

Developing an Orchestrational Framework for Collective Inquiry in Smart Classrooms: SAIL Smart Space (S3)

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Abstract: This paper describes PLACE - a 12-week cross-contexts curriculum for grade 11 physics that engaged students at home, in class, in their neighbourhoods, and in a smart classroom setting. Using a design-based research approach we introduce a smart classroom infrastructure (SAIL Smart Space; S3) and investigate its role in supporting students in the curriculum as a knowledge community. The present paper focuses on the culminating smart classroom activity, where students use the community knowledge base to scaffold their solving of ill-structured physics problems involving popular Hollywood movies. We examine the efficacy of the tools and the environment, including software agents and data mining approaches that serve to define S3, and help orchestrate the flow of activities, materials, and students during the activity's enactment. We conclude with a set of design principles that support collaborative inquiry in smart classrooms and across learning contexts.

Supporting Knowledge Communities and Inquiry Learning

Within the field of learning science there is a growing call to think of classrooms as knowledge communities where students approach learning as a collective endeavor (rather than an individual one), towards solving authentic and personally relevant real-world problems (Slotta & Najafi, 2010). The knowledge community approach, with its focus on user-contributed content and student driven inquiry, is particularly well suited for investigating learning that goes beyond the traditional confines of classroom settings. For example students may visit a local stream or waterway to investigate issues around water quality (Hsi, Collins & Staudt, 2000), or a playground to investigate geometry principles (Milrad et al, 2013). Within this work there is a corresponding challenge of connecting this learning across contexts back into the classroom in meaningful ways.

In response, a promising new approach to supporting such designs is the digital embedding of aspects of the community's inquiry in the walls, ceilings, and floors of the physical learning environment. Examples include a simulated ecology of bugs living in a classroom's walls (Moher, 2006), and evolutionary simulations of rainforest fauna and flora over millions of years (Lui & Slotta, 2013). By connecting students to these inquiry environments with personal, portable and connected computing devices (such as tablets), we can unchain them from traditional classroom configurations, instead fostering a dynamic "smart classroom" model where students can move throughout the room engaging in spatially index real time collaborative activities (Slotta, 2010).

The enactment of complex real-time inquiry activities places a high load on teachers, requiring them to simultaneously manage changing student roles and groups, assign activities, and organize materials – including potentially large and diverse community-generated content from the knowledge base (Tissenbaum & Slotta, in press). The supporting of teachers and students in the enactment of such activities is often termed orchestration (Dillenbourg, Jarvella, Fischer, 2009), and has been highlighted as a major design challenge in the learning sciences (STELLAR, 2011). In response, technology enhanced learning spaces like smart classrooms, may offer a means for supporting the orchestration of such curricula, including tracking student movement within the room, providing procedural scaffolds, and making real-time decisions including student group formation and the delivery of timely materials (Tissenbaum & Slotta, 2013).

In order to investigate the role that a smart classroom could play in supporting a knowledge community curriculum, we needed both a pedagogical model and an underlying technology infrastructure. The pedagogical approach we used for this study is the Knowledge Community and Inquiry (KCI) model, which engages students to work collectively, contributing, tagging and improving content in a shared knowledge base that serves as a resource for subsequent inquiry. In KCI, inquiry activities are carefully designed so that they engage students with targeted content and provide assessable outcomes, allowing students some level of freedom and flexibility but ensuring progress on the relevant learning goals (Slotta & Najafi, 2013). The teacher also plays a critical role within a KCI curriculum, as they must be able to adapt (orchestrate) the designed script "on-the-fly," based on emergent themes and community voices (Tissenbaum & Slotta, 2013).

SAIL Smart Space (S3) – a Technology Framework for Smart Classrooms

In order to successfully enact the kinds of complex designs required for KCI, we needed a flexible and adaptive infrastructure to support the design and orchestration of collaborative activities that include spatial, social, and semantic dependencies. To this end, we developed SAIL Smart Space (S3), an open source framework that coordinates complex pedagogical sequences, including dynamic sorting and grouping of students, and delivery of materials based on emergent semantic connections. S3 allows the physical space of classrooms or other learning environments to play a meaningful role within the learning design – either through locational mapping

of pedagogical elements (e.g., where different locations are scripted to focus student interactions on different topics) or through orchestrational support (e.g., where physical elements of the space, like projected displays), help to guide or coordinate student movements, collaborations or activities. S3 was developed to add a level of intelligence to classrooms or other learning environments, including real-time data mining and computation performed by intelligent agents to support the orchestration of inquiry scripts. A key component to these agents is that although their roles are well defined within the activity (e.g., grouping students with peers they have not previously worked with), who (or what) will satisfy these conditions cannot be known *a priori*, rather they emerge during enactment (requiring agents to process information in real-time; Tissenbaum & Slotta, in press).

In order to investigate S3 as a smart classroom infrastructure to support collaborative inquiry, three questions have driven our research: (1) How can S3 support students' inquiry activities? (2) How effective are intelligent software agents and data mining in providing students with needed materials and enacting specific pedagogical moves? (3) How does S3 support the teacher in orchestrating class activities? Below, we discuss an implementation of S3 within a grade 11 physics classroom, highlighting specific orchestrational supports (including the design of intelligent agents), and evaluating their effectiveness for supporting classroom inquiry.

Methods

We employed a co-design methodology (Roschelle, Penuel & Shechtman, 2006) working closely with a high school physics teacher to ensure that he was an active voice in the design and that the designed intervention fit his goals for the students and expectations for student learning. As the study took place in a "real class" (rather than a canned lab) a design based-research approach was employed (Wang & Hannafin, 2006). Generally, design-based research does not attempt to validate a particular curriculum, rather it strives to advance a set of theories on learning that transcend the particulars in which they were enacted (Barab & Squire, 2004). As such, a major outcome of this research was the design of the curriculum and supporting technologies themselves. To evaluate the enacted design we used a mixed methods approach to triangulate the data and get a more complete picture of the intervention (Mason, 2006). Sources included pre- and post-interviews with teacher and students, server logs, the user-contributed artifacts, and video and audio recordings.

Design of the KCI curriculum

In order for the smart classroom to be more than a supplemental activity, we needed to develop a complete curriculum in which the smart classroom was one of several learning contexts, integrated with activities across classroom and home settings. We also wanted to investigate how the smart classroom could leverage student-contributed content for authentic learning activities, and we therefore also needed the curriculum to produce artifacts that could be reused in meaningful ways. To this end, we worked closely with the high school Physics teacher to develop a curriculum that implemented KCI, including collaborative and collective forms of inquiry and critical reflection. In initial co-design meetings with the teacher he identified two main goals for the curriculum: First he wanted to help students recognize "physics in their everyday lives" and bring this view back into the traditional class setting; Second, he wanted a way for students to develop a coherent understanding of the underlying physics principles of the course, and connections amongst them (i.e., to "see that all the principles are tied together"). In response to the second goal we began by generating set of fourteen "core" principles (Table 1) that the teacher felt were of core relevance to the content of the course.

Table 1: Grade 11 fundamental principles for kinematics, force and motion, & work, energy, and power

• Vectors	• Acceleration	• $F_{net} = 0$	• Kinetic Energy
• Newton's First Law	• Uniform Motion	• $F_{net} = \text{Constant (non-zero)}$	• Potential Energy
• Newton's Second Law	• Kinetic Friction	• $F_{net} = \text{non-constant}$	• Conservation of Energy
• Newton's Third Law	• Static Friction		

We then co-designed a 12-week grade 11 physics curriculum, named PLACE (Physics Learning Across Contexts and Environments), which guided students to capture examples of physics in the world around them (through pictures, videos, or open narratives). PLACE was organized into three major units covering the first three units of the course: (1) Kinematics, (2) Forces and Motion, and (3) Work, Energy, and Power. For each unit, we developed a script that allowed students to upload, tag, and interact with physics examples.

For each unit in the curriculum students were required to upload their own found examples of physics principles (i.e., from their everyday life experiences) to a shared social space, including tags and explanations according to the relevant physics principles. The wider class community was encouraged to respond to these user-contributed artifacts: debating tags or explanations, voting, and adding new tags – with the stated aim of developing consensus about each item. Students were required to upload at least one example and to complete the *idea refinement script* on at least two of their peers' examples: (1) voting on existing tags and/or adding a new tag, (2) voting on the contributions of their peers, and (3) adding a reflection or rationale of their own. This ensured that students focused on the principles, reflected on the work of peers, and added their own thinking.

Students were also encouraged to upload their class lab reports, to gain feedback on methodologies and results and to connect them to the contributed examples. The teacher also developed homework multiple-choice problems, which the students solved using a script similar to the *idea refinement script*, where they tagged, answered and reflected on the problem. In-class, students were given further inquiry tasks, and asked to develop “challenge problems” for their peers, which built upon examples from the community’s knowledge base.

The products of these various inquiry activities became a dynamic knowledge base used within the community from one part of the overall unit to the next. This knowledge base, called *PLACE.web*, served as a resource for a culminating smart classroom activity where students applied what they had learned in the three units to solve ill-structured physics problems relating to selected Hollywood movie clips. The smart classroom environment, detailed below, was called *PLACE.neo*, and provided an important technology enhanced environment in which we could develop and test the orchestrational framework that is at the heart of this paper.

Developing S3: Orchestrating Cross-Context Inquiry in PLACE

To help students work as a knowledge community at home, in their neighbourhoods, and in class, we needed to develop a technology environment that facilitated the various interactions and knowledge contributions required by our curriculum. Consistent with Scardmalia and Bereiter’s (2006) argument that the technology environment (in their case, the Knowledge Forum) should be developed to support the particular epistemic and pedagogical forms within the research (in their case, knowledge building), we needed to develop specific software tools to support our own designs around KCI. S3 was developed to support student interactions, data structures, and pedagogical flow, including two specific software systems: *PLACE.web*, a collaborative social network, which supported students in contributing and engaging with the products of their teacher and peers; and *PLACE.neo*, a smart classroom environment in which the culminating Hollywood physics activity was orchestrated. Below we describe both learning environments, their role in supporting student interactions across context and as a knowledge community, and the role of intelligent data mining and software agents in facilitating these actions.

PLACE.web

The *PLACE.web* learning environment consisted of five distinct interaction spaces for students in support of the scripted activities described above: (1) The student status page, which showed aggregated newsfeeds that provided students with updates on the community knowledge and their own contributions; (2) The contribution upload page, where students uploaded their examples; (3) The user contribution discussion pages; (4) The assigned homework pages; (5) And the “Associative Web”- a visualization of the community knowledge, showing a complex interconnected web of social and semantic relations, where students could filter the resources to match their interests or needs.



Figure 2. The smart classroom with (1) An interactive whiteboard that orients students towards a specific Hollywood scenario, aggregates scenario specific student contributions and facilitates idea negotiation; (2) A second board with a different scenario; (3) Individual tablets provide students instructions, allow them to access the knowledge base, and contribute ideas to the shared display; and (4) An ambient display showing where students are in the room, completed tasks and time left in the current task.

PLACE.neo

An important goal of this project, in terms of developing S3, was to create a culminating activity (i.e., the Hollywood physics activity) where students needed to use materials from earlier co-constructed knowledge as a resource for an inquiry project. This would support our design of S3 intelligent agents and other features that could gather and distribute materials, assign student groups, and coordinate the pedagogical flow of activities. The overall script for the Hollywood physics activity involved three micro-scripts that spanned home, classroom, and smart classroom settings, At home, students were tasked with reviewing a collection of problems drawn from the proceeding 12 weeks (including student generated challenge problems), verifying the principle tags that had been applied by their peers, and adding equations that might be used in solving the problems. In

class, students worked in small groups to achieve consensus on a “final set” of the tags and equations for each problem. The resulting set of problems, tagged with principles and equations, were then used as raw materials for the final smart classroom script, where students would be orchestrated in a complex sequence of rotating small group assignments to set up and solve the Hollywood physics problems.

When students entered the smart classroom they were presented with four scenarios drawn from popular Hollywood movies (e.g., from the movie Ironman, a short scene where he survives a ballistic fall to earth). Each video was shown in one quadrant of the room (Figure 2) on a large display, together with other information added by students progressively throughout the activity. The activity was broken into four different steps: (1) Principle Tagging; (2) Principle Negotiation and Problem Assignment; (3) Equation Assignment, and Assumption and Variable Development; and (4) Solving and Recording. In each of these steps, intelligent agents played a role in assigning students to a new group (i.e., “move from video A to video D”) and coordinating the inquiry activities in the next step. This included distribution of materials (e.g., presenting the group with a set of equations that were datamined according to the tags the previous group had added), communications with the teacher, and coordination of group activities (e.g., consensus or voting).

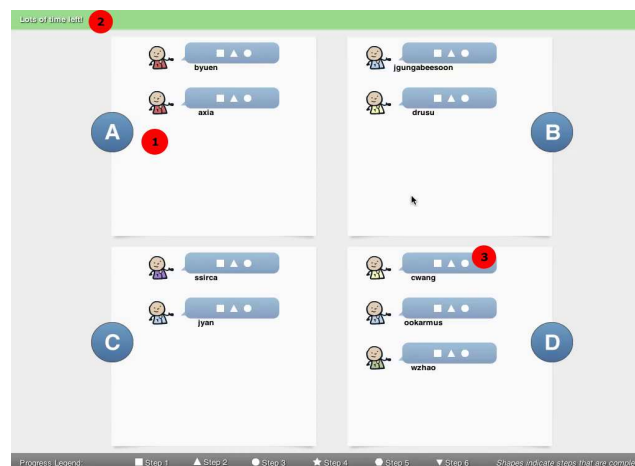


Figure 3: The ambient display (1) tracked each student within the room - when students moved location (or were sorted by an agent) their avatars moved on the display; (2) the timing of activities was tracked using a colored bar at the top of the display, which moved from solid green to flickering red time ran out; and (3) updated student progress by displaying an icon next to their avatar on the completion of each task.

The physical design of the room was a major consideration in supporting classroom orchestration. Similar to successful Problem-Based Learning (PBL) approaches, we wanted to support the teacher as a “wandering facilitator” (Hmelo-Silver, 2004). To this end, in a manner similar to the use of post-it boards in PBL, we placed the products of inquiry (the videos and collaboratively constructed student work) on the wall-mounted displays (Figure 2). This wandering facilitator model, which includes the demands of managing student groupings, monitoring the timing of tasks and supporting their inquiry with resources from the knowledge base, produces high levels of “orchestrational load” (Dillenbourg, 2012). To reduce this load we developed several technical supports. First, following a recent method shown to be effective (Alavi et al., 2009), we designed an ambient display for the front of the smart room (Figure 3). A teacher tablet was also developed, iterating on observations and feedback from previous designs (Tissenbaum & Slotta, 2012), from a device that showed student work *post hoc* (which the teacher could not act upon), to a regulatory orchestrational tool. This version of the teacher tablet showed him where each student was within the script and alerted him when he was needed to approve a group’s work (at the end of Step 3). The goal of these devices (the display and the tablet) was for them to sit at the periphery of the teacher’s awareness so that they only needed to be attended when necessary (Ishii et al., 1998).

Another critical support in managing the orchestrational load of the teacher was the use of intelligent software agents and real-time datamining, which were able to respond to the emergent class patterns in order to make on-the-fly decisions. During the smart classroom activity, four agents were implemented: (1) *The Sorting Agent* sorted students into groups and assigned room locations first (between Step 1 and Step 2) based on the frequency of their tags at each board during Step 1; and the second (between Steps 2 & 3) based on placing them students they had not previously worked with; (2) *The Consensus Agent* monitored groups requiring consensus to be achieved among members before progression to the next step; (3) *The Bucket Agent* coordinated the distribution of materials to ensure all members of a group received an equal but unique set of materials (i.e., problems and equations in Steps 2 & 3); and a *Student Progress Agent* which tracked individual, small group, and whole class progress to send status updates to other devices (e.g., the teacher orchestration tablet).

To support student participation the smart classroom activities, we developed tablet applications and interactive displays. Students' personal tablets facilitated their login at each zone, provided task specific materials and instructions, and collaboration support. Any student work done on his/her tablet while in a zone (e.g., adding tags, suggesting variables) instantly appeared on the zone's interactive display, which also held a persistent representation of all of the student-negotiated contributions. These displays were also used during group negotiation phases (e.g., deciding which equations would help in solving the video), where students physically dragged the individually suggested items into "Yes" or "No" boxes until consensus was reached.

Results and Discussion

In evaluating PLACE, two forms of analysis are important: 1) the inspectable artifact of PLACE, including the tools and the environment, including software agents and data mining approaches, that serve to define S3, 2) the student produced artifacts and collaborations that characterize learning in a KCI model. The present paper focuses on the first analysis, confirming that PLACE was enacted according to its design, specifying the technology elements that allowed such an enactment. One outcome of this work will be a set of design principles that support collaborative inquiry in smart classrooms and across learning contexts.

Student Contributed Content

In total, 169 student examples were created, with 635 total discussion notes contributed around those examples. Students also attached 1066 principle tags to the examples and cast 2641 votes on those tags. On average, students uploaded 3.84 examples, which is greater than the requirement of 3 (one per unit), suggesting active community engagement. Figure 4 shows the times of day at which students contributed to the knowledge base, with uploads or comments made at nearly every time except 3am to 6am. This highlights the ability of PLACE to seamlessly connect students within their overall community whenever they felt the desire to take part, with 53% of the contributions taking place outside of school hours (4pm-9am).

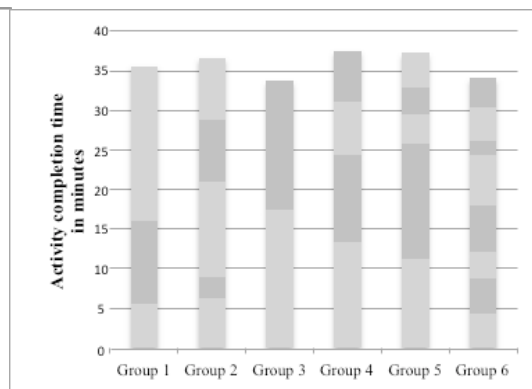
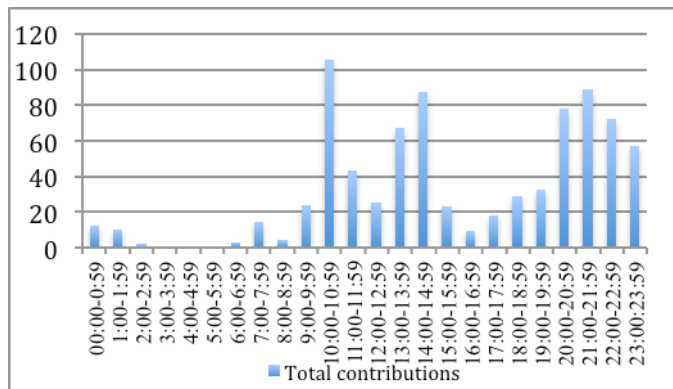


Figure 4. Student contributions to PLACE.web by time of day

Figure 5. How many problems Bucket Agent sent to each group, and time spent on each.

During the "challenge problem" script, student groups (n=3 or 4) were tasked with developing problems for the class to use as review, drawing from the wider knowledge base of peer-contributed examples. The script successfully engaged students in leveraging the collective knowledge base towards developing new objects for peer engagement and investigation. In total, 13 challenge problem were developed by the groups, each referring to on average 2.23 examples from the knowledge base. The Associative Web employed the underlying S3 data mining structures to support students in the activity, helping them find examples that matched their expertise groups and supported their creation of challenge problems. Post-interviews indicated that students found the Associative Web very useful for filtering the overall knowledge base and finding artifacts that matched their search criteria, noting that it "made it clear what examples are related to our concepts, because you could see what example was related to more than one of the concepts, and it's easy to browse through multiple areas."

S3 Orchestration Across Contexts: The Hollywood Physics Culminating Activity

Within the culminating activity, students were able to access, contribute to, and use the knowledge base at home, in class, and in the smart classroom. The activity was an important test of S3's capabilities to support seamless orchestration of learning activities, and the intelligent software agents and data mining were central to our success. The following sections address how S3 supported the learning within and across these contexts.

Orchestration of the at-home activity: At home students were scaffolded in answering a subset of problems from the knowledge base depending on their “expertise groups” from the previous units. S3 agents were used to ensure that students representing all fourteen principles saw each problem.

Orchestration of the in-class activity: In-class, the S3 agents successfully grouped students and facilitated consensus building on homework problems. Two items were of particular interest to this study. First, was the ability of S3 to capture the individual student work (i.e., the assignment of principles and equations), and to re-visualize them as aggregates for the in-class activity. This highlighted S3’s ability to effectively contextualize artifacts from the knowledge base based on the scripted activity. Second was the effectiveness of the *Bucket Agent* in orchestrating the real-time distribution of problems to individual groups. As soon as a group finished a problem, the *Bucket Agent* dipped into the “bucket” of problems and sent the group a new one, until the bucket was empty. This allowed a large collection of resources to be distributed to groups as they worked in parallel, such that all the resources were attended to in a single 60-minute class and every group finished within 3 minutes of each other (Figure 5). In this way, agents were able to accommodate variations in resource difficulty and group skill levels (i.e., some resources were more challenging and some groups were quicker).

		Teacher Orchestration Move						
		Check Status	Explain Task	Start Task	Check Timing	Check/Assign Location	Clarify Task	Approval Task
Orchestration Technology	Teacher Tablet	11	4	17	0	0	0	6
	Ambient Display	2	0	1	12	10	0	0
	Student tablet	8	6	0	0	0	1	0
	Large Format Display	2	0	0	0	0	11	0
	None	4	6	0	2	4	3	0

0
 1-5
 6-10
 11-15
 16-20

Figure 6. Frequency of teacher orchestration moves

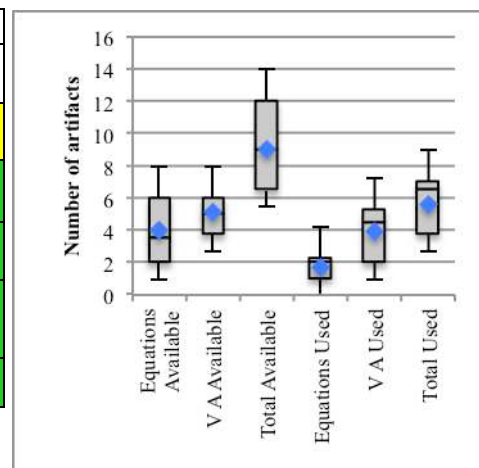


Figure 7. Negotiated Equations, Variables and Assumptions (VA) and their use in solution.

Orchestration of the smart classroom activity: The S3 agents successfully responded to emergent student actions (i.e., actions that were not known or knowable beforehand), drawing on semantically relevant artifacts from the community knowledge base to support follow-up tasks. During Step 2, the *Bucket Agent* supplied each group with problems whose principles matched those that had been negotiated by students for their scenario. The agents connected, on average, 23 problems to each scenario, distributed evenly across all group members, who then promoted 3.4 problems on average; these were negotiated down to 2.6 on average. During Step 3 (“Equation Assignment”), the *Bucket Agent* drew equations from the knowledge base, which had been tagged in the pre-activity, to the negotiated problems, to serve as a further resource for students. From these agent-filtered equations, students recommended an average of 4.9 equations, which were negotiated down to 4.3 on average.

The *Sorting Agents* also successfully sorted students based on the frequency of the tagging after Step 1, and the condition of working with new group members after Step 2. The ability of these agents to sort students based on pre-defined pedagogical goals where the students who would fit their conditions could not be known *a priori* was an exciting outcome. Grouping and moving students is a complicated and time intensive task in any classroom, and being able to automate it *and* include the processing of emergent patterns (an impossible task for a human in real-time) provided critical support for managing of orchestrational load. The success of the sorting agents used in PLACE holds promise for the design of more complex agents, and the scripts that employ them. “It was such a paradigm shifting kind of lesson, with the pacing and, the kinetics, and the motion in the room and kids moving around was a lot to follow. [But] I didn’t need to worry about it, it was just taken care of by the various technologies” (Teacher).

Video analysis of the teacher during the smart classroom activity provided insight into the orchestrational support provided by the various S3 technologies. All the teacher’s orchestrational “moves” were time stamped and coded for use of any orchestrational technology (e.g., looking at the ambient display – Figure 6). This revealed the potential efficacy of certain technologies to support certain tasks over others – such as the ambient display to check student locations, and the teacher tablet for checking group status. Exit interviews with teachers and students support the effectiveness in these technologies for support the enactment of complex smart classroom activities and in managing orchestrational load. “With the board it was like this is where we have to

go and that's how much time we have left so we didn't need the teacher for that any more. He could just focus on going around and talking to the groups" (Jen).

Analysis of the student-generated final products and server logs indicate that S3 was effective in supporting student inquiry. We compared the groups' final answer sheets with their co-developed evidence on the large-format displays and found, on average, groups used 54.6% of the assigned equations and 76.8% of the assigned variables and assumption (Figure 7 above). We were curious why (especially when compared to variable and equations) the percentage of equations was so low. Exit interviews indicated students preferred to keep more equations on hand (in their tool belt) until they were sure which they would use. "If [we were] not totally sure like it's a grey area we would put it in "yes" just in case" (Sarah).

In exit interviews, students indicated that the interactive large-format displays were effective in supporting their co-construction of evidence and in supporting them in approaching the final problem-solving step (Step 4). "Just looking at what other groups had left us you got a good sense, and then from there the group could take over and be like this is what we need to do to solve it" (Robert).

Comparing the interactions around the board with regular class activities, students indicated a greater sense of collaboration and involvement in discourse and idea generation. "In class if a teacher were to tell [a group] to solve a problem together then [laughs] I would say that rarely everyone participates, and there are one or two people who are just not doing anything, but in here it really engaged us to participate" (Rebecca).

Cross-Context Learning: Factors and Design Principles

An important outcome of this research is a description of how our design supported a knowledge community – not only *within* multiple contexts, but also in the transitions *between* contexts. This work has led to the following high-level design principles for cross-context learning. While these principles are not the only ones for supporting cross-context learning, they are grounded in a successful design and offer concrete guidance in support of future designs for cross-context learning that include individual and collaborative inquiry activities, at home, on field trips, in-class, or in smart classrooms. These principles are situated within three important aspects of cross-context learning:

Visualizations of Community Knowledge

In PLACE we needed to consider the transition from the *individually collected examples to collaborative online activities*. We wanted student inquiry to be the focus of the activities (rather than materials found in textbooks or other professionally curated materials). Our main challenge was finding ways for the students to effectively search a large repository of student artifacts to find materials that fit their specific needs. In response to this we built the Associative Web, allowing students to mine artifacts based on their assigned tags, and present them in a ways that were useful to their given context.

At home, we wanted students to see how *in-class activities* affected their own contributions to the knowledge base. This was the impetus for the aggregated newsfeeds, which leveraged system generated metadata about individual students (e.g., which artifacts they had worked on) providing them with contextualized updates and a macro view of the whole class' activities. These different aggregated and filterable views served as a bridge for students to orient themselves within the larger knowledge community.

Design Principle: In order to bridge different learning contexts, visualizations of the community knowledge must present the aggregated information in ways that are relevant to the present context and activity.

Data Structures and Semantic Metadata Supports

An important transition concerned the movement of materials and student roles between the *at-home stage* (i.e., on PLACE.web) and the *in-class stage* (using tablet apps in the classroom). In order for small groups to work on the assignment of principles and equations in class, we needed S3 to aggregate the individual homework responses in ways that fostered collaborative discussion and debate. Because the underlying metadata were semantically well defined (e.g. using tags such as "problems", "principles", "equations"), we were able to easily create views that supported the desired scripted interactions. Metadata also played a significant role in connecting the *in-class* artifacts to the *smart classroom*. In the smart classroom, S3 agents could easily leverage the semantic metadata generated by students during the activity around each video (e.g., their negotiated tags), to query all artifacts that had been similarly tagged in the *in-class stage*. These metadata allowed information to flow seamlessly across contexts and to be repurposed for the particular scripted goals within each context.

Design Principle: To facilitate the organization of student materials for use across contexts, data structures should be defined to support flexible query and representation by students, and access by intelligent agents

The Orchestrational Role of Intelligent Software Agents

In the *smart classroom* we knew that we wanted students to be able to use materials from the *in-class stage* as resources for their problem solving, and that we wanted these materials to be evenly distributed among group

members; however the materials would be needed by each group and the students that would make up those groups could not be known *a priori*. Thus, we needed to develop agents that could respond to emergent class patterns in to support our pedagogical designs – a task that on their own would place a prohibitive level of orchestrational load on the teacher (and students). Similarly, during the *in-class stage* we needed to distribute the aggregated problems completed during the *at-home* activity to the individual groups. Here, the goal here was not that *every* groups saw the same number of problems, rather it was to ensure that every problem was attended to only once in a 60-minute class. The ability of the *Bucket Agent* to quickly assess the state of the activity and draw the required materials from another context in pursuit of the scripted goals provides another layer of adaptive orchestrational support.

Design principle: To help orchestrate sequences of activities, intelligent software agents can be designed to retrieve materials from the knowledge base or execute pedagogical logic in response to real time conditions or emergent patterns within student data.

Conclusions and Future Directions

This study addresses the challenge of supporting a knowledge community that blends rich inquiry practices in the world around them with well-defined pedagogical and curricular goals. We show the promise of smart classroom infrastructures such as S3 for leveraging the products of a knowledge community in support of inquiry activities. Within PLACE.neo, we introduced a role for intelligent software agents to support the orchestration of these activities, by responding to emergent class patterns and enacting pedagogical moves that would be impossible to orchestrate “by hand”. This work demonstrates the potential for smart classroom designs to support both long-term student investigations through persistent portals such as PLACE.web, and in real-time enactments as in PLACE.neo. We believe that going forward, such infrastructures have the potential to create new avenues for knowledge awareness for individuals by connecting them more directly with the work of their peers, and for the broader community by producing unforeseen “rise above” themes for further investigation.

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