Scaffolding a Knowledge Community for High School Physics

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Abstract: This paper presents a design study of a collective inquiry model, where student-contributions are captured, aggregated, tagged and represented in a coherent visualization in the context of an advanced high school physics course. We have developed a flexible new technology layer that allows the investigation of collaborative inquiry scripts to support the aggregation of peer responses, including the collection of student explanations and semantic tags. We also discuss why these scripts must take into account both the longer (macro) scripts that are enacted over a long-term curriculum, and consider how they can support (and be supported by) in-class (micro) scripts. Below we outline our rationale for inquiry design in Physics, the role scripting and orchestration play in the successful implementation of this curriculum, the role of the "smart classroom" in their enactment, and three successive iterations of our curriculum.

Knowledge Communities for 21st Century Learning

As we move further into the "knowledge Age" (Zuboff, 2004), today's modern workplace is shaped by new technologies, where activities are increasingly data-driven, collaborative, and predicated on a set of fundamental skills commonly referred to as information literacies (Livingstone, 2008). This shift is particularly pronounced across STEM (Science, Technology, Engineering, and Mathematics) disciplines where workplace practices have increasingly shifted towards data-intensive practices and large, multidisciplinary collaborations across ever-widening spatial and temporal scales (e.g., the Human Genome project, sea floor mapping). This transition, sometimes referred to as "science 2.0" (Gray & Szalay, 2007), highlights the need for the integration of such practices into science education. Otherwise, we risk students' future success in STEM related careers (NSF, 2008).

A theoretical perspective from the learning sciences that is well suited to learning and instruction in the 21st century is that of knowledge communities, as exemplified by the Fostering Communities of Learners (FCL) project (Brown & Campione, 1996), and Knowledge Building (Scardamalia & Bereiter, 1996), amongst others. These researchers have advanced an epistemological perspective where students come to consider learning as a social process, and value the collective knowledge of their peers. Although difficult to enact (van Aalst & Chan 2008; Sherin et al, 2004), the knowledge community approach has garnered renewed attention, partly as a result of Web 2.0 capabilities, which have the capacity to support complex pedagogical constructs (Slotta, 2010; Slotta & Najafi, 2010).

One promising avenue of research is the investigation of a socially oriented, "Web 2.0" model that actively engages students as participants in a knowledge community that is active in the production, aggregation, and assessment of science topics, with an emphasis on inquiry and collaboration (Peters & Slotta, 2010). Providing students with the opportunity to contribute their own content allows them to make connections amongst the often disparate pieces of information within a domain (Ulrich et al., 2008; Ito et al., 2009). The most common way of creating such connections is by assigning meta-data, or "tags", to discrete content elements (Mathes, 2004; Wiley, 2000). This process allows individuals to assign descriptors without the knowledge of other content elements that share the same designation. Participants can rely on the emergent collective data set, and are guided by tags that reveal meaningful connections across content elements (Hayman & Lothian, 2007). It is now possible to reveal flexible data representations in "real time" (Shirley et al., 2011) resulting in a new functionality (e.g., audience response "clicker" systems) that could not have been achieved in traditional pen and paper learning environments. Krajick et al. (1998) have identified such representations as an important element of science inquiry learning.

Emerging conventions for user-contributed, tagged repositories (e.g., FlickR, YouTube) provide natural mechanisms for supporting the aggregation and refinement of student generated content (Anderson, 2008; Mathes, 2004; Wiley, 2000). Moreover, recent advances in semantic representation (e.g., PicLens or Taggraph) have enabled the development of a new media that provides personalized access to the user-created dataset. Researchers can now provide the mechanisms for students to become active members of a knowledge community, where they upload and tag elements according to prescribed content tags, or user-defined tags (i.e., as in a folksonomy). Questions remain about how such collections of content can best serve student learning and foster knowledge communities. Two aspects of such research that will be important to the present paper are those of reflection and scripting, and are discussed below.

Reflection, Discourse, Scripting and Orchestration in Learning Activities

An important dynamic within most inquiry or knowledge community research is that of reflection, which is typically embedded within student learning activities (Bielaczyc & Collins, 2006, Slotta & Linn, 2009). While generally accepted as an essential part of the learning process, reflection takes on particular significance in digitally mediated learning environments (Johnson & Aragon, 2003). In such environments, many interactions take place asynchronously, providing students with the opportunity to think critically about the ideas of their peers before adding their own ideas to the public discourse (Garrison, 2003). The act of placing one's own ideas into words, for inclusion into the community discourse, also allows learners to reflect on their own understanding, construct coherent ideas, and reconcile misconceptions (Chi, 2000). By adding discourse with peers to the reflective process, we can provide students with opportunities to ask or answer questions, and elaborate on or challenge the ideas of their peers. Such activities have been shown to be an effective means for individuals to rehearse their knowledge, monitor their own understanding, and recognize and repair gaps in their knowledge (Roscoe & Chi 2007).

Another topic of interest to learning scientists is the notion of scripting and orchestration (Dillenbourg, Jarvela & Fischer, 2009; Dimitriadis, 2001), where specified learning and interaction designs (i.e., "the script") are enacted ("the orchestration") by teachers and students. The script can be seen as a formalism that captures the pedagogical structure of a learning design. For example, each student could be required to upload two relevant videos for discussion. It could also entail collaborations, including a wide range of interaction patterns among students, their peers, and the teacher. When user-contributed materials are introduced, the script becomes more open-ended (Peters & Slotta, 2010), and any inquiry design must be left somewhat "unbounded" to allow for emergent themes, directions or content. Teachers can be seen as "orchestrators" of the script – although this responsibility is also shared amongst students. In technology-enhanced learning environments, teachers receive real-time feedback about student ideas, resulting in opportunities for evidence-based decisions that can influence the script itself (i.e., real-time "course corrections"), and provide opportunities for teacher professional development (Dillenbourg & Jerman, 2007; Lui, Tissenbaum & Slotta, 2011; Slotta & Linn, 2009).

Research Context

This paper presents a design study of a collective inquiry model, where student-contributions are captured, aggregated, tagged and represented in a coherent visualization in the context of an advanced high school physics course, with a teacher who was actively engaged as a research partner. We have developed a flexible new technology layer that allows the investigation of collaborative inquiry scripts to support the aggregation of peer responses, including the collection of student explanations and semantic tags. While we have not adopted the complete pedagogical and epistemological commitment of the "knowledge community" approach, we have introduced a layer of social knowledge construction where students actively create a shared repository of physics homework problems (solved, tagged and explained), uploaded relevant examples, and other creative artifacts. In order to support these complex interactions, we have developed a new "smart classroom" technology environment that supports all student activities in the classroom, at home and in the field. In the sections below, we outline our rationale for inquiry design in Physics, the role scripting and orchestration play in the successful implementation of this curriculum, the role of the "smart classroom" in their enactment, and three successive iterations of our curriculum in a high school physics setting.

In a design-based series of iterative advancements, we began in iteration one with a straightforward script for tagging, responding and explaining, which we implemented and evaluated in terms of student learning and teacher practice. In iteration two, we introduced a dimension of specialized expertise into the script, as well as new supports for teacher feedback. The first two iterations were formative, providing important information about how students collaborate using such real-time digital features. In iteration three, we dramatically expanded our designs, moving from single session smart classroom scripts, to a persistent digital layer that supported periodic inquiry and collaboration for the duration of the physics class. We worked closely with the teacher to develop designs, including a powerful new repository of user-contributed materials, and social and semantic tags. This repository facilitated the development of new scripts for teachers and students alike. Our specific research questions are as follows: How can the aggregated products of student inquiry cultivate a knowledge community in high school physics? What kinds of scripts can best aid students in leveraging user-contributed materials towards creating deeper understandings of physics? What technology supports can support teachers in the scripting of curriculum within an emergent knowledge community?

Method

This research employs a design-based method, involving successive cycles of design, enactment, analysis, and redesign within authentic classroom settings (DBRC, 2003; Brown, 1992). Using a co-design approach (Roschelle, Penuel, & Schectman, 2006) our team of researchers, technologists, and teachers worked together developing technologies, curricular materials, activities, and interaction patterns. The study was set within an urban high school, with all activities occurring as part of students' regular homework and school activities. All materials and interactions reported in this paper were delivered using SAIL Smart Space (S3)– a technology infrastructure for smart classrooms and knowledge communities (Slotta, 2010; Slotta, Tissebaum & Lui, 2011).

Table 1: SAIL Smart Space (S3) Architecture	
Student Portal • Entry point to learning environment • Student Registration & Account Management • Connects students to learning activities • Facilitates grouping of students	Agent Framework • Tracking student interactions in real-time • Used for mining and aggregating student work • Manage student interactions
Central Database • Stores designed curriculums • Stores student metadata, solutions, and discourse • Persistent and searchable	Visualization Layer • Controls how materials are presented to students, teachers, & researchers • Device dependent (laptop, handheld, smartphone, large-format displays)

Iteration 1 – Developing a Cross-Context Physics Problem Solving Activity

The aim of the first design was to investigate how the aggregation and representation of peers' work generated outside the classroom (i.e., at home) could be leveraged for in-class knowledge building. We also investigated how different technologies could aid the teacher in gaining insight into the state of class knowledge in support of different scripting and orchestration moves. Students first solved a set of multiple-choice physics problems individually in an asynchronous homework activity. In a follow-up synchronous activity, small groups re-solved these problems using the aggregated responses of their peers from the homework stage. To support the process, we developed a portal allowing the teacher to customize the activity (i.e., the number of questions to be served, and the type of questions presented), a visualization displaying the student-negotiated answers and relationships (tags) between problems (Figure 1), and an aggregated report of students' homework responses. By viewing the report and visualization before class, the teacher had the opportunity to adjust the upcoming class script based on his perception of the students' understanding. The teacher could also use both tools during live classroom activities to gain insight into student group work in real-time, helping inform activity orchestration, or as a post-activity discussion tool.

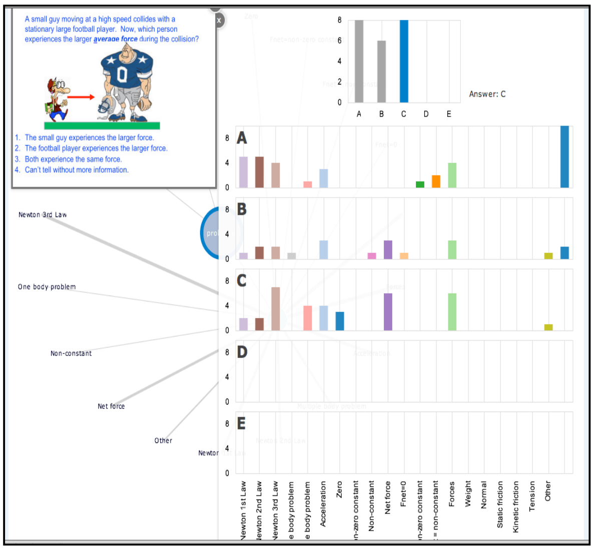

Figure 1. Aggregated class visualization showing student responses and tags

Design:

Our study consisted of two physics classes, with twenty students (n=20) in the first trial and sixteen (n=16) in the second trial. The co-design team consisted of a high school physics teacher, four researchers, and three technology developers. During the enactment, the teacher logged into the portal and uploaded five homework questions. Upon receiving an email alert, each student *Tagged, Answered, and provided a Rationale* (TAR) for his or her answer before the start of the next class (two days later). In advance of the in-class session, the teacher logged into the portal to view the aggregated student work to develop a sense of the class' understanding of the ideas present in the homework. During the in-class activity, student groups were shown the aggregated answers of the whole class and were given the opportunity to work together to form a consensus and to re-TAR the question (Figure 2).

Data Sources:

Data were drawn from three sources: 1) All student and group tags, answers, and rationales were captured by the system; 2) Researchers collected field notes of the in-class activity; 3) A follow-up debriefing of the activity was conducted with the teacher. The field notes provided us with an understanding of how the students were engaging with the curriculum and their peers while in class. The captured student data was examined to reveal changes in the accuracy of responses between students answering individually versus in groups, as well as in the rationales. Finally, the follow-up debriefing with the teacher provided insight into his perceived effectiveness of the added technology scaffolds in meeting their curricular goals.

Findings:

Overall, groups faired significantly better at solving problems (97% correct) than individuals at home (80% correct), with $t=2.02$, $df=41$, and $p<0.05$. One problem, for example, had marked improvement with 45% of students answering incorrectly at home, while100% answered correctly in groups. A potential confound is that the groups were solving problems they had seen individually as homework. However the addition of the whole class' rationales made it worthwhile to re-engage the students with the same set of problems.

Throughout the in-class activity, groups were observed reading their peers' tags and rationales, and engaging in discussion around them in an attempt to make sense of differences. Overall, student groups recorded forty-eight rationales with their answers (seventeen rationales were left blank, concentrated primarily around three groups). A comparison of individual answers versus those provided by groups showed that in 24 cases (55%) the groups' rationales were unique – not identical or nearly identical to any individual answer (with an intercoder agreement of 83%). This suggests that students did not simply regurgitate individual ideas during the group activity (although, it is possible they ignored those ideas, which is equally problematic). For those that did provide rationales identical or nearly identical to an individual response, it was unclear if this was due simply to re-stating the original idea, or if they really believed the individual answer was best. These outcomes suggest the potential benefits of a script that engages students groups around the aggregated individual contributions of their peers.

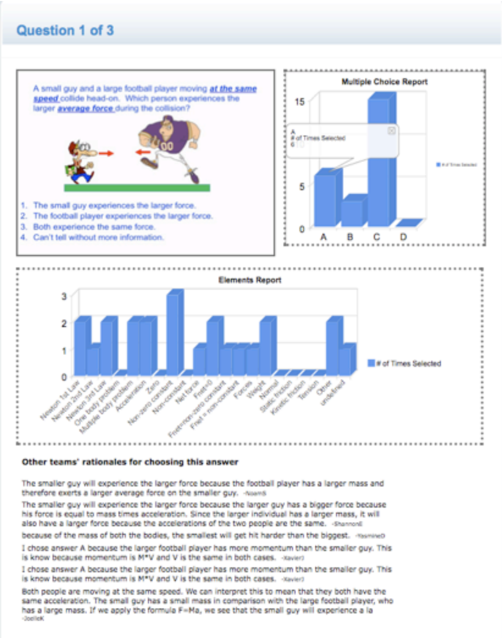

Figure 2: Aggregated student TARs for group activity

In post-interviews, the teacher stated that he found the real-time reports useful in understanding where students were having problems with the content prior to conducting the class. During the first class, the teacher decided to allow the lesson to run without changing the script, preferring to see how students fared in their small groups. However, seeing the students struggle on a particular question prompted him to intervene (i.e., adapt his script). Drawing from this insight, he then adapted the class orchestration more readily on the second day to address the issue as it arose, reducing the potential for student frustration.

One issue was the need for the teacher to refresh his laptop screen to see updates in student activities during the live activity. Although the teacher mentioned that overall the visualization was useful, the delay made it difficult for him to know what was happening in true "real-time," preferring to use it for post-activity discussion. The teacher relied instead on the large format displays to inform his in-class orchestration.

The results of this preliminary study point to the efficacy of certain tools for gaining insight into the state of student knowledge at different points within the script, and in aiding the teacher in making necessary adjustments. This study also highlights the limitations of certain tools within a live activity – particularly the visualization – given its inability to provide information at key moments within the script. Future designs need to better coordinate the flow of information based on teacher needs.

Iteration 2 – Adding student expertise groups and real-time feedback for the teacher

The second iteration aimed to further aid the teacher in orchestrating the script as well as to improve students' use of the aggregated work of their peers to inform their own understandings about physics topics. We designed a teacher report application for a tablet computer using a colour-coded matrix that displayed group performance on problem solving in real-time: green if answered correctly, red if incorrectly (Figure 3). The teacher could touch the icon of any problem to bring up an individual groups' TAR response, helping inform his understanding of how that group had approached that particular problem. The tablet was designed so the teacher could also use a group's TAR response to engage them in discussion if he noticed something interesting or erroneous in their response. We were interested in how this tablet application could provide new opportunities for understanding the state of the class' knowledge in real-time and how this affected the orchestration of class activities. Building upon the first iteration we also wanted to further understand what scripts better aided students in the depth of the reflections, and the role aggregated information played in forming these reflections. The two different conditions that were enacted to examine these differences are described below.

Design:

A similar activity to the previous iteration was enacted, where the teacher uploaded thirty-five homework questions, representing five distinct topic areas. Each student was assigned to one topic area, and received five (of seven in that area) problems for homework. During the smartroom activity, students were placed in groups of five (one student from each area), and given five questions – one from each area - that no member had seen before as homework. This complex tracking of prior exposure to problems, and selection of suitable items, was achieved using the S3 intelligent agent framework, and allowed for a design feature that would have been vexing in a traditional approach. For the first physics class, no aggregated information from peer homework was given to the student groups; rather, they relied only on group negotiation to solve the problems. During the second day, groups were given their peers' aggregated answers from both classes. The teacher was also given slightly different conditions: on day one, the teacher only had the large-format displays in the smart classroom for information about class activities; on day two the teacher was provided with the tablet for real-time updates.

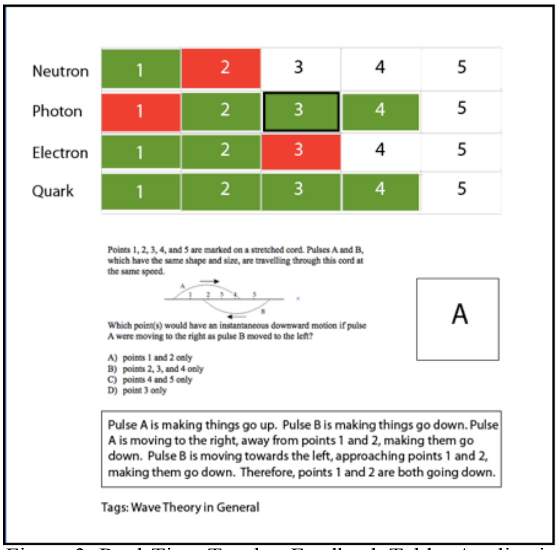

Figure 3: Real-Time Teacher Feedback Tablet Application

Data Sources:

Data collection for this iteration was similar to that of the previous design: 1) All student and group tags, answers, and rationales (TAR) were captured by the system; 2) Researchers collected field notes of the in-class activity; 3) Student and teacher interactions within the classroom were captured on video; 4) A post-activity discussion was held with the participants after the second day's run to gauge students' feelings about the intervention; 5) A follow-up debriefing of the activity was conducted with the teacher. Student TAR data was examined to see any changes in the correct responses between students' answering individually compared to in groups without the aggregated work of their peers (Day 1) and in groups with the aggregated work of their peers (Day 2). Individual student and group rationales were also examined using a four-point scale developed conjunction with the teacher to evaluate the depth of student understanding. A follow-up teacher interview gave insight into the effectiveness of the tools towards future refinements.

Findings:

Two researchers evaluated all student and group responses using the co-developed scale (with an intercoder agreement of 83%). Overall, the group on Day 2 that received the aggregated responses of their peers significantly outscored both the individual students during the homework phase ($t=4.13$, $p<0.01$, $df=51$), and the groups from Day 1 that were not provided with aggregated responses ($t=4.19$, $p<0.01$, $df=50$) (See Table 2). In groups, students got more questions correct both days (Day 1=83%, Day 2=84%) versus individually (71%), however both cases were only marginally significant. Taken together, these findings suggest that students in groups perform better than individuals in terms of correct answers, without or without access to the broader class' ideas, but that access to this information helps in the depth and quality of their reflections.

Table 2. Problem solving accuracy for individual homework, and two group work conditions.

Condition	Average Score
Homework	1.32
Day 1	1.21
Day 2	2.0

Similar to the previous iteration, the teacher was observed actively moving throughout the class, interacting with students where he felt necessary. At several points during the activity, the teacher was able to read the rationales being written by the groups (projected on the large format screens in the smart classroom) to prompt them to refine their thinking towards focusing on the deeper principles relevant to solving and understanding the problems, rather than focusing solely on the formulas and equations. As the intervention progressed the teacher adopted a catch phrase "words more than numbers", in response to what he observed in the class. The large format displays also allowed him to quickly look between the groups to get a sense of the state of the whole class, addressing groups that he felt needed his attention the most..

The teacher's interactions with the tablet elicited surprising results. Initially, he was very engaged with the tablet, clicking on group responses, reading rationales and watching for wrong answers. Eventually however, he abandoned the tablet, stating that it divided his attention and hampered his ability to monitor the class. He noted that although useful for seeing group errors, the information came too late to intervene at critical moments, and he could more effectively monitor the class by watching the large displays. This revealed the importance of thoughtful design - not only of technologies and materials, but also the need to understand the "temporality" of when information or interaction patterns are most relevant or helpful within an inquiry script.

Iteration 3: PLACE.Web, A persistent, collaborative inquiry environment for multi-context learning

Our most recent design builds upon our findings from the previous, formative iterations, and expands the design towards a persistent yearlong curriculum. We sought to add a dimension of student-contributed content, while still allowing the teacher to insert new materials, based on emergent patterns within the script. In PLACE.Web (Physics Learning Across Contexts and Environments) students are encouraged to capture examples of physics in the world around them (through pictures, videos, or open narratives), which they explain, tag, and upload to a shared social space. Within this knowledge community, peers are free to respond, debate, and vote on the ideas presented within the examples towards gaining consensus about the phenomena being shown, empowering students to drive their own learning and sense making. The visualization of student work was expanded to represent student ideas as a complex interconnected web of social and semantic relations, allowing students to filter the information to match their own interests and learning needs – making the knowledge not only collective but also extremely personal. The visualization also became the focal point of real-time smart classroom activities in which students leveraged the products of the class in the creation of challenge problems. S3 pedagogical agents coordinate these activities and inform the teacher of student knowledge at-a-glance. The tablet application was redesigned as a *student* application, allowing them to focus on communications with peers while the teacher relied on the large format displays to inform his orchestration. Tools were also developed to allow the teacher the ability to assess student work, review individual student progress, and to record their own reflections on class understanding to aid scripting decisions.

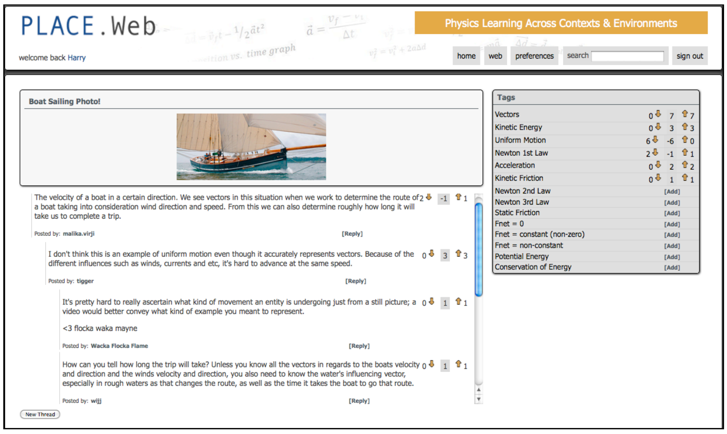

Figure 4: Example of PLACE.Web student negotiated artifacts.

Building upon the findings of the earlier studies, we designed seven key activities for the teacher to enact within the curricular script: Student development of phenomena for peer debate, voting, and discourse; Teacher created homework problems; Student created challenge problems for their peers; Smart classroom activities that draw from the collective knowledge base; In-class discussion around artifacts within the knowledge base; Student created longer reflections/investigations for peer discussion; And group development of shared narratives within the smart classroom. Although initial scripts were co-designed with the teacher, the activities were developed with as openly and flexibly as possible to allow the teacher to adjust their implementation as he saw fit within the context of the class' emerging knowledge.

Design:

This iteration involved two grade 11 physics classes (n=20, n=25), spanning three separate curricular units over a six-moth period: Kinematics; Force and Motion; and Energy, Work, and Power. The units were thematically connected, allowing content to carry over between each unit. To start, each student was given one concept (tag) from a list of 13 developed by the teacher as "fundamental" to the understanding of the grade 11 curriculum (as the class progressed students were given more concepts to work with). Students were expected to focus on their own assigned concept when capturing examples for inclusion in the community knowledge base. To assess how the depth of the negotiated discourse of the knowledge community approached expert descriptions, a selection of student submitted examples were given to graduate physics students (as experts), who were asked to tag (from the list of 'fundamental concepts') and describe in words how those concepts were being exhibited.

For each of the three units, we altered the designs of the script towards formalizing a set of interactions that (1) fostered the growth of the knowledge community, (2) supported the teacher in altering the scripts to address student needs, and (3) helped students to apply the knowledge base in service to their own individual constructivist learning. During the first unit we employed a "loose" script in which the activities within the script were specified, but the teacher was free to employ them at any time without prescribed conditions for their enactment. Students were expected to upload at least one example during the unit and to comment and vote on two of the examples of their peers. This was designed to see how actively the students would engage with the environment without a formalized script for how and when they would interact with it.

During the second unit, we more tightly structured the timing and implementation of the activities through the introduction of three new scripts. The "collective inquiry cycle," (CIC) where: (1) Students submit individual inquiry items to the knowledge base; (2) Collectively (at home or in class) students examine and tag peers' work, adding comments to explanations; (3) Teacher reviews the community knowledge, to prepare a discussion; (4) In-class activity engages students with collective knowledge artifacts chosen by teacher; (5) Students reflect individually. The second, "Design, Feedback, Revise" (DFR), where: (1) Students design an artifact (i.e. a lab report, or video); (2) Peers provide critique of the design based on science principles; and (3) Students revise their design and explain their revisions. The third, "Revisit, Reexamine, Reflect" (RRR) where: (1) Student revisits examples uploaded from the previous unit; (2) Student reexamines the example for new insights based on his/her evolving understanding of the curriculum; (3) Student submits a reflection on his/her new understandings. These scripts were enacted throughout the unit and the teacher was tasked with recording how the tool helped in providing insight when adjusting the script based on the emergent class knowledge.

The third unit was much longer, and allowed the teacher to be more directly involved with the students' information searching and discourse. It included a culminating group project, using the DFR script, in which students groups used the collective knowledge base as the information source for creating videos to explain real-world phenomena. In a smart classroom activity, the semantic web of student ideas was broadcast on eight interactive screens throughout the room, each with a different view of the student work. Students walked throughout the room collecting a set (akin to "example bingo") on tablet computers with their group, which were used as the basis for the challenge problem creation activity. After collecting their examples, the groups worked in the smart classroom to create their challenge problems, with the teacher aiding them as he saw fit.

This iteration provided many rich sources of data: 1) All student interactions and discourse were tracked by the site; 2) Researcher field notes collected during in-class activities; 3) Pre- and Post-tests to observe changes in student curricular understanding and epistemological views on science; 4) All of the collected teacher notes, and entries in the "curriculum journal"; 5) Pre-, Mid-, and Post-interviews with the teacher; 6) Video recordings of student interactions during smart classroom activities. In response to feedback from the students and teacher, small adjustments were made to the ways in which students interacted and received updates within the environment (e.g., to their individual student newsfeeds, or their ability to save drafts of their work, or the filtering abilities of the visualization.)

Findings:

While the third iteration is still in progress, findings are encouraging, as students are submitting content to the community, debating and voting on the work of their peers. Examinations of the discourse taking place suggests an evolving understanding of science content and inquiry processes. Several times the teacher used information from PLACE.Web to inform class activities, including using student submitted examples as a starting point for discussion. Student responses to questions suggest a deeper level of connection to physics principles.

Conclusion

These studies have begun the process of formalizing a set of scripts that successfully engage students in a knowledge community while providing teachers with the tools to adjust the scripts in response to emergent ideas within that community. These scripts must take into account both the longer (macro) scripts that are enacted over a long-term curriculum, and consider how they can support (and be supported by) in-class (micro) scripts. Further we have begun to formalize an understanding of the informational needs of the teacher in the execution of these scripts, and the role technology can play in both helping, and hindering, this execution. We are developing an understanding of the important role that a smart classroom infrastructure plays in supporting the orchestration and coordination of real-time knowledge building activities in ways that were simply not possible with traditional pen and paper approaches. These affordances allow students to coordinate their information seeking practices with a group or class towards a common goal. The results from the three studies also promote the role of community voting, debate, and individual reflection around user-created artifacts, as an effective means for developing deeper understandings of the curriculum. Visualizations of this work can also provide powerful means for filtering, sense-making and the re-application of aggregated student work in structured knowledge building activities.

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