# Smart Classrooms for Knowledge Communities: Learning Across Contexts in Secondary Science

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As society enters the "Knowledge Age" everyday workplace practices are increasingly shaped by new and advancing technologies (Zuboff, 1988; 2002). This change is particularly pronounced in the areas of Science, Technology, Engineering, and Math (STEM) where practices increasingly emphasize collaboration, large, shared datasets, and flexible methodologies (Gray & Szalay, 2007). A failure to integrate these practices in the ways students learn STEM content and prepare for STEM careers could hinder students' future success in related careers (NSF, 2008).

Unfortunately, the integration of such "21st century knowledge skills" into classroom activities still lags far behind student engagement outside of school (Buckingham, 2007; Collins and Halverson, 2010). One promising research area is that of "socially-oriented" (e.g., Web 2.0) models of learning that leverage the collective contributions of all community members in the production and aggregation of content (Buckingham 2007; Ulrich et al., 2008; Ito et al., 2009). The use of carefully constructed meta-data (tags) for student-contributed content provides opportunities for students and teachers to filter, sort, and use their collective products (Al-Khalifa & Davis, 2006). This also offers opportunities for flexible data representations and visualizations, identified as an important element of science inquiry learning (Krajcik et al., 1998). Moreover, collaboratively developed student content can also provide "real-time" insight into the state of classroom knowledge, allowing teachers new opportunities for evidence-based decisions and classroom orchestration (Dillenbourg & Jerman, 2007; Lui, Tissenbaum & Slotta, 2011).

This paper presents a design study of a technology-enhanced collective inquiry model where student contributions are captured, aggregated, tagged and re-visualized towards enabling students to work as a "knowledge community" negotiating their understandings of Physics topics. In conjunction with this research, we have developed a new "smart classroom" technology environment that supports all student activities in the classroom, at home and in the field.

## Knowledge Communities, Inquiry, and Reflection

As seen in the work of Fostering Communities of Learners (Brown and Campione, 1996) and Knowledge Building (Scardamalia & Bereiter, 1994), knowledge communities can provide students with opportunities to connect with peers, ask questions, develop ideas, and investigate issues as a community — mirroring many features that are hallmarks of today's socially-oriented "Web 2.0" knowledge communities (e.g., Facebook, Flickr, YouTube). Researchers have noted the valuable epistemological outcomes that occur when students move away from "learning for themselves" and toward a perspective of "learning within a community" (Palincsar & Brown, 1984; Slotta & Najafi, 2009; Bielaczyc & Collins, 2006).

Another commonly advocated feature of inquiry learning is regularly embedded reflection within student learning activities (Bielaczyc & Collins, 2006; Quintana et al., 2004; Linn & Eylon, 2006; Krajcik et al, 2008). Within a digitally mediated knowledge community, reflection can help students monitor their own understanding, recognize, and reconcile gaps in their knowledge as they post their ideas and respond to those of their peers (Sorensen, 1999; Johnson & Aragon, 2003).

Recent technology advances offer new ways to mediate the delivery of materials and the coordination of activities in support of inquiry and knowledge communities (Linn, Husic, Slotta & Tinker, 2007; Slotta & Linn, 2009). These advances include the ability to connect students through rich, multi-media experiences, the automatic connection of student work by intelligent digital agents, and customizable visualizations of student work, depending on the needs of its recipients (Lui, Tissenbaum & Slotta, 2011).

### Scripting and Orchestration of Learning Activities

When teachers enact complex pedagogical designs (i.e., collaborative inquiry and technology), they must respond to the unique contexts (both formal and informal) and configurations (individual/small group/whole class interactions) in which learning takes place (Lemke, 2000). The description of these factors is often referred to as a "script", and includes the timing and sequencing of activities, planned moments for student reflection, and clear roles for students and teachers (O'Donnell & Dansereau, 1992; Dillenbourg & Jermann, 2007, Hakkinen & Makitalo-Siegl, 2007). By embedding such scripts within a technology-enhanced environment, we can scaffold their various elements, and capture the products of interactions, providing them to the teacher both synchronously and asynchronously. Such feedback can provide the teacher with insight into students' understandings of the curriculum, supporting classroom orchestration through evidence-based decisions (Dillenbourg, Jarvela & Fischer, 2009). We are developing a flexible, open source "smart classroom" infrastructure called SAIL Smart Space (S3 - see Table 1) that integrates technologies to support collaborative inquiry and knowledge construction scripts, including teacher orchestration supports.

**Table 1: SAIL Smart Space (S3) Architecture**

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

## Research Questions

The present study addresses the question of how to design curricular activities where students contribute content within a knowledge community and develop a deep understanding of science topics. To guide our development of activities, we incorporate the principles of Knowledge Community and Inquiry (Slotta, 2007; Slotta and Peters, 2008). Reflection is included as a primary component in supporting students as they make personal sense of community knowledge, and apply that knowledge within consequential learning tasks. Specific research questions include:

1. What forms of collaborative knowledge construction best support a knowledge community approach for high school physics?
2. What inquiry activities will engage students with the collective knowledge in such a way that they develop a deep understanding of physics topics?
3. How can we support teachers in using student-contributed materials for the planning and orchestration of curricular moves?

## Method

This research employs a design-based research 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 work together developing technologies, curricular materials and activity flows. The study is situated within an urban high school, with all activities occurring as part of students' regular homework and as real-time collaborations within the smart classroom.

## Iteration 1 – Tagging and Solving Physics Problems

### *Design Goals*

Our first design was aimed at investigating notions of aggregation and representation, as well as to pilot test our technology infrastructure for coordinating learning within a physical classroom setting. The study engaged students in the smart classroom around the domain of force and motion, with the goal of helping students understand the underlying principles behind their problem solutions. We investigated the impact of aggregating students' multiple-choice problem solving within small groups on students' accuracy of tagging principles, as well as their solving of qualitative and quantitative physics problems. We also observed the impact of aggregated visualizations on the teacher's orchestration of student activities.

### Participants

A total of thirty-two students across two grade 12 Physics classes took part in the study. Two sessions were conducted over two days, with sixteen students in each.

### Design

Students were organized in four groups as they worked synchronously to individually Tag, Answer and provide Rationales ("TAR") for a set of sixteen multiple-choice questions. Once completed, the groups were shown four of the questions again, along with the aggregated TARs from the whole class. They were asked to form a consensus and then "re-TAR" those questions. The groups were then presented with four quantitative problems, and asked to choose a set of elements and equations that would help setup the long problem for solving, and explain their choice. During the first day's activity, student groups collaborated around a single shared laptop; on the second day, each groups' work was shown on large-format displays in front of them.

### *Findings*

Students working in groups performed closer to the expert model than individuals, in measures of tagging accuracy and structuredness (Hasemann & Mansfield, 1995 – Figure 1). Additionally, these gains increased in the large display condition as compared with the laptop only condition (Figure 2), although there are possible confounds, given the fixed ordering of those conditions. Still, a possible explanation that matched our observations is that the large-format displays provided the teacher with the ability to see groups' summary responses in "real-time," providing opportunities for meaningful interactions. In one episode, the teacher was watching one group discussing the class' aggregated answers and saw that no students from the individual phase had approached the problem correctly. In other words, the aggregate data was incorrect! The teacher adapted in real-time, advising students (in this case) not to listen to "the wisdom of the crowd."

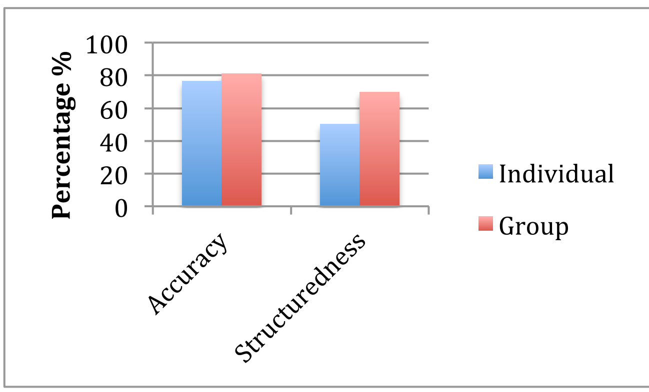


**Figure 1: Average accuracy scores were 80.94% (groups) compared to 76.57% (individuals), For structuredness, groups (69.73%) significantly outperformed individuals (50.11%) by 19.62%, $F(1, 30) = 10.756$, $p = 0.003$.**

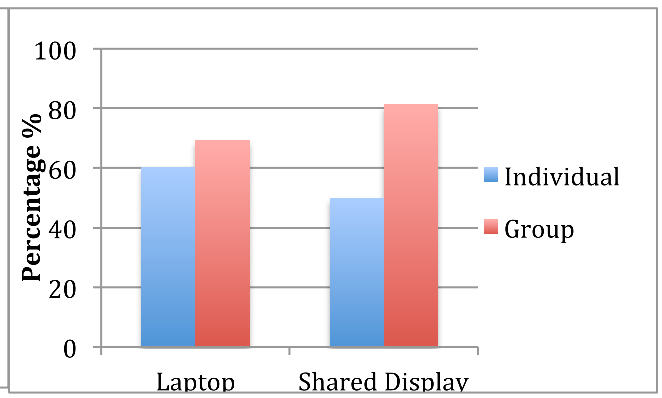


**Figure 2: Both conditions showed better group performance versus individual performance. However, shared display groups gains (from 50% to 81.25%) were greater versus only laptops (from 60.38% to 69.23%).**

## Iteration 2 – Adding Homework to Bridge Learning Contexts

The second iteration of our curriculum built upon our previous findings. To save class time, we moved the individual TAR step to a homework activity, and provided the teacher with a Web portal allowing him to see student results before class - aiding in his orchestration of upcoming activities.

### Participants

Two new physics classes were engaged (n=36) with twenty students (n=20) in the first class and sixteen in the second (n=16). The same group of researchers, technologists, and teachers engaged in co-designing the activity.

### *Findings*

Overall, groups faired significantly better at solving problems (81% overall accuracy) than individuals working at home (50% overall accuracy), with $t(20)=2.85$, and $p<0.05$. One problem, for example, had marked improvement with 45% of individual students answering incorrectly, but 100% answering correctly when working in groups. A possible confound here is that the groups were solving problems that they had seen in homework the night before.

Comparing individual rationales versus group rationales showed that in twenty-four cases the groups' rationales were unique - not identical or nearly identical to any individual answers (with an intercoder agreement of 83%). During post-interviews the teacher noted that the portal view had been useful in understanding student ideas both prior to class as well as during the orchestration of in-class activities.

## Iteration 3 – Adding Student Expertise areas, and Teacher Tablet

### *Design Goals*

We further refined our curriculum, adding student specialization groups, addressing confounds identified above, and adding a teacher tablet PC to further enhance opportunities for class orchestration. A new tablet application for the teacher used a colour-coded matrix that displayed group performance on problem solving in real-time – green if answered correctly, red if incorrectly.

### *Participants*

This iteration also engaged another two physics classes with 33 students in total (first day n=15, second day n=18) and the same co-design team.

### *Design*

Thirty-five questions were uploaded, representing five distinct topic areas. Each student was assigned to one topic area, and received five (of 7 in that area) problems for homework. During the smartroom activity, students were placed in groups of five (one student from each area), and given 5 questions – 1 from each area - that no member had seen before as homework. The complex tracking of prior exposure to problems, and selection of suitable items achieved through the S3 intelligent agent framework 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 for information about class activities; on day two the teacher was additionally provided with the tablet for real-time updates.

### *Findings*

An examination of individual students' rationales versus group rationales indicated that the groups who had received the aggregated individual answers provided significantly deeper rationales than both other conditions (**Figure 4**).

| Condition | Average Score |
|---|---|
| Homework | 1.32 |
| Day 1 | 1.21 |
| Day 2 | 2.0 |

**Figure 4: Average rationale scores of the Day 2 "aggregated responses" group significantly outscored both the individual homework (t=4.13, p<0.01, df=51) and Day 1 (t=4.19, p<0.01, df=50) conditions. Based on a 4 point rating scale developed in conjunction with the teacher measuring the depth of student answers (percent agreement between intercoders 91%).**

Teacher interactions with the tablet elicited surprising results. Initially, the teacher was very engaged with the tablet, clicking on group responses, reading rationales and watching for wrong answers. Eventually however, the teacher abandoned the tablet, stating 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.

## Discussion

Taken together, the three iterations point to several conclusions about the use of technology-enhanced learning environments to promote collective inquiry in secondary science classrooms. First, technology can serve to capture and aggregate large amounts of student data, representing it in ways that are personally relevant to students and teachers alike. For students it provided insight into the work of their peers and engaged them in collaborative problem solving. For the teacher, the aggregation and re-representation of student work is a powerful tool for gaining insight into the state of student knowledge, enabling them to refine the script before, and orchestrate it during classroom enactment. These ideas will inform our subsequent designs of a more integrated physics course (4 months in duration, and the topic of current co-design efforts). This includes a new construct of PLACE.Web – a persistent, semantic network representing the combined products of a knowledge community, centered around the major topic areas of the physics course.

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