‘go’, to ‘come off; he wants to ‘succeed’ by his own expertise” (Huizinga, 1955, pp. 10-11). This aim is rooted in aesthetics: “Play has a tendency to be beautiful. It may be that this aesthetic factor is identical with the impulse to create orderly form,
which animates play in all its aspects” (p. 10). Play thus typically involves aspects of aesthetic experience, such as tension and poise, balance and contrast, solution and resolution, repetition and variation.

Following Papert (1980), well-designed and open-ended computer-based environments are effective at providing mathematical microworlds that operate outside of ordinary life. Such microworlds also provide the kind of “mathland” that Papert described as being like the immersive environment in which language learning occurs—where many words may not be fully understood, but in which fluency can develop. We conjecture that they might be especially effective at promoting mathematical play. In order to investigate this conjecture, we analyse several different instances of intellectual play, in the sense of Featherstone, in which K-7 children are engaged in two open-ended computer-based environments. Our goal is to examine how these environments, including the teacher, help create propitious conditions for play. The first environment is a free, multi-touch App called TouchCounts, in which children use their fingers and gestures to count, add and subtract, and which provides auditory, haptic, visual and symbolic feedback. For example, when one finger taps the screen, the word “one” is said aloud, a disc appears and the symbol “1” appears on the disc. The environment is open-ended in that there are no prescribed tasks and no evaluative feedback provided. Teachers may propose some tasks, as may children. The multi-touch feature encourages children to work together on the screen, as multiple fingers can be used simultaneously. Prior research on the use of TouchCounts with young children has focused on the ordinal aspects of number that the app facilitates, as well as on the way that the gestures for making numbers, adding and subtracting change the way that children think about number. Coles and Sinclair (2017) have argued that children’s tendency to create large numbers (beyond those prescribed by grade-level curricula) provides them with a sense of the structure of numbers, which facilitates their understanding of place value—not as a cardinal concept, but as a temporal and symbolic one. The second environment is an online Dynamic Geometry platform that features a collection of Web Sketchpads, where children manipulate various geometric shapes and create geometric designs within interactive sketches. Visual and dynamic component allows learners to play and explore, test conjectures, discover patterns, think creatively, and otherwise get engaged. Students are excited to interact with the software, which offers many opportunities for collaboration and discussion.

In the paper, we consider three different episodes involving two or more children and first show how they can be identified as examples of intellectual play. We then analyse these episodes to better understand the children’s aims, how those aims emerged, and how aesthetic features of their activity shaped their play. We also study how children’s play enabled them to develop relational meanings in the absence of any concrete objects or real-life settings. In doing so, we identify features of the environment that gave rise to intellectual play in young children including, most significantly: (1) the symbolically structured nature of the environments, where the symbols are mathematical in nature and the structure enables relational meanings to emerge (Coles & Sinclair, in press); and (2) the participative revoicing of the teacher in the children’s process of goal setting.

Guess my secret pattern: Imaginative explorations through operating as points on a walking scale number line
Jasmine Y. Ma and Sarah C. Radke

This paper investigates fourteen middle schoolers’ engagements in a large-scale number line activity called Secret Pattern, in which students performed a walking pattern along a giant number line on the floor for others to guess. The somewhat competitive nature of the activity, the open-ended possibilities for completing the task, as well as the imaginative requirements of operating as a point along a giant number line supported a playful atmosphere for mathematical reasoning. We present findings here that describe how these students’ mathematical engagements shaped and were shaped by their play.

Secret Pattern took place on the first day of an elective mini-course called Math Battle! that ran for three hours a day for five days during the school’s mid-winter “minimester,” designed for students to explore innovative extensions of the school’s regular curriculum. Math Battle! was advertised, in part, as an opportunity to design a giant game of Human Battleship, in the context of which students would explore the number line and the coordinate system using their whole bodies. It took place in an empty gymnasium-sized space in the school building. On the first day the students engaged in activities on what we call a Walking Scale Number Line, a long orange number line made of painter’s tape placed on the floor (Figure 1). The number line was partitioned by unnumbered hash marks made of short pieces of blue tape placed at equal intervals (the length of the second author’s shoe). Every other hash mark was slightly shorter than its neighbors. Secret Pattern took place after students had each chosen a “home position” on a hash mark, placing an index card labelled with his name there (all students in the mini-course were boys). The group then explored the number line, negotiating physical logistics.
of moving along the line as a group and developing shared language for discussing their location on the line and relative to each other.

Figure 1. Math Battle! students standing on their home positions on the walking scale number line.

Our analysis is framed by contemporary theories in the learning sciences that foreground whole bodies and movement as constitutive of processes of meaning-making (e.g., Hall & Stevens, 2016; Marin, 2013; Taylor, 2017). From this point of view, multimodal and multisensorial aspects of mathematics activity are not epiphenomenal to reasoning, but instead must be taken into account in an analysis of knowledge and learning. Walking and attendant embodied sensations are forms of place-making, of coming to know and simultaneously producing place (Ingold, 2007). Our analysis focuses on walks on the thin strip of tape that we called a number line, and how students infused it with mathematical meanings and developed corresponding representational practices (Hall, 1996) in repeated walks along its surface.

Data collected included documents related to instructional design of workshop activities, detailed fieldnotes written after each workshop day, multiple streams of video and audio recordings, including stationary video cameras mounted on tripods, GoPro cameras worn on students’ chests, and digital audio recorders placed on the floor. Analysis followed multimodal, microethnographic methods (Jewitt, Bezemer, & O’Halloran, 2016; Streeck & Mehus, 2005), following students’ coordinated movements and talk as the site of mathematics sense-making, and attending deliberately to sociomaterial phenomena of relevance to participants in the data, and meanings produced in unfolding interaction.

Findings explore the tension between wanting to develop and perform a pattern difficult for the other team to guess while also producing a good performance. This tension supported the flexible and creative recruitment of existing mathematical understandings in the service of meeting the challenge. Enyedy and his colleagues (2012) described how students in socio-dramatic play “often spend more time articulating and negotiating the rules of a play situation than they spend actually in character ‘playing’ their parts...as a result, the rules that govern a situation become visible and explicit for children” (p. 353). If we take students operating as points on a number line to be a form of socio-dramatic play, then we see how negotiations between members of the group made explicit, challenged, and expanded their understandings of the mathematical relations that would govern their pattern and how it would be performed on the walking scale number line. These negotiations included suggestions for mathematical patterns proposed in talk (e.g., adding one each time or the Fibonacci sequence), trial walks implementing the pattern on the number line, and revisions aimed at either making the pattern walkable given the constraints of the taped line or making the pattern more complicated. Analysis illuminates how, through imaginative exploration, students’ moving bodies and the tape on the floor accumulated mathematical meaning over the course of negotiation.

The emergence of mathematical thinking through construction play
Lara Jasien, Ilana Horn, and Melissa Gresalfi

Mathematics education research emphasizes student sense-making as foundational to mathematics learning (Hiebert, Carpenter, Fennema, Fuson, Wearne, & Murray, 1997). However, we need tools and frameworks that support mathematical inquiry, particularly ones that engage students’ personal agency with respect to decision-making and reflection in mathematical activity. Within the constraints of the U.S. school system, a focus on making progress on content can become so dominant that it overshadows a focus on exploration. This is particularly ironic, since play is a core activities of childhood, yet it is increasingly eliminated from U.S. schools. The reduction of play represents a loss not just to children’s physical and emotional health, but to their intellectual health as well: play supports sophisticated forms of negotiation, reflection, experimentation, persistence, and
learning — all disciplinary practices of mathematics. Indeed, Lev Vygotsky (1933/1978) proposed that when playing, children are able to act “...a head above themselves,” (p.95) literally by engaging in a zone of proximal development because of their freedom from the constraints of the “real” world. Following this perspective, in this study, we look at how students’ play with mathematical objects to consider specifically how play centered on building or designing — often called construction play (Forman, 2006) — supports formal concepts and reasoning.

Prior studies have shown that preschool children who engage in construction play in informal environments develop relationships to materials and ideas that seem to support later success in math (Stannard, Wolfgang, Jones, & Phelps, 2001). Similarly, older children who do well on construction tasks also tend to perform well in mathematics (Casey, Pezaris, & Bassi, 2012). However, little of this scholarship has explored how or why such playful activities might support mathematical thinking, and indeed have only rarely made claims about the mathematical concepts that might be engaged in children’s play (Seo & Ginsburg, 2004), leaving us with little knowledge about children’s actual mathematical sense-making in constructive play. In addition, few studies of children’s play take place in environments with materials explicitly designed to direct children’s attention to mathematical concepts. This is a large theoretical and methodological gap, as the mathematical generativity of children’s play is linked to material constraints that lead children to experience trouble as they work to achieve their goals (Bergen, 2009; Forman, 2006; Papert, 1980). In overcoming the constraints of materials, children not only engage in creative problem solving but also often become increasingly systematic in their examination of the object’s properties (Karmiloff-Smith & Inhelder, 1974). We argue that examining children’s self-chosen and self-directed play with mathematically structured objects is likely to provide rich information about children’s emerging mathematical concepts and sense-making.

To better understand how mathematics is engaged in children’s play, we examine school-aged children’s activity in a mathematics playground at the Minnesota State Fair called Math On-A-Stick (MOAS). MOAS has nine exhibits, each with unique mathematically structured objects such as tiling pentagons, pattern machines, tessellating turtles, and 6x5 egg crates with colorful plastic eggs. Over 10 days, we collected video data using head-mounted GoPros, capturing children’s perspectives of their play (n = 348). Children’s average MOAS visits lasted 26 minutes, with median visit per exhibit at approximately four minutes. Out of the 348 participants, this study focuses on older children (7 – 12 years old, n = 277, visit length: m = 28 minutes), because this age group’s mathematical play is understudied.

To understand how mathematics was engaged in children's play with the mathematical objects at MOAS, we used interaction analysis (Jordan & Henderson, 1995), a method that centered the children's perspectives. Specifically, we initially reduced our data to look for sustained engagement towards one goal for at least two minutes, as we hypothesized longer episodes of engagement were more likely to contain more complex forms of play. Then we inductively coded our video data to look for when children experienced trouble (e.g., when they stopped to reorganize, expressed frustration or confusion, etc.) and then worked to repair it, what we called episodes of trouble-and-repair. Trouble was often signaled by audible expressions of frustration or confusion, and repair was signaled by solicitations for help or multiple revision attempts. We conducted a close examination of how children’s strategies and goals shifted as they engaged with and experienced push-back from the mathematical objects. As children persisted in their attempts to repair, they often became increasingly systematic in their efforts. This systematicity involved careful exploration of the objects’ properties and relations between them. When this kind of systematicity and exploration arose in children's play as they persevered through trouble in order to meet their goals, we have come term this activity mathematically generative play.

Our analyses suggest that Mathematically generative play arises when children explicitly engage with mathematical properties of objects (although they do not necessarily name them with mathematical terms), which often involves children’s use of disciplinary practices such as attending to precision and making generalizations. This is not only a feature of play, but also of the objects in the exhibit; throughout our analyses it appeared that the mathematical affordances of the objects makes it more likely that children attend to and engage with mathematical concepts. This research serves to deepen our understanding of school-age children's mathematical sense-making as we begin to look at children's spontaneous mathematical concepts and ways of thinking in contexts that center children's decision making and agency.

“Playing” the game: Exploring the underlying mathematical structure of an immersive game
Panchompoo Wisittanawat
One challenge in understanding play is that play describes both 1) a form of activity and 2) a stance or orientation toward an activity (Malaby, 2009). In the first sense, play describes a form of activity that is game-like either with implicit and emergent rules (e.g. children’s pretend play) or formal and more stable rules (e.g. soccer, chess, videogames). In another sense, play describes a mode of cultural experience that occurs in many forms of activity. This means that an activity that looks like a play activity may not be playful (e.g. students play a mathematics game to complete a homework assignment). On the other hand, an activity that does not look like a play activity may in fact be playful (e.g. students solve a homework math problem with a playful stance). Conceptualizing play in this second sense, as a mode of orientation toward an activity, raises the question: when students appear to be playing a mathematics videogame in a classroom, are they playing, and what are they playing at?

This case analysis draws data from a larger research project that investigates an educational videogame designed to support mathematical problem solving. The game, called “Boone’s Meadow,” builds on a project-based curriculum that was developed as part of the “Adventures of Jasper Woodbury” project (Cognition and Technology Group at Vanderbilt, 1997). In this game, students play the role of a wildlife rescue assistant who transports injured animals from a nature reserve to a clinic. Players make rescue plans (i.e., deciding which plane and which route to fly and) and act out their plans (i.e., flying a plane to transport an animal). The conjecture that framed the design of the game was that greater engagement with the game narrative would lead to consequential engagement with mathematics (Gresalfi & Barnes, 2015), when students increasingly used mathematics to make and reflect on decisions in the game.

This paper presents a case analysis that explores a unique form of play that emerged as Calvin, a student gamer (grade 6), played Boone’s Meadow. This form of play, common in videogame communities, is unique in this context in the sense that this is the only observed case in our data corpus. While most of his peers played the game by adopting the goal according to the game narrative (i.e., rescuing an injured animal), Calvin temporarily set aside that goal and “played” the game to expose its mathematical structure. Calvin presented himself as a gamer, someone who played a lot of games and was knowledgeable about genre(s) of videogames. How Calvin played the game became of analytic interest because this is a case that did not fit our design conjecture. Prior analyses demonstrated that while Calvin and his partner were very engaged with the game narrative, they appeared as though they didn’t engage with mathematics in the game, at least not in the ways intended by the designers. Calvin and his partner were not enthusiastic about conducting calculations that were required to make precise recommendations about saving the eagle, and did not use the calculations they did to inform their game choices. However, upon closer analysis, Calvin appeared to interact with the game in a deeply mathematical way. He took an explorative, playful stance toward the game, and intentionally “played” the game to expose its underlying mathematical structure.

Data include screencapture recordings of three class periods of game play. This analysis used methods of interaction analysis, attending to talk and game actions, and in particular, what Calvin noticed in the game and with whom he shared his noticing. Calvin and his partner sometimes addressed the computer (“Dear Boone’s Meadow creators …”) or directed his comments to researchers in the room. Comments directed to “designers” contained game jargon (e.g. “8-bit graphics” or “It’d be cool if it goes like a turn-based JRPG.”), and they often included his evaluations of the game.

Analysis of Calvin’s play revealed playful attunements to the activity that were different from the intended forms of engagement envisioned by the designers. First, Calvin engaged in a kind of beta testing: In gaming communities, the goal of beta testing is to creatively challenge the design in order to push the limit of the design, and it is an important mechanism for a co-creative game production (Wirman, 2012). The beta testing frame oriented Calvin to seek the limit of the game. Despite some objection from his partner, when he had a chance to maneuver a plane in the game, he tried different backflips and diverted the plane away from the destination to find the edge of the game world. He commented to one of the researchers, “Can you give us a little more room to fly the plane?” Calvin also noticeably attended to visual details: he first noticed many “texture issues” with the game. For example, “There are texture issues. This is when people went cheap on the game and they did not give Larry the proper texture, because they want to go cheap on him. … His thumb just went through his arm!” This suggests that Calvin’s ways of seeing in the game included paying attention to very minute visual details. Finally, Calvin’s play served to expose the underlying mathematical structure. His Calvin’s careful attention to visual cues was also integrated in how he “played” the game to expose its underlying structure, which he seemed to assume to be mathematical. In running two of their eagle rescue operations, Calvin and his partner used two different planes, and they crashed because they ran out of gas both times. After the second plane crashed, Calvin expressed his surprise: “Our thing died at the exact same time as the one that had the most fuel efficiency.” This comment suggests some intentionality in how Calvin varied his game actions, i.e., he was cognizant that what was varied between the two trials was fuel efficiency. Also implicit in this comment was an expectation that two planes with different fuel efficiency should not have crashed at the same location. This expectation entailed
an understanding that some common relationship governed these two flight trials, which should not have yielded the same result given that an important factor in that relationship (i.e., fuel efficiency) was varied. In terms of a learning goal in this game, this form of reasoning demonstrated a sophisticated understanding of proportional relationships. Through his playful exploration, Calvin uncovered and (mildly) questioned the accuracy of these underlying relationships in the game.

At least in the early attempts, Calvin didn’t play the game to save animals as most of his peers did. He took a playful stance toward playing the game to explore the underlying mathematical structure of the game world. As someone familiar with videogame media, he was highly attuned to visual cues, and the beta-testing frame possibly heightened this attunement that led to him noticing and questioning the mathematical structure of the game. After some playful explorations, Calvin started to take up the game mission according to the narrative, commenting to his partner, “Dude, we have to do this [again]. We’ve killed two eagles in the span of 5 minutes. … I feel so bad. I was starting to drive legit too.”

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