Scaffolding a Knowledge Community for High School Physics

Mike Tissenbaum, James D. Slotta, University of Toronto, 252 Bloor St. W., Toronto, Canada
(miketissenbaum@gmail.com, jslotta@gmail.com)

Abstract: This paper presents a design study of a collective inquiry model for high school Physics, where student-contributions are captured, aggregated, tagged and represented in a coherent visualization. We have developed a flexible technology layer that supports the aggregation of peer responses, including the collection of student explanations and semantic tags. We investigate collaborative inquiry scripts and discuss how they must comprise both the (macro) scripts that are enacted over a long-term curriculum, and the (micro) scripts that are enacted in class. 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" today's 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 disciplines, where workplace practices are shifting towards large, data-intensive, multidisciplinary collaborations across ever-widening spatial and temporal scales (e.g., the Human Genome project).

A theoretical perspective from the learning sciences that is well suited to learning and instruction in the knowledge age 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 consider learning as a social process, and value the collective knowledge of their peers. Although difficult to enact (Sherin et al, 2004), the knowledge community approach has garnered renewed attention, partly as a result of Web 2.0 capabilities, which can support complex pedagogical constructs (Slotta & Najafi, 2010).

Using "Web 2.0" technologies, students are active participants in a knowledge community that is engaged in the production, aggregation, and assessment of science topics, with an emphasis on inquiry and collaboration (Peters & Slotta, 2010). The socially-oriented process of adding of meta-data (tags) to user-contributed content can provide opportunities to reveal meaningful connections and flexible real-time representations (Mathes, 2004). However, questions still remain about how such collections of content can best serve student learning and foster knowledge communities. Reflection and scripting, are two important aspects of such research and will be discussed in the present paper

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 (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), where many interactions take place asynchronously. Students are provided with increased opportunities to reflect on their own understanding, think critically about their peers' ideas, construct coherent arguments, and reconcile misconceptions, before adding to the public discourse (Garrison, 2003; Chi, 2000).

Another topic of interest to learning scientists is the notion of scripting and orchestration (Dillenbourg, Jarvela & Fischer, 2009), 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, 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. While teachers are the primary "orchestrators" of the script, this role 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

In this paper we present 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 a high school Physics course. We have developed a flexible 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. In the sections below, we outline our rationale for inquiry design in Physics, we describe the role scripting and orchestration play in the successful implementation of this curriculum, and we discuss the role of the "smart classroom" in supporting complex interactions in three successive iterations of our curriculum.

The research progressed through three design-based iterative advancements. The first two were formative, providing important information about student collaboration using 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, both at home and in the field. We worked closely with the teacher to develop designs, including a repository of user-contributed materials, and social and semantic tags, which 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 aid 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). 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, Tissebaum & Lui, 2011).

Iteration One – 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, and 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 individually solved a set of multiple-choice Physics problems as a 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, and an aggregated report of students' homework responses. By viewing the report and visualization before class, the teacher could 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, or as a post-activity discussion tool.

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. 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 viewed aggregated answers of the whole class ,reached consensus, and decided whether or not to re-TAR the question.

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 in-class activity field notes; 3) A follow-up debriefing with the teacher. The captured student data was examined to reveal changes in the accuracy of responses between students answering individually versus groups, and in their rationales. The field notes provided us with an understanding of how the students were engaging with the curriculum and their peers. Finally, the follow-up with the teacher provided insight into his perceived effectiveness of the added technology scaffolds in meeting 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, while 100% 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 read their peers' tags and rationales, and attempted to make sense of differences through discussion. Overall, student groups recorded forty-eight rationales with their answers. A comparison of individual answers versus group answers 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%) – suggesting that students did not simply reiterate individual ideas during the group activity (although, it is possible they ignored those ideas, which is equally problematic). For rationales that were 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 original answer was best. These outcomes suggest the potential benefits of a script that engages students groups around the aggregated individual contributions of their peers.

In the de-briefing, 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 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. The teacher revealed that although the visualization was useful, the need to refresh the screen made it difficult for him to know what was happening in true "real-time". Instead, he relied 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 Two – Adding student expertise groups and real-time teacher feedback

The second iteration aimed to improve students' use of the aggregated work of their peers and to further aid the teacher in orchestrating the script. Building upon the first iteration we wanted to further understand what scripts guided students to in depth reflections, and also the role aggregated information played in forming these reflections. In addition, we designed a teacher report application for a tablet computer that used a colour-coded matrix to display group performance on problem solving in real-time. The teacher could touch the icon of any problem to bring up an individual groups' TAR response, helping inform his understanding of the group's progress. We were interested in how this tablet application could provide new opportunities for understanding the state of the class' knowledge and how this affected the orchestration of class activities.

Design:

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 smart classroom activity, students were placed in groups of five (one student from each topic area), and given five questions (one from each topic area) that no member had seen before as homework. This complex tracking of prior exposure to problems, and selection of suitable items, made possible by the S3 framework, would have been challenging using the traditional approach. On the first day, students were not provided with aggregated homework content; rather, they relied on group negotiation to solve the problems. During the second day, groups were supplied with their peers' aggregated answers from both classes. The teacher was also given slightly different conditions: on day one, he only had access to the large-format displays in the smart classroom for information about class activities; on day two, he was provided with the tablet for real-time updates.

Data Sources:

Data collection for this iteration was identical to iteration one. Further, student TAR data was examined for 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 evaluated using a four-point scale, developed conjunction with the teacher, to evaluate the depth of student understanding.

Findings:

Two researchers evaluated all student and group responses using the co-developed scale (intercoder agreement of 83%). Overall, the group on Day 2 (score of 2.0) significantly outscored both the individual students during the homework phase (score of 1.32) ($t=4.13$, $p<0.01$, $df=51$), and the groups from Day 1 (score 1.21) ($t=4.19$, $p<0.01$, $df=50$). 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.

Similar to the previous iteration, the teacher actively moved throughout the class, interacting with students where necessary. At several points during the activity, the teacher read the rationales being written by the groups (projected on the large format displays) and prompted them to refine their thinking towards focusing on the deeper principles relevant to solving and understanding the problems. As the intervention progressed, the teacher adopted a catch phrase "words more than numbers", in response to what he observed in the class.

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 underscored the importance of thoughtful design, and cultivating a deep understanding of the interaction patterns that are most relevant or helpful within an inquiry script.

Iteration Three: A persistent, multi-context collaborative inquiry environment

In our most recent design 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 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 respond, debate, and vote on ideas, towards gaining consensus about the phenomena being shown. Student work was visualized as a complex interconnected web of social and semantic relations, allowing students to filter the information to match their own interests and learning needs. 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 coordinated these activities and informed the teacher of student knowledge at-a-glance. The tablet application was redesigned as a *student* application. 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.

Building upon the findings of the earlier studies, we designed six activities for the teacher to enact within the curricular script: (1) student-developed phenomena for peer debate, voting, and discourse; (2) teacher-created homework problems: (3) student-created challenge problems for their peers; (4) smart classroom activities drawn from the collective knowledge base; (5) in-class discussion around artifacts within the knowledge base; and (6) group development of shared narratives within the smart classroom. Although initial scripts were co-designed with the teacher, the resulting activities that emerged were flexible, 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 units. To start, each student was given one concept (tag) from a list of 13. The teacher considered these concepts to be "fundamental" to the understanding of the grade 11 curriculum. Over the six-month period, students were given more concepts to work with). Students focused on their 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 units, we altered the script design towards formalizing a set of interactions that (1) fostered knowledge community growth, (2) supported the teacher in altering the scripts to address student needs, and (3) helped students to use the knowledge base for their own individual constructivist learning. Across the three units two scripts were enacted that engaged students in six the activities mentioned above. The "collective inquiry cycle," (CIC) where (1) Students submitted inquiry items to the knowledge base; (2) Collectively (at home or in class) examine and tag peers' work, adding comments to explanations; (3) Teacher reviews the community knowledge, (4) In-class activity engages students with collective knowledge artifacts chosen by teacher; (5) Students reflect individually. The second, "Revisit, Reexamine, Reflect" (RRR) where: (1) Student revisits previously uploaded examples; (2) Reexamines the example for new insights based on his/her evolving understanding of the curriculum; (3) And submits a reflection on his/her new understandings. In the third unit a culminating smart classroom activity was added where students leveraged the collective knowledge base to collaboratively highlight and correct violations of Physics in Hollywood films. During this activity the S3 agent framework responded students work in real-time, altering group configurations, sending specific and timely content to students and the teacher on their tablets, and to the interactive large-format displays around the room.

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 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 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 executing 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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