Using Collective Conceptual Networks in Learning and Teaching: Linking school science to the real world with the aid of new IT tools

Les réseaux conceptuels collectifs en enseignement et en apprentissage : l'usage de TIC pour relier la science scolaire avec la réalité extérieure

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A fundamental concern in science education, and physics in particular, is to overcome the difficulty students experience in building robust understandings of core principles and concepts. Equally difficult to achieve is the application of knowledge in settings that are different from the original learning, including recognizing the similarities between in-class and out-of-class activities – i.e., preparation for transfer. Recent studies tell us that pluralistic approaches may be an answer to such challenges. For instance, engaging students in collaborative learning, using pedagogical innovations, using tools designed to support learning through various social and cognitive processes, to list a few. While there is already research looking at pedagogical styles there is still a lot to learn about designing pedagogical tools and assessing their effectiveness. This current research was aimed at addressing this need. It examines the impact and effectiveness of a designed learning tool called the Distributed Active Learning Interactive Technology Environment (DALITE).

DALITE is a web-based learning platform. It is designed to engage students in conceptual learning using principles from the fields of cognition, learning and instruction – e.g., role of collaboration in conceptual change (Roschelle, 1992); self-explanation (Chi, Leeuw, Chiu, & LaVancher, 1994). But pragmatically, DALITE allows students to use *peer instruction* asynchronously.

Peer Instruction (PI) was developed by physicist Eric Mazur at Harvard University (Mazur, 1997; Crouch & Mazur, 2001)). In PI, students are presented with conceptual multiple-choice questions; they select an answer; then they communicate it to the teacher (often with a remote response device, often referred to as *clickers*). With this information, the teacher can determine the next pedagogical move based on this real-time response. When answers between students are inconsistent they are asked to find someone around them that has a different answer and try to convince them. This engages students in the processes of: verbalizing what they think; actively listening to what their partner says; and, critically evaluating explanations. After this brief discussion, students again communicate a response to the teacher who can then use this information to better guide the rest of the lesson. PI has been used extensively as a way to implement active learning pedagogy and its use has grown dramatically around the world (Meltzer & Thornton, 2012; Henderson, 2008). Until now PI has been used only as an in-class face-to-face activity. The question is, Can the benefits of PI be taken outside the classroom?

Our research team has designed DALITE, an online learning platform to allow students to use PI asynchronously. This article discusses the impact of DALITE and its contribution to a student-centered active learning approach. Using a computer or mobile device, students can log into the system, engage with concepts being covered in their course. DALITE is intended to be part of an active learning pedagogy and allows the course content to follow students outside of class; and, they share understandings with peers asynchronously, through the unique database of student-generated answers and explanations. Specifically, each time students answer a question in the DALITE platform they are asked to provide an explanation (or rationale). It requires students to communicate these rationales in writing thereby making it different from traditional PI that depends only on verbal discussion. Self-explanation, explaining to others and practicing the language of the scientific discipline are emphasized. The student-generated rationales become part of the DALITE database, and eventually used in the DALITE *script* for future students. DALITE assignments provide teachers with the opportunity to see what their students are thinking, either before or after classroom instruction.

How DALITE works and what are its implications for learning and instruction is the focus of this paper. In the following pages we discuss the impact of the system on students and instructors as part of a student-centered active learning pedagogy. The research questions addressed in this study are the following:

(1) *Can an asynchronous online learning system, DALITE, support conceptual learning compared to regular instruction? Are these learning outcomes the same or different when compared to face-to-face Peer Instruction?*

(2) *What is the impact of DALITE on students' conceptual knowledge development as related to preparation for transfer*?

(3) *How closely did DALITE's use match the intent of its features? How was it used by the students, and by the instructors? What did the students think? How did the instructors use it?*

Theory and Background

A common lament of traditional science instruction is that many students have difficulty achieving a deep understanding of fundamental concepts – e.g., motion, diffusion, and evolution. Education research confirms and validates these observations with empirical studies that identify this type of learning as requiring what is considered *conceptual change* (Chi, Slotta & deLeeuw, 1994). Studies of conceptual change report improved results when instruction includes activities such as: intentional reflection (Sinatra & Pintrich 2003), self-explanation (Chi, et al., 1994), reciprocal teaching (Palincsar & Brown, 1984), collaborative and discursive practices (Stahl, 2006), and student-centered activities (Charles & Lasry, 2010; Charles, Lasry, & Whittaker, 2013). Inspired by constructive and social constructivist theories and models of learning pedagogical innovations too have emerged (popularly referred to as student-centered *active learning*). Findings from that body of research show strong improvements in student's conceptual learning (Meltzer & Thornton, 2012).

A major feature of PI is the potential of discussion and debate between students with opposing viewpoints. It is believed that such activity can lead to *cognitive dissonance* and deeper reflection, mechanisms arguably responsible for conceptual change. While PI has been used at high school and college levels (Lasry, 2006, 2008; Lasry, Mazur, & Watkins, 2008), some of the most successful implementations of PI have been those found in university settings that involve large lecture halls, with hundreds of students, supported by small armies of teaching assistants. Rich discussions can arise in such setting because of the laws of large numbers and greater facilitation ratios. Specifically, there is a higher probability of diversity among student's answers in the large lecture halls compared to the smaller class sizes typical in college or high school settings. Additionally, with a large number of TAs there can be more monitoring of student conversations leading to more effective pairing of students to maximize discussions between students with different points of view.

How might college and high school settings improve the potential of PI? One solution is designing a system to purposefully increase the diversity of explanations a student is exposed to, as well as monitoring the quality of explanations, even for the same answer. Equally, even in the best PI implementations a weakness is that not all students are given equal opportunity to express their view or join the discussion. Some students choose not to participate and some are silenced by social factors involved in group dynamics. The impact on this latter population of students is particularly worrisome. Therefore it is optimal to design a system of PI that encourages everyone to participate and gives a voice to those who find it daunting to express an alternative conception, which can sometimes be the correct way of reasoning. DALITE is such a system.

What Does The Student Do in DALITE?

In DALITE, students log into the system and are directed to a prepared assignment that consists of sets of questions similar to those used by in-class PI. Students are asked to follow the sequence of six steps, which we consider the "script." Step 1, students select an answer for a multiple-choice question, similar to the first step in PI. Step 2, students write a rationale for their answer (Figure 1). This step varies widely from PI because all explanations are written and because this step ensures all students to generate a conscious explanation for their answers.

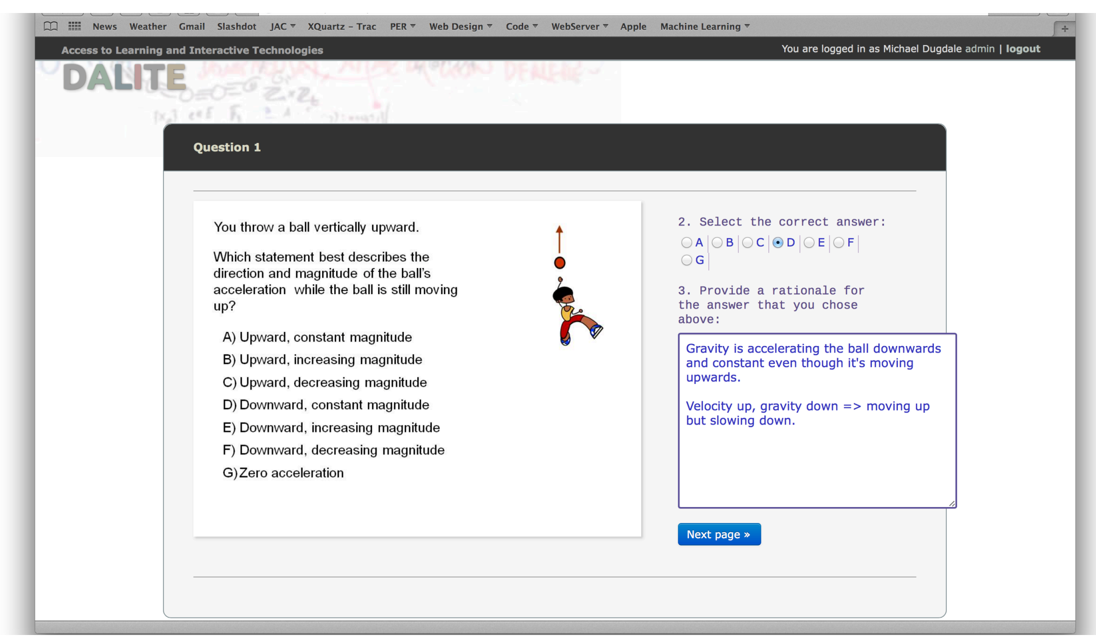

Figure 1. DALITE screens for steps 1 and 2: select, vote and write rationale – i.e., *self-explain and explain to others.*

In Step 3, students are asked to reconsider their original answer in the context of rationales for their own answer, and a similar selection of rationales for an alternative answer. This purposeful comparison is designed to provide the variety that is sometimes missing in face-to-face

PI. Step 4, students re-select their answer, choosing to stay with their original selection or change, based on the rationales (Figure 2).

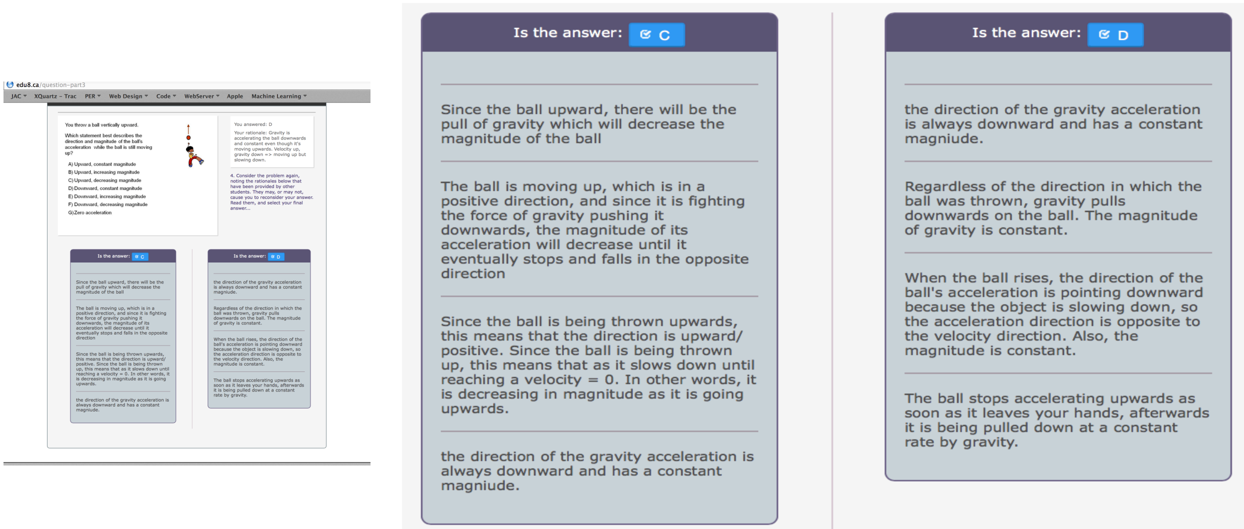

Figure 2. DALITE screens for steps 3 & 4.(compare & contrast). And, close up of DALITE screens in Figure 2, answer D is correct.

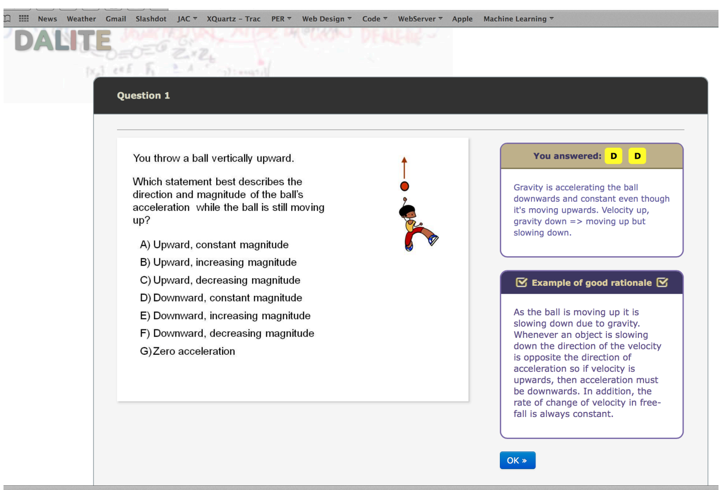

Figure 3. DALITE screens for steps 6, expert rationale.

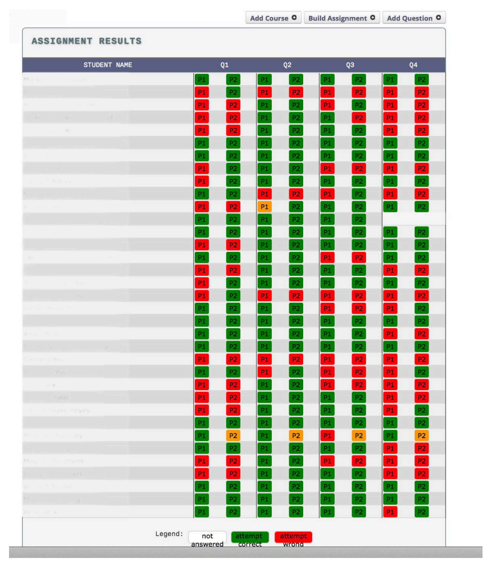

Figure 4. Teacher analytics report of vote and revote results for an assignment containing four questions.

Step 5, students are asked to vote on most convincing rationale presented (optional step). Step 6, students are asked to review their rationale in the context of a rationale for the question that is positioned as an expert's rationale (Figure 3).

For the instructor, DALITE provides a display of the homework results including the students' first and second votes. Additionally, there is a roll-over feature in which the individual student's rationales can be viewed (Figure 4).

Summary of DALITE's main theoretical principles

Taking the discussion described above, we designed DALITE on five main principles, and other models of learning as summarized in Table 1. Furthermore, DALITE is also a way to explore how we might make the growing interest in active learning pedagogies more accessible – e.g., help implement the flipped classroom approach. DALITE allows us to test these models of learning as described by the education and learning sciences literature and add to this body of knowledge.

Table 1. DALITE's design feature and theoretical relationships.

Design feature	Theoretical implications
Peer-Instruction model	conceptual change – *intentional reflection* (Sinatra & Pintrich, 2003); collaborative learning (Roschelle, 1992; Stahl, 2006)
Written explanation "Rationales"	self-explanation (Chi, Leeuw, Chiu, & LaVancher, 1994); *science talk* (Lemke, date)
Compare and Contrast	Concept formation, similarity and differences (citation)
Multi-context use	transfer as *intercontextuality* (Engle, 2006)
Self-directed feedback	creating *epistemic agency* (Scardamalia & Bereiter, 2003); changing "habits of mind"

Methods

Methodological background

This study used a research approach called *design-based research* (DBR). DBR is a pragmatic approach to educational research that keeps in mind both the intended practice and the context. Instead of producing grand theories of learning, this method allows researchers and pedagogical designers to examine the conditions and context that surround the implementation and use of an innovation. In this way innovations generally are iteratively tailored and adapted to better support learning. Anderson and Shattuck (2012) describe DBR as consisting of six main features: (1) situated in real educational contexts; (2) focuses on the design and testing of significant innovations (e.g., pedagogical approaches, instructional tools and systems) that theoretically based; (3) generally spans a period of several iterations of the innovation; (4) a collaboration between researcher and practitioners; (5) uses mixed methods for data collection; and (6) involves evolution of design principles, thereby adds to the understanding of educational theory.

As an example of DBR this current research adheres to the six features described above. In particular, it used a mixed methods approach to data collection. In other words, it asked research questions that required the use of various research designs and the collection of both quantitative and qualitative data. As a consequence, it is divided into three studies. In the upcoming sections we will describe the methods of these three studies, the data collected and the results of the analyses.

Research Design – Mixed Methods

Study 1: a *quasi-experimental* design. It investigates whether the use of DALITE promotes deeper conceptual understanding compared to control conditions (addressed by Research Question 1).

Study 2: a _case study_ design. It investigates the development of capabilities (cognitive, social, affective) emerging from the students' use of the DALITE (Research question 2).
Study 3: a _comparative case study_ design. It focuses on the conditions that enable, or inhibit, the students' and the teacher's adoption of DALITE (Research Question 2 and 3).

Context and Participants

The DALITE experiment involved five sections of a first year introductory physic course equaling over 150 student participants. All were first year science majors between the ages of 17 – 19. The ratio of male to female students was approximately 2 to 3. The five sections were distributed across three colleges and taught by four instructors: (1) College A, one instructor teaching two sections – groups T09 & T10; (2) College B two instructors teaching 1 section each – T07 & T08; (3) College C, one instructor teaching one section – T06. The curriculum for the physics course was equivalent across all section. Instructors used an active learning pedagogy but had varying degrees of experience with this practice. The instructor for groups T09 and T10 had the most experience (+6 years). The instructor for group T08 had the least (2 years). These differences are taken into account in the interpretation of the results and discussion.

Study 1 used two cohorts of comparison groups. Cohort 1, the regular instruction, was created using FCI results from a large database (N=2913). These data represented students taught with a variety of pedagogical approaches thereby providing an unbiased comparison. Cohort 2, the "peer instruction no-DALITE" group, used a *purposeful sampling* method. These students were part of two sections, one taught by a teacher in College A and another taught by a teacher at a larger institution of higher education (N=188). Both instructors had used PI in their classes for several years. Comparison to such a sample is critical and ensures our results are authentic and meaningful.

Procedure

DALITE was assigned weekly as homework via the web. The DALITE experiment included a system for the teacher to report on the students' homework in class. The extent to which this was done varied by teacher. In addition, two instructors introduced the extended activities of explanation: (1) T06 the concept mapping; (2) T09 & T10 the tagging activities.

Data Collection

The data collected for these three studies included both quantitative and qualitative sources listed below. In addition to the standardized assessment it was necessary to develop new types of assessments to capture and triangulate the developing student's conceptual understanding: (1) common conceptual test (CCT); (2) concept mapping and tagging activity; and, (3) "sorting task" activity. We will not discuss the concept mapping and tagging activities.

- <u>Force Concept Inventory</u>: The Force Concept Inventory (FCI; citation) is a standardized 30-item multiple-choice questionnaire. It surveys students' understanding of the concepts of force and motion. It is a widely used and researched instruments in physics education (McDermott & Redish, 1999). FCI was administered as a pretest and posttest.

- <u>Common Conceptual Test</u> (CCT): Three CCTs targeted the types of activities designed into the DALITE experiment. Each test required students to answer a conceptual question, write a rationale and evaluate rationales produced by others. Each covered a different concept: (1) CCT#1 Kinematics principles; (2) CCT#2 Dynamics principles; and, (3) CCT#3. The CCT was administered at the end-of-unit as part of the mid-term quizzes.

- Sorting Task Activity: These activities were designed to promote the development of deep understanding of the conceptually common features among questions regardless of their surface feature differences. This design is based on the expert-novice literature, which suggests that novices have a difficult time recognizing deep structural similarities between questions (phenomena) compared to experts who are not easily distracted by surface similarities. This in-class assessment had an individual and a group component.

- Student and Instructor Interviews: Open-ended questionnaires were designed for the student (14 questions) and instructors (6 questions) respective interviews. The student interviews were conducted both individually and in groups of 2-3, for convenience. A total of 20 students were interviewed. Instructor interviews were administered as paper questionnaires.
- DALITE database: Database of student answers and rationales for DALITE homework questions. DALITE questions assigned and completed ranged from 65 to 45. Answers and rationales from 150 students make up this data source.

Results of Studies 1, 2 and 3

Study 1

This study answered research question 1. First it looked at the normalized conceptual gains on the FCI questionnaire and compared the gains of DALITE students to those from the matched control group (regular instruction) and then to the Peer-Instruction no-DALITE students. Last, it compared the gains of all five DALITE groups. The results are described below.

Conceptual gains of DALITE students vs matched controls

The results (Figure 6) show that the DALITE students outperformed this regular control group (0.47±0.02 vs 0.35±0.006; $p<0.00001$). See Figure 5.

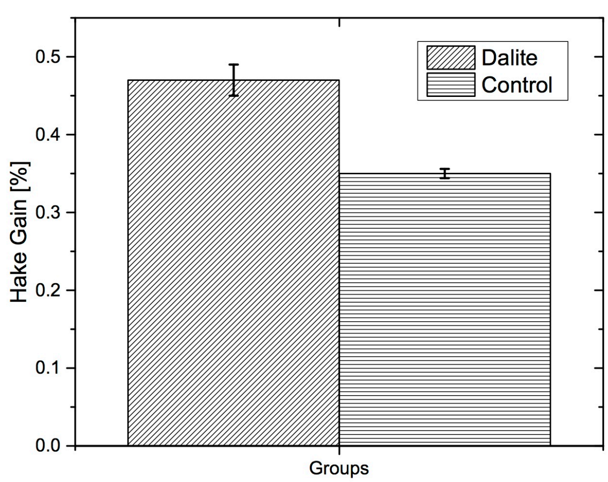

Figure 5. Shows that students using DALITE (n=137) in their college courses had significantly higher conceptual gains at the end of the semester ($p< 0.00001$) when compared to controls (n=2912)

Conceptual change in DALITE vs Peer Instruction no-DALITE

The results show that there were no differences between the conceptual gain of the DALITE students and those who had in-class Peer Instruction (0.47±0.02 vs 0.48±0.02 ; p=0. 84). In other words, students using DALITE (n=137) in their college courses do not differ significantly in conceptual gains (p= 0.38) than students who used real-time Peer Instruction (n=188).

Comparing conceptual change between the five DALITE sections

The results show a surprising similarity between four of the five groups and a small difference with a fifth (section T06). The overall differences are between groups are not statistically significant ($g_1 = 0.50$; $g_2 = 0.50$; $g_3 = 0.47$; $g_4 = 0.48$; $g_5 = 0.38$; p= 0.06) with four of the five groups being extremely similar and close to all the variation residing in the fifth group. We will discuss this difference for section T06.

Study 2

Study 2 extends the study on conceptual learning by asking how students transfer new conceptual knowledge to novel situations. We compared both *within group* and *between groups* using the three end-of-unit conceptual assessments – labeled as Common Conceptual Test (CCT). The between group comparisons show that students in DALITE sections were consistent with the T-comp section on the conceptual question, exception T07 (see Figure 6). However, the DALITE students outperformed the T-comp on the rationale selection task. Once again the exception was T07, which was explained by a particular circumstance.

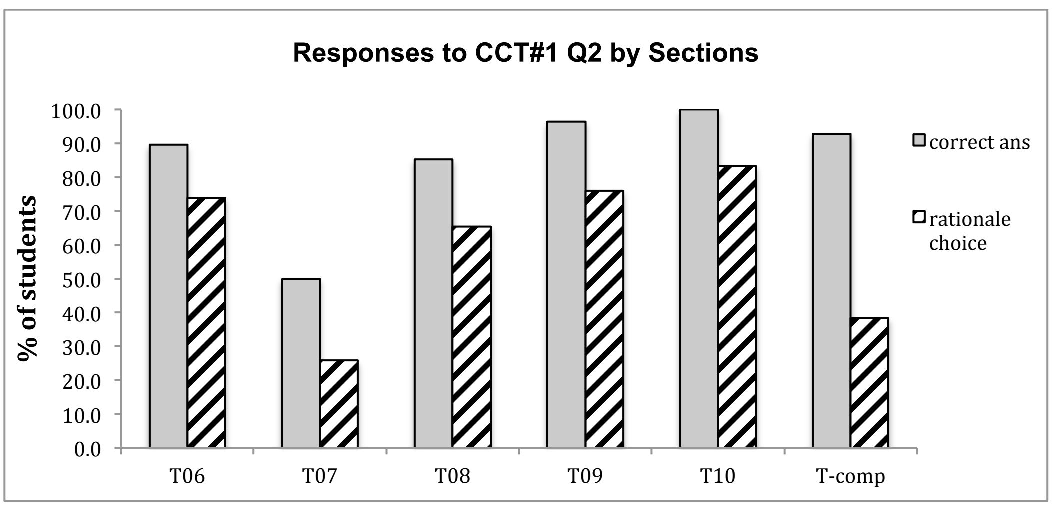

Figure 6. Results of CCT1.Q2 for each of the five treatment and one comparison group.

Study 3

This study addressed the question of DALITE as a design-base research project. It brought together all the data collected and provides answers to the questions: (1) for whom does DALITE work, under what conditions and what are the most likely mechanisms to explain these findings?

Reporting on this study we turn back to each of the design features of DALITE and match the data to the intention.

1. Supporting conceptual change was the foremost designed feature of DALITE. How does DALITE support conceptual change?

Our data suggest that the conditions and context for successful conceptual change depends on the use of some form of active learning pedagogy. However, instructors need not use the same forms of active learning. DALITE, in conjunction with a variety of forms of active learning, has produced almost the same results.

There is nonetheless one dependency that is important to mention. There is evidence to suggest that DALITE's effectiveness is tempered by entry-level knowledge. In the instance where a large number of incoming students have below average physics knowledge (low FCI pre-test scores) the conceptual gains were less than the other sections – still, this difference was not statistically significant.

In regards to promoting intentional reflection we turn to the interview data. Of the 23 students interviewed approximately 50% (16/23) talked about the impact of DALITE in helping them to reflect more on the concepts being learned. An example of this type of comment follows:

> ***G1_T09***: *I want to know which one makes more sense… there is one side [that] convinces you so much, and you like, ok, it must be that [answer]. But then in the back of your head, you know these other people make a good point. So then you get conflicted.*

2. Supporting self-explanation is a second design feature of DALITE. How does DALITE support Self-explanation?

Our database having over 7,000 student-generated rationales supports the claim that DALITE can facilitate the production of explanations. The data also show that generally speaking students took the task seriously with over 75% completing all assignments. As previously described, student-generated explanations populate a database from which rationales are selected and shown to future students answering the same question. We presume that some students choose to write more detailed explanations because they understand that other students will be reading them. Hence, it may be a sense of contribution to the community, a way of working out ideas for themselves in writing or a combination of both. We have evidence that it could be working out ideas for themselves:

> ***B5***: *I find that it helps you out to write [rationales] down, because it's much easier to say "oh yeah I understand that" but then to try and explain it in words, to be concise, it really shows you understand the matter. It helps out a lot.*

Then again, we also have evidence that students understand rationales as their contribution to the community, a combination of social and cognitive factors. The quote below is particularly interesting. The student recognized that when she was reading other people's "choppy" rationales were hard to read. This seemed to inspire her to write better rationales realizing that others would be trying to understand her thoughts from her writing:

> ***G11***: *I used to write short rationales just thinking why I thought this was the answer, but now I explain the concept behind it and everything, so I give more detailed rationales…*

at first I found [rationales] like all over the place and choppy, but then I got used to [rationales] being somebody's thinking, so it's easier to read now…. Since you have to present [your rationale], you have to say "ok this is what we think and why." It organizes your thoughts.

Hence, DALITE appears to support the development of students appreciating the value of self-explanation, particularly the value of written explanations. The conditions and context that makes this feature work seems to be when the student comes to value the social contribution they are making.

3. <u>Promoting comparing and contrasting</u> is the third design feature of DALITE. How does DALITE support comparing and contrasting? Students recognized this feature and appeared to value it as something that helped them to learn, as illustrate by the following quote:

> ***B2****: Yeah... when you try to explain [to] yourself and you're still not sure, and then you give your answer and you can read through everybody's explanations, you're able to make sense of what you're saying, and see where your thought process might have been wrong or what the other people's thought process is. And, you can look at what answers actually make more sense to you. So I guess it helps because you're seeing other people's point of view and sometimes you like theirs better.*

4. <u>Preparing students for transfer of learning</u> is the fourth design feature of DALITE. How does DALITE support preparation for transfer? Are students able to use the types of reasoning practiced in the DALITE homework in a different context?

Starting with the instructor interviews, these data show instructors believed the DALITE system helped prepare their students to engage in the student-centered activity. And, in some cases, the instructors were able to better communicate their epistemic values – i.e., the importance of conceptual understanding.

> *T2. I particularly appreciated DALITE when students initiated questions based on the DALITE questions, which happened on both the individual and class level. In other words, DALITE allowed access or entry points into the subject and opportunities for students to self-regulate.*

> *T1. Using DALITE as a pre-instruction tool also let me motivate students to do the reading in preparation for class and it let me get a better sense of their prior knowledge. As a post-instructional tool it let me push the classroom material to try and get students to understand at a deeper level.*

> *T3. Another aspect is, that by putting such a focus on conceptual understanding, communicating and reflecting, [DALITE] provided an opportunity to communicate more clearly to the students that I, as a teacher, value conceptual understanding more than the ability to perform certain calculations by rote.*

The student interviews also show that students recognized the similarity between the context of learning at home and learning in the classroom is essential. Additionally, DALITE facilitated preparing students for transfer of the teacher's epistemic values.

G5: In class you have the clicker problems that we have to complete, and we discuss it with the partner. So [DALITE] is kind of the same… [because] reading some people's rationales you figure out both people's thought processes…

B1: Yeah, the stuff in class he does often isn't so much about the math, but about understanding the concept behind it, which I think is what DALITE is all about.

G3: Everything [in the course] relates to each other, so DALITE has the most similarity… it's like all theory [conceptual]… it's making you think, like physicist…That's the best way, like physics is logical.

5. Supporting the development of self-regulation and new habits of mind is the fifth design feature of DALITE. Can DALITE promote "habits of mind" that lead to learning? We call this epistemic agency because it involves development of the awareness that learning involves taking actions that lead towards knowledge construction.

DALITE was able to promote such thinking. Some students referring to how they were "learning how to learn" when doing their DALITE assignments. Here are some examples of their comments that illustrate these points.

***G2**: Usually I look through my book to look at the theory to see this is right … You have to look to your notes to try to get more understand… at the same time, it forces me to read, not just look at and then think myself yeah I know why, and makes me like, it forces me to read the rationale and try to understand why it is that answer.*

Lastly, DALITE also provided an opportunity for students to take their responsibility for their own learning further. One student reported that DALITE rationales helped her learn how to read the "grammar" of physics. The following quote demonstrates this impressive active of epistemic agency:

***G3**: … whenever I have to read an English websites with all the terms, I would not understand it at all. And also just the wording, the way the concepts [are] presented was totally different… with the rationales we had to write, I kind of see the structure that's behind them, so it really helps me to understand better the overall concepts... So I read [physics text] better now. I find I can really now see the information better than just many scientific terms everywhere.*

Conclusion

This research tells us several important things about how to promote conceptual change and transfer of learning. It also tells us about the design of tools to support and assess such learning. Lastly, and most importantly, it tells us about the impact the design features and how these could further the understanding of the theory they are built on. In particular, we learned that DALITE, as a web-based tool used primarily as homework, can support students' learning by providing opportunities to practice the following: (1) understanding and explanation of conceptual knowledge; (2) cognitive skills of comparing and contrasting; and, (3) development of self-regulatory skills such as self-reflection and epistemic agency. DALITE can support teachers' efforts to implement active learning pedagogies by supporting this type of learning both in-class and outside of the classroom. Generally the case study teachers reported they like the system. One teacher states: "*I like DALITE a lot,*" at the same time they state, *"there's still a lot of work to do to make it easier to use."* Others describe their experiences and what they believed worked, notably: (1) *"[DALITE] gave me insights into student conceptions and misconceptions"; (2) "it helped my students read (scientific writings)"; (3) "it helped some of my students progress from a high school mentality to a more self-aware learning".*

What does the future hold for DALITE? There has been a lot of interest from a variety of sources – other colleagues, different disciplines (e.g., biology, Nursing), and linking it to other platforms for eLearning. The most important outcome of this project may well be these opportunities that will take DALITE to a higher contribution to the college network.

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