

Co-design of Collaborative Collective Knowledge Environment

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Abstract: This paper reports on a new program of research investigating the use of a “smart classroom” technology to scaffold learning in the domain of physics. Using a co-design approach the research team and college teachers developed a computer-supported collaborative collective knowledge physics activity and tool. The activity’s designs aimed to help students overcome problems distinguishing contextual clues in physics, which influence their ability to transfer knowledge. Working first in dyads the students solved, tagged, and provided a rationale for a set of multiple-choice questions. A second stage involved the dyads pairing up as “supergroups” to analyze and critique the aggregated wisdom of the class towards establishing a shared understanding of the concepts being presented. Thirty-two college students participated in the study. Results showed improvements between the dyad and group activities, and highlights how the aggregated visualizations afforded new ways for teachers to gain insight into students’ conceptual misunderstandings in real-time.

Introduction

Over the last decade there has been increasing interest in building technology-rich collaborative learning environments that complement a more social constructivist educational paradigm. Examples include such initiatives as the SCALE-UP project (Student-Centered Active Learning Environment for Undergraduate Programs) at North Carolina State University and TEAL (Technology-Enabled Active Learning) at MIT (Dori & Belcher, 2004). Research outcomes from these programs reveal promising results with regard to student learning, including increased attendance, decreased failure rates, improved user satisfaction, and enhanced conceptual understanding (e.g., Saul, Deardorff, Abbott, Allain, & Beichner, 2008).

More recently, research to improve the interactive, networked, and adaptive potential of such classrooms have resulted in efforts to develop “smart” spaces. Much work is required to understand how to best design the technology for such environments and to bring together the needs of the content domain, theory-based pedagogical practices and technological affordances for learning. This current study is a design experiment (Brown, 1992) that used a co-design approach (Penuel et al., 2007) to build a computer supported collaborative learning environment that leverages the potential of community knowledge and visualization tools, along with an engineered curriculum, to teach physics. We refer to this environment as the Distributed Active Learning Interactive Technology Environment (DALITE). Our main interest in this study was to investigate how the students’ use of the reflection and tagging tools helps to promote discourse, which in turn may help to deepen their understanding of the concepts and broaden the contexts in which these concepts may be applied (i.e., preparing for transfer). At the same time our investigation focused on the scripted orchestration of the learning (Dillenbourg & Fischer, 2007) and how the implementation of DALITE might be improved.

Theoretical Foundations for the Design of DALITE

It is widely agreed that construction of knowledge and active participation is facilitated by inquiry-based activities (Slotta & Linn, 2009) and other forms of problematizing content (Engle & Conant, 2002). Students need to have something to challenge their understanding, to motivate their interest in sense making and to promote their willingness to engage in reflective discourse. Collaboration with peers and intentional reflection is believed to facilitate restructuring of certain beliefs and ideas that generally go uninspected by novices, considered conceptual change (e.g., Sinatra & Pintrich, 2003). We propose that aspects of this restructuring process include identification of the deep structures (i.e., elements of physics principles) and patterns across the different contexts that are presented in physics curricula.

Guided by social constructivist principles such as Vygotsky’s notion of Zone of Proximal Development (ZPD; Vygotsky, 1978) we designed DALITE so that the students participating in the space are aided by having access to the work of their peers. Small group collaboration towards a goal of understanding the subject area provides the social and cognitive support that allows students to achieve results that would not be possible were they to do the work alone (Stahl, 2006). This idea is extended by the notion of a Knowledge Community where students work in close collaboration with their peers and teachers in the formulation of their learning goals, how they will achieve them, and in the exchange and critique of ideas with their peers (Slotta & Najafi, 2010).

Collaborative Collective Knowledge Visualization

A knowledge community is another way of conceptualizing communities of practice (Lave & Wenger, 1991). How it differs is its reliance on new technological capabilities that can bring together distributed knowledge, most importantly, the capability to produce collective knowledge artifacts. For example, *collective collaborative tagging* (Choi, et. al., 2008), a categorization process that can produce emergent ontologies from within a collectively built knowledge repository. At its core, such collective knowledge is dependent on the communication and interactions produced around particular domain thinking, exemplifying learners' growing awareness of norms and practice (e.g., Cobb, 2002). In this way the focus is on community knowledge advancement rather than that of the individual (Scardamalia & Bereiter, 2006).

DALITE provides students with visual representations of such collective artifacts including aggregated group reflections (aka rationales) and collaborative tagging (aka categorization). Such representations might be considered as shared objects or artifacts that facilitate communication between the system's participant communities, allowing for sharing and the development of *common ground* (Clark & Schaefer, 1989).

Design Specifications

The underlying infrastructure that drives the DALITE curriculum centers on a powerful, flexible open source platform called SAIL Smart Space (S3), which in turn is built on the rich framework of Scalable Architecture for Interactive Learning (SAIL; Slotta & Aleahmad, 2009). S3 specifies a framework for the configuration of devices and displays, running off a set of core underlying technologies: (1) a portal for student registration and software application management; (2) an intelligent agent framework for data mining and tracking of student interactions in real time; (3) a central database that houses the designed curriculums and the products of student interactions; and (4) a visualization layer that controls how materials are presented to students on various devices and displays (Slotta, 2010).

Built upon two previously successful studies (Tissenbaum & Slotta, 2009), this project extends the platform to a physics classroom at an urban College in Quebec. The curriculum was developed using a co-design approach, working in close collaboration with physics teachers at the College, to be enacted regularly throughout a semester in one section of the introductory physics course in mechanics.

The curriculum covers the major content areas in mechanics - kinematics, dynamics and energy. Each content area is presented as a separate activity involving a curriculum set of three to four concept questions that may be used as an introduction or a review of the topic area. Influenced by the Ohio State *conceptest* questions (Lee, 2009), each set is sequenced as a series of increasingly difficult multiple-choice problems built on similar deep structures with different surface features, or similar surface features with different deep structures. We propose this design as a possible solution to the problems students have distinguishing contextual clues in physics, which influence their ability to transfer knowledge (e.g., Lobato, 2006). The teacher has control over the selection and upload of the questions using a specially designed teacher portal; thereby he/she can customize the problem set to meet the perceived knowledge level of the students.

The curriculum is orchestrated (Dillenbourg & Fischer, 2007) to include activities at three levels of social organization - the individual, the dyad and the small group (supergroup). At each level the student or students are asked to perform four tasks: (1) categorize the type of question by tagging the major elements (element list provided), (2) write a short rationale to explain the choice, (3) answer a multiple-choice question, and (4) write a short rationale to explain the categorization. The steps are scripted in such a way as to encourage students to think about the underlying principles involved in the problem *prior* to solving it (step 1), and then to reflect on why/how this helped them solve the problem (step 3). These steps are carried out first as homework (at the individual level), and then repeated in class (at the dyad and supergroup levels). At the dyad and supergroup levels students are able to view the collective work of the rest of the class (from the homework phase of the activity) in the form of the aggregated histogram of tags and individual reflections. The aim of this is to provide a richer set of information (using the wisdom of the crowds) to draw from as contextual clues towards solving the problems. At each level students enter their answers into the DALITE system by logging in with their unique user IDs and passwords. As they move from one level to the next the questions become more challenging, requiring the thinking of many minds. Additionally, as students move from individual to dyad, and dyad to supergroup, they are asked to reflect on the collective knowledge produced by their peers.

To illustrate the in-class process, starting in dyads, one of the two students is required to log into the DALITE system. As a pair, the students answer the set of questions one at a time, each time choosing from a list of multiple-choice answers then writing a rationale for the choice. Next, the students are asked to categorize the question by tagging its relevant physics principles (aka elements). Upon submitting these to the system, they move on to the next question and repeat the procedure until the question set is completed.

These answers, reflections, and tags are collected and uploaded to the server and the aggregate of the students' responses are displayed in a representation made available to the teacher to review at any time through a DALITE teacher report (see Figure 1). At the next stage of the orchestration students, working together in *supergroups* (made up of the two dyads), are given the same set of three to four questions but this time asked to

reflect on the answers and rationales generated by their peers. This is presented in a summary visualization, much like the teacher representation (see Figure 1).

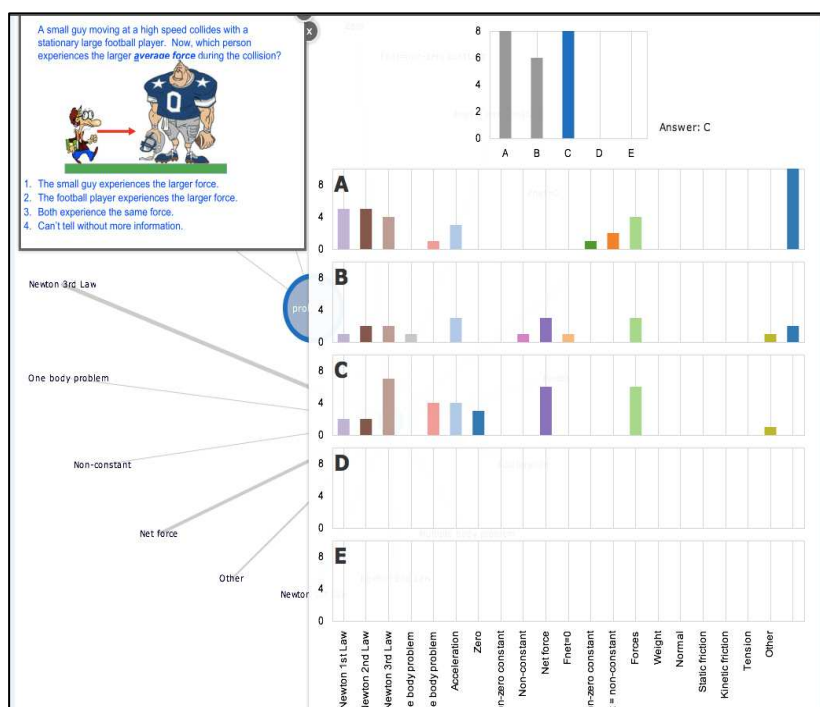


Figure 1. Teacher report showing histogram of students' answers to the multiple-choice question and tagged elements for the respective choice.

The answers are presented in standard histogram style showing the number of students for each of the multiple-choice answers. Clicking on any of the histogram bars reveals the tagged elements list for that particular answer (i.e., categorization of the question selected by students who chose that particular multiple-choice answer). At each stage students are given the time to discuss within their supergroups which answer seems the most correct. They then submit their "final" supergroup answer, categorization (element tags), and rationale for choosing those elements. Each question that was assigned is completed in turn, but the activity is designed so that the teacher can stop the students between questions in order to engage the students in discussion or to correct any lingering misconceptions.

Methods

Research Design and Context

Using a design experiment approach we investigated the learning environment developed for the second implementation of DALITE, introduced as part of an active learning pedagogy that included other active learning approaches, e.g., peer instruction (Mazur, 1997). Participants were a class of 32 first year college science students (17-18 years old) enrolled in an introductory physics course. All classes were held in a technology-rich smart classroom environment, an active learning space with a seating arrangement designed to facilitate collaboration. Configured this way there were eight groups of four, our supergroups made up of two dyads each. The topic covered in this piloted portion of the DALITE curriculum was from the dynamics section (Newton's Laws) of the course in Mechanics. The teacher was a member of the co-design team.

Selection of Physics Problems for Study

For this study we selected a set of four questions about a block on a ramp, sometimes held by friction, sometimes not. The sequencing of the questions was very important, with Question 1 being the easiest and Question 4 the hardest. The four questions share the same deep structural elements, which are variations on Newton's First Law. Thus, while there was a maximum of 16 elements to choose from (Newton's 1st 2nd and 3rd Law, single body problem, $F_{net}=0$, etc.), only 5 or so elements are relevant to the four questions. In all cases the acceleration of the block is zero ($F_{net}=0$), accordingly, the net force exerted by the ramp must be vertically upwards with a magnitude equivalent to the force of gravity on the block. It was anticipated that the typical introductory-level students would have little problem with Question 1, and would correctly categorize this question. However, for Questions 2, 3 and 4, Newton's 3rd law is essential in deducing the net force on the slide, which would not be as easy to identify and correctly tag.

Data Collected

Recall that the reflection and categorization (tagging) tool was designed to be used on three levels of social context - individual, dyad and small group. We focus here only on the dyad and super-group data. Data collected include the DALITE teacher report, which shows: (1) the raw numbers of students' answers to the four multiple choice questions, (2) the written rationales for the answers, (3) the results of the categorization exercise, with a list of the tagged elements, and (4) the written rationales for the tagged elements. These data are

identified for both the dyads and the super-groups. Audio recordings of a representative sample of four super-groups (eight dyads) were made. Additionally, the teacher orchestration of this implementation was recorded.

Results

The results show the effectiveness of the reflection and categorization (tagging) tool for scaffolding learners' thinking and discourse about the deep structures of the content knowledge.

Answers to Multiple Choice Questions

The impact of the reflections tool (the rationale for answers). From the repository-generated teacher report we see, on average, for Questions 1, 2 and 3, an 80% change towards the correct answers after the dyads discuss their answers in their supergroup (see Figure 2). The difficulty posed by Question 4, however, continued to be challenging with only 50% of the supergroups getting to the right answer. Clear improvements are shown over the course of the activity where 71% of supergroups where both dyads were incorrect changed to the correct answer after the discussion in the supergroup. Additionally, 86% of groups where 1 dyad was wrong showed a change to the right answer after the discussion in supergroups. Additionally, the reflections in writing are much improved in the supergroups.

The impact of the tagging tool (the rationale for tagging questions). Turning to the tagging activity, the data shows that while 80% of the eight supergroups were able to identify and tag the major elements (Newton's 1st Law, $f_{net}=0$, etc.) that number dropped to 40% with the more challenging identification of 3rd Law effects in Questions 2, 3 and 4. However, the three supergroups, Groups 2, 3 and 5 (and later Group 7) who were correct in this identification also produced good justifications for their tagging of Newton's 3rd Law and demonstrated that their discussion as a supergroup had an impact on this change (i.e., the related dyads did not identify this element).

Of the four groups the collected audio data from Group 5 and 7 showed a deepening of their understanding related to the discussion around the DALITE activities. Group 5 got all the questions correct, and

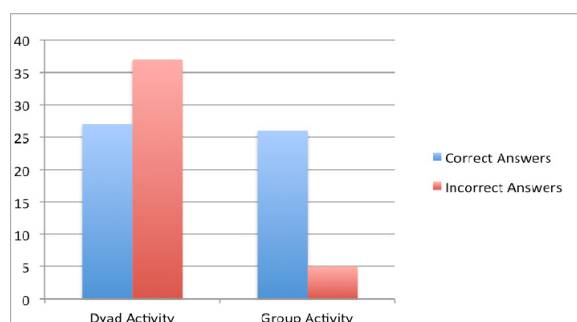


Figure 2. Distribution of correct to incorrect answers for dyads and groups.

largely had reasonable tagging (although they missed the 2-body problem for Question 2). Overall, they seemed to develop a robust understanding of the way Newton's laws are at work in these problems. Group 7 was also interesting in that they seemed to realize that something was missing from their Question 3 thinking and caught their misconception while solving Question 4. On the other hand, Groups 1 and 8 showed very little change as a result of their discussions. From the audio data it appears while one of the four students in Group 8 understood the concepts and could perform the tagging, he choose to go with a majority vote instead of trying to reason out the problem and convince his peers.

Discussion

The finding of improvement in scores across the groups in comparison to the dyads is encouraging. Whether this improvement is a result of students becoming more familiar with the questions and element tags, the ability to see the rationales of their peers, the increased collaborative discourse in the larger groups, or of the “wisdom of the crowd” (i.e., by reviewing the aggregated answers of the class) – or some combination of the above – these results suggest that the curriculum provides value in its ability to guide student problem-solving. This sentiment is highlighted by the groups in which at least one of the dyads answered incorrectly during the first phase of the activity – by leveraging the tools provided to them by this activity many of these students were able to correct their earlier mistakes and in the process construct their own understanding of the curriculum.

The ability for the teacher to see collective product of these interactions through the customized teacher report page was useful in aiding him in understanding the conceptual misunderstandings of the students in the class in real-time. This was particularly useful in that it allowed the teacher to adapt the orchestration of his lesson to address these misconceptions with a greater understanding of the students' needs. Furthermore, by projecting the teacher report onto a large surface in the classroom it was also adapted as a learning tool for the students. The teacher was able to show the collective work of the students and discuss the various answers, rationales, and tags (for both correct and incorrect answers) for each question to further class discussion and reflection.

Taken together the use of the aggregated knowledge, varying contexts of individual and group work, and real-time representations and visualizations opens the door to future research. Moving forward our co-design team plans on investigating other complex pedagogical configurations, including bridging formal and

informal learning contexts, expanding the activity to become part of the regular curriculum of the class, and how availability of a growing and persistent knowledge base can provide new avenues for student inquiry and collaboration.

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