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An Exploratory Study of a Novel Online Formative Assessment and Instructional Tool to Promote Students' Circuit Problem Solving

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Editor: Michael Russell
russelmh@bc.edu
Technology and Assessment Study Collaborative
Lynch School of Education, Boston College
Chestnut Hill, MA 02467

Copy Editor: Kevon R. Tucker-Seeley
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Abstract:

We examined a novel formative assessment and instructional approach with 89 students in three electrical engineering classes in special computer-based discussion sections. The technique involved students individually solving circuit problems online, with their real-time responses observed by the instructor. While exploratory, survey and interview responses from 26 students suggest the technique offers important instructional and assessment advantages: Compared to typical discussion sessions, a large majority of respondents reported being more engaged, learning more, and interacting more with the instructor. Students reported the anonymous mode allowed them to ask "dumb" questions. The instructor was able to address student problems and questions immediately, and the amount of formative assessment information from the interaction far exceeded what was available in typical settings.

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Introduction

A cornerstone of undergraduate education reform is the shift in emphasis from teaching to student learning. A key effort in reform is promoting active learning. Active (or student-centered) learning refers to the set of practices and activities designed to promote students' engagement with content. Examples include collaborative learning (e.g., learning communities, group activities), undergraduate research, writing and oral communication across the curriculum, integrative learning experiences (e.g., capstone courses), self-learning activities (e.g., encouraging students to reflect on their learning), and activities that require students to engage in cognitive processes beyond memorization (Boyer Commission, 1998; Chickering and Gamson, 1987; Education Commission of the States, 1995; Ewell, 1998; National Research Council [NRC], 1995, 2003; National Science Board [NSB], 2003; Terezini and Pascarella, 1994; Tinto, 2002; Wulf, 1998).

Underlying student-centered learning is formative assessment. Formative assessments provide information on what, how much, and how well students are learning, for the purpose of improving the quality of student learning. Formative assessments require close observations of the student learning process, are ongoing, capitalize on the expertise and experience of instructors using the assessments, and respond to particularities of individual students, instructors, and class settings (e.g., Angelo and Cross, 1993; Baker, 1998; Black et al., 2003; Black and Wiliam, 1998; Brookhart, 1999; Cross, 1988, 1998; Ewell, 1998; Sadler, 1989; Wiliam et al., 2004). Using formative assessments can have a profound effect on instructors and their understanding of their students (e.g., Steadman, 1998), and there is some evidence that formative assessments improve student achievement (Brookhart, 1999; Olmsted, 1991). The promise of formative assessment is if instructors have timely information on whether students are learning; then their instruction can be modulated with greater precision and accuracy, resulting in improved student learning.

Despite repeated calls for change in undergraduate education and encouraging findings when implemented, most colleges and universities have been slow to adopt the practices known to have real impact on student learning (Boyer Commission, 2001). Current instructional practices in the science and engineering fields continue to rely on the lecture. Chen (2002) reported that 83% of science and engineering instructors use the lecture as their primary method of instruction in at least one class. The problem with lectures is not that the format is inherently ineffective; it is just that other formats are likely to be more effective for more students (Terezini and Pascarella, 1994).

Several researchers have documented the undergraduate science and engineering student experience as an impersonal, anonymous, and competitive journey where students passively learn facts as they march through a rigidly structured curriculum taught by instructors who are boring, inaccessible, and intimidating (Kardash and Wallace, 2001; Lewis and Woodward, 1984; Seymour and Hewitt, 1997; Tobias and Raphael, 1996). Seymour and Hewitt found that one of the most common reasons directly contributing to students' decisions to switch out of the major was faculty pedagogy (e.g., poor teaching, help with problems, advising). Dissatisfaction with faculty pedagogy – more so than poor academic performance – led to student departure and remained a source of dissatisfaction with students who continued in the field (Adelman, 1998; Seymour and Hewitt, 1997). With a student departure rate of 40% (NSB, 2004), it is hard to envision how the demand for science and engineering graduates will be met.

Like Terezini and Pascarella (1994), we think the main issue with lecture classes is not the format per se. Rather, the learning environment, *in the absence of effective instructional supports*, often leads to open-loop instruction: an instructor covering material with little or no a) interaction with students; or b) information on what students have learned or not learned. The main determinant of learning is the degree of cognitive processing of the to-be-learned content, regardless of instructional format (deWinstanley and Bjork, 2002; Mayer and Wittrock, 1996; Wittrock, 1989). That is, students who engage the material – who commit attention and cognitive resources toward comprehending and understanding the content – will learn more than those students who do not. The learning environment is a powerful mediating variable that affects learning indirectly by promoting or inhibiting meaningful engagement.

Formative Assessment in Lecture Classes

Typical large-class instruction is one of "dead reckoning": Marching through the syllabus with little information on how well (or poorly) students are really doing and hoping for the best. Classroom assessment techniques have been developed to address this situation and specifically designed to minimize the data-processing load on the instructor. For example, the *one-minute summary, muddiest point*, and other techniques are easy to administer and summarize (Angelo and Cross, 1993). These assessments focus on asking students what was unclear to them during the lecture. Informative as they are, however, these assessments are indirect measures of learning as they do not ask students to perform on tasks that indicate understanding of content.

Increasingly, researchers are turning to technology to provide formative assessment information (e.g., Fitch, 2004; Griffioen et al., 1999; Heath et al., 2005; Kashy et al., 2001; Lieberman et al., 2001; Marks, 2002; Schaeffer et al., 2001; Twigg, 1999). For example, Web-based systems have been used to deliver homework and low-stakes quizzes. The basic idea is that online systems can provide rapid feedback and students benefit from immediate knowledge of results and potentially, the opportunity for multiple practice trials. The impact of these systems on course outcomes has ranged from none (Bonham et al., 2003), some (Hall et al., 2004; Mestre et al., 2002; Paull et al., 1999), to large (Oakley, 1996; Woolf et al., 2000). The key difference among these systems appears to be the quality of the interaction. Oakley allowed scoring of assessments and multiple types of interactions with instructor and peers (e.g., posing questions and issues). Woolf et al. used an intelligent tutoring system, which presented leading questions to guide students' interaction with the system. In contrast, the other systems provided only information on whether students go the problem correct. It appears Oakley and Woolf et al. used feedback effectively – providing information on whether the student was correct or incorrect, and if incorrect, specific steps to take to improve performance (Black and Wiliam, 1998; Kluger and DeNisi, 1996; Sadler, 1989). Interestingly, while all of these systems were individualized, scalable, and focused on content and performance as measured by multiple-choice tests, only the Oakley system allowed students to ask questions of their instructors, although this was not in real-time. The capability to gather students' input on what they are not understanding can be very informative.

Finally, some approaches are based on real-time interaction technology such as personal response systems (i.e., clickers). These systems have been used to increase student interaction in large lecture classes (e.g., Dufresne et al., 1996; Fitch, 2004; Heath et al., 2005). Such systems provide an efficient and simple way of gathering student responses.

While the newer response systems are easy to set up and use for instructors and students, they generally accommodate only selected-response formats (e.g., multiple-choice) and offer little or no support for observing students' problem solving or more complex communication modes (e.g., open-ended responses). The capability to observe the process of students' problem solving is important, particularly in engineering when how one solves a problem is often more important than the final answer.

Our conclusion is that the most important elements of an effective formative assessment system are a) the capability of the system to provide good information about what students know and do not know; and b) the use of that information by instructors to provide feedback to students about their performance, and to adjust instruction accordingly. As with effective tutoring (Bloom, 1984) and instructional techniques that promote interaction and engagement (Hake, 1998), the fundamental enabling capability is the bidirectional flow of accurate information between student and instructor.

Research Questions

Thus, our study focused on capturing a student's problem-solving response when it was "hot." Our assumption was the accuracy and precision of the assessment information are highest when the students are engaged in the *process of problem-solving*. Our research was exploratory and focused on utility and feasibility: To what degree did students perceive that the system promoted learning, interaction, and engagement with the content? To what degree did the system provide the instructor with useful information about students' understanding?

Method

Participants

The computer-based discussion sections were held during the instructor's office hours and participation was voluntary. We tested the system in three different undergraduate electrical engineering (EE) classes at a large public university in Southern California: EE10 (Circuit Analysis I), EE115A (Introduction to Analog Circuits I), and BREES (Bridge Review for Enhancing Engineering Students). Five discussion sessions were held in EE10 and EE115A, and three sessions for BREES. The same instructor taught all courses.

Across all courses, 89 students participated at least once. The sessions were typically attended by roughly 20 students. In general, out of all students who attended, over half attended two or more sessions. Of all the participants, 26 participants responded to requests to complete a survey at the end of the quarter. Of the 26 participants, 8 agreed to participate in interviews. Thus, the findings should be interpreted as exploratory. Survey respondents were paid $10 for their time, and interviewees were paid $20.

Table 1 shows the participation rates by course. The table values show the number of times the same student attended the computer-based discussion section. For example, the computer-based discussion section was offered five times in EE115A, and 5 students attended all sections and 8 attended two sections. In general, about half of the participants attended only one section.

Table 1: Number of Times a Student Attended the Computer-based Discussion Section

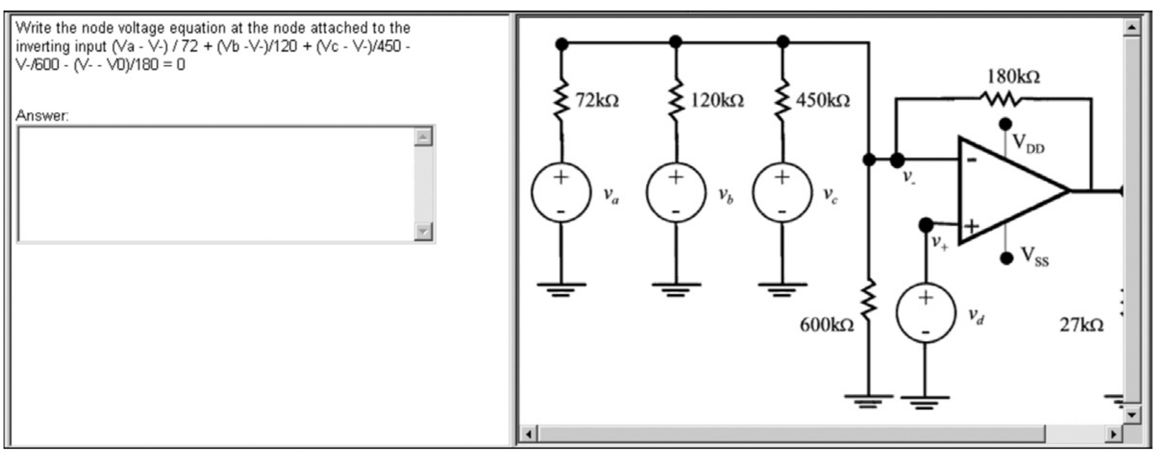
	Number of times the computer-based section was offered				
Course	**1**	**2**	**3**	**4**	**5**
EE10	14	6	8	4	N/A
EE115A	24	8	2	9	5
BREES	1	0	8	N/A	N/A

Online Formative Assessment and Instructional Tool

The tool we used was Discourse (ETS, 2003). Discourse is a client-server formative assessment tool that provides instructors the capability to author and administer assessments, track student responses, and generate reports of student performances. For the purposes of this study, we used only its interactive problem-posting and discussion capabilities.

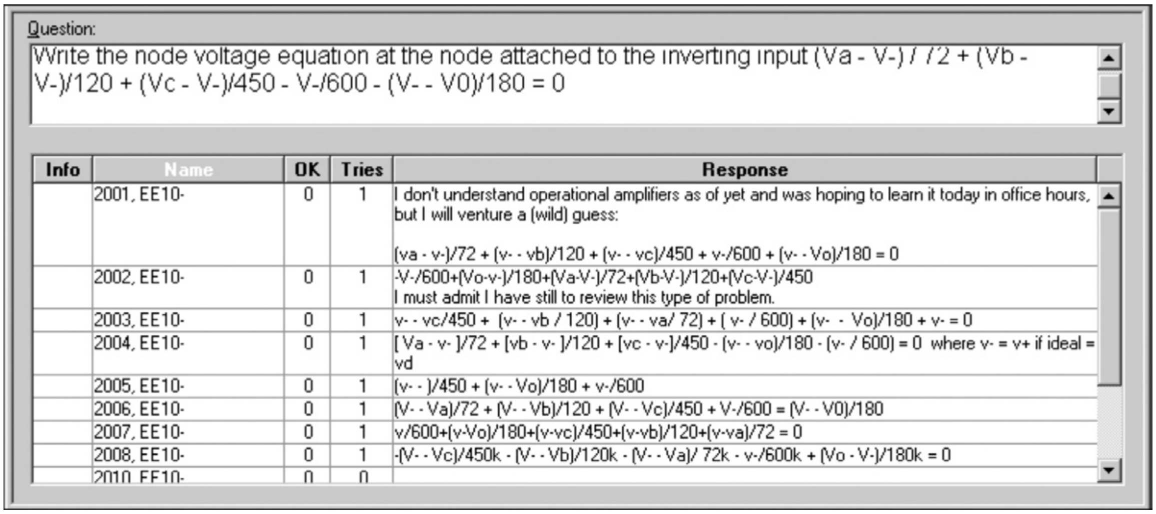
Each student used a laptop, which was connected wirelessly to the instructor laptop. The instructor would post a prompt (e.g., "Compute the voltage at node 1.") and circuit schematic. The student computer received the posting and displayed the prompt and circuit schematic. Students typed their responses in a text-entry area and could respond with an equation or enter a question or other response. Figure 1 shows the student user interface. The box below "Answer" is where students typed their responses. While Discourse was designed with numerous formative assessment capabilities, we used only its instructional capabilities, which included the capability for the instructor to present a prompt and schematic and to observe students' real-time responses.

Figure 1: Student User Interface



As shown in Figure 2, each student's anonymous response (keystroke level) was displayed in a row on the instructor's computer, allowing simultaneous observation of all student responses (large window). Each student was identified by a number ("Name" column). Students could also communicate via an anonymous instant messaging interface to ask the instructor questions and receive an individualized response (screen not shown, but essentially a "chat" application). The instructor could also use the whiteboard and conduct whole-group discussions, which were based on the real-time information from the students.

Figure 2: Instructor User Interface



Measures

Data were gathered from student surveys, student interviews, and instructor interviews.

Student Surveys

The student surveys and interviews focused on gathering information on students' perceived impact of the experience, relative to other typical discussion sessions. The survey mainly consisted of selected-response, Likert-scaled questions. In addition, participants were provided with space to write comments or specific examples.

Learning of Course Material

Participants were asked to indicate, on a 5-point Likert scale, how effective the computer-based discussion was compared to typical sections with respect to learning of course content (1=*much more effective*, 2=*more effective*, 3=*similar*, 4=*less effective*, 5=*much less effective*).

Interaction

Participants were asked to indicate, on a 5-point Likert scale, how effective the computer-based discussion was compared to typical sections in terms of facilitating interaction with the TA or instructor (1=*much more effective*, 2=*more effective*, 3=*similar*, 4=*less effective*, 5=*much less effective*). We defined interaction as communicating or asking questions, or responding to the TA or instructor.

Engagement

Participants were asked to indicate, on a 5-point Likert scale, how effective the computer-based discussion was compared to typical sections in terms of facilitating engagement with the material that was being covered (1=*much more effective*, 2=*more effective*, 3=*similar*, 4=*less effective*, 5=*much less effective*). We defined engagement as how much students were thinking about or working on the course material, as opposed to doing homework for other classes, playing games, and engaging in other non-content-related activities.

Overall Impression

This item was intended to gather participants' overall impression of their experience. Participants were asked to indicate their impression of the computer-based (i.e., Discourse) sessions on a 4-point Likert scale (1=*very positive*, 2=*moderately positive*, 3=*moderately negative*, and 4=*negative*).

Specific Course Outcomes

Finally, we asked students to report on a 5-point Likert scale (1=*very big effect*, 2=*big effect*, 3=*some effect*, 4=*little effect*, 5=*no effect*, and not applicable), how much of an impact the computer-based section had on the following outcomes:

- learning of specific analysis techniques
- development of circuit analysis problem solving skills
- completing homework assignments
- performance on exams
- performance on the course (EE10/EE115A/BREES)
- the student's improvement on attitudes toward electrical engineering
- the student's attitudes toward (EE10/EE115A/BREES) in particular
- the student's attitudes toward engineering in general
- the student's making new friends/networking

Student and Instructor Interviews

The student interviews were intended to gather in-depth responses to the issues of learning, interaction, and engagement. Interviewees were asked to elaborate on their survey responses. The course instructor and a TA were asked about their perceptions on the same issues, but from their perspective as instructors. Interviewees were free to elaborate on as many issues as they saw relevant.

Results

Our first research question, *To what degree did students perceive that the system promoted learning, interaction, and engagement with the material?* was addressed with student survey responses to questions, written comments, and follow-up interviews. The second research question, *To what degree did the system provide unique information about students' learning and understanding?* was addressed with instructor interviews. We examined the relation between frequency of participation and specific course outcomes (homework, exams, and grades) and found no significant relations. This result should be interpreted in light of the voluntary and transient nature of students' participation in the study, a situation that resulted in varying treatment lengths (Table 1, page 8). However, evidence from the student surveys and interviews was convergent and is presented next.

Students' Overall Impression

In general, participants perceived the computer-based section positively. Four rated the section as very positive, 16 as moderately positive, and 4 moderately negative. No one reported the experience as negative. While the student survey responses were encouraging, the follow-up interviews offered insight into the learning processes occurring during the computer-based section.

One of the most discouraging findings was an echoing of Seymour and Hewitt's (1997) findings of poor instruction in engineering in general. In most of the interviews conducted, students complained of the quality of instruction of most professors. Conversely, one of the most encouraging overall findings was students' reporting of a dramatic shift from passive to active learning. In regular discussion sections, students reported being passive compared to the computer-based section, where they participated and engaged in problem solving. One student reflected on this change of roles:

> At first I was kind of confused about what we were doing. After every session, I believe it was two or three times, it was actually kind of helpful. Because we did the examples and we actually had to participate in class, or were expected to participate and do the examples and give the answers and then check them.

Students reported being very satisfied with the section because they could visualize circuit analysis and see it more accurately on the computer. When asked if the computer-based discussion section had any impact on the level of comprehending circuit analysis, one student responded:

> Biggest impact because we were actually using it so that's a big impact. You understand it better than before because we were using it. We were doing concrete examples. I can see…if I make a mistake…You can weed those out by doing problems there, then when you go to the exam, you pretty much know how to do the problems, because you've already done it before.

Students' Perception of Learning, Interaction, and Engagement

As shown in Table 2, when participants were asked to compare the computer-based section to typical discussion sections, the general response was positive. The computer-based section appeared to have the largest impact on students' engagement with the material. In any case, student responses were generally positive across all three areas, with only two or three students reporting their experience in the computer-based section to be less effective than typical sections.

Table 2: Students' Perception of the Relative Impact of the Discourse Session (Compared to Typical Discussion Sections) ($N = 25$)

	Much more effective	More effective	Similar	Less effective	Much less effective
Learning course material	3	12	7	2	1
Interaction	5	11	7	2	0
Engagement	8	15	0	2	0

Table 3 (next page) shows perceived impacts on specific aspects of the course. Surprisingly, about one third of students reported the computer-based discussion section had a big or very big effect on course outcomes (homework, exams, grades). Students found the computer-based discussion section having a big or very big effect on completing homework assignments. This is unsurprising as the problems covered in the discussion section were taken from the textbook or closely modified homework problems. The perceptions that the computer-based discussion section helped with performance on exams and the course was encouraging, as it suggests that about a quarter of the students perceived the experience as highly useful. However, as mentioned earlier, no statistical relation was found between participation and course outcomes.

Even more surprising was that the experience resulted in some students reporting a big or very big impact on non-cognitive outcomes such as attitudes toward engineering in general and in making new friends/networking. These are interesting findings given the variability of treatment effects (Table 1, page 8). Further, these results suggest that there may be side-effects to this type of instructional delivery. That is, while the original focus was to improve learning, about a quarter of the students apparently perceived attitudinal benefits as well.

Table 3: Students' Perception of the Impact the Computer-Based Session had on Different Course Outcomes

	n	Very big effect	Big effect	Some effect	Little effect	No effect
Learning of specific analysis techniques	25	3	3	8	7	4
Development of circuit analysis problem solving skills	25	2	1	11	7	4
Completing homework assignments	24	5	7	7	2	3
Performance on exams	24	2	7	9	2	4
Performance on the course	24	2	4	11	4	3
Your improvement on attitudes toward electrical engineering	24	2	3	13	5	1
Your attitudes toward EE10/EE115A/BREES in particular	24	0	4	8	10	3
Your attitudes toward engineering in general	24	3	4	10	6	1
Your making new friends/networking	24	6	5	7	5	1

We interpret these results as students perceiving the computer-based discussion section as benign at worst, and in many cases more effective than typical discussion sections. Students' perception of effects on most of the course and attitudinal outcomes were generally positive. In particular, students appeared to perceive engagement as the most powerful impact of the computer-based discussion section. In the following section, student interviews provide insight underlying the survey responses.

Analyses of Student and Instructor Interviews

Perceived learning of course material. The computer-based discussion section required students to understand every step and the professor to explain and clarify those steps. In general, the analyses of student interviews suggest that students felt more in control of the material and understood it more thoroughly. While students reported that the discussions were helpful because it forced them to solve the problem, the technology alone did not constitute good instruction. One student, "the fact that he [the professor] takes the problem and solved it on the board and explained it in detail. That's the most useful thing."

But this mode of instruction was not helpful for all students, particularly for those who were able to solve the problem quickly. One survey respondent commented: "The process of learning seems to be slowed down a little too much. Though the discussion can be changed to fit our learning needs, every example takes too long. This makes the class a little boring."

Perceived Interaction

One of the most important dimensions reported by students as a barrier for their learning was related to their social inhibitions. Nearly every student we interviewed had said that he or she felt intimidated in a large classroom and in the presence of a professor to raise their hands and ask to clarify incomprehensible material. Students expressed their concerns that professors would consider their questions to be stupid or inappropriate, and that professors would remember them as students who asked stupid questions:

> For example…I'm hesitant to ask questions during class and since this is anonymous…the professor won't point anyone out or anything so he'll just be able to answer a lot of questions, and then you'll see a lot of students making common errors. So he'll be able to answer those specific ones.

In the computer-based discussion section, student responses were anonymous and an individual could correspond with the professor directly. Students felt that anonymity was very important to participation, and participation increased their level of understanding of the material. One survey respondent commented about the anonymity:

> I think that maintaining anonymity is very crucial in the interaction aspect of the discussion. Many, including myself, may feel a little embarrassed asking a "dumb" question but with this method, I don't feel that people will hesitate to ask those questions.

While many students cited anonymity as important, not all students felt this way. A small number of students reported that it simply would be easier to just raise their hands and ask questions.

Perceived Engagement

A seemingly obvious activity that should be occurring in a circuit analyses discussion section – computer or no computer – is problem solving. However, students' interview responses suggest this is typically not the case in non-computer sections. Thus, one important benefit of the computer-based discussion section was that it required students to solve circuit problems. Each student had his or her own laptop and was required to solve circuit analysis problems. When students were asked about their level of engagement, all interviewees said engagement was much higher in the computer-based discussion section compared to typical discussion sections. For example, one student said:

> Definitely, ten times more engaged. [In a typical discussion section] You don't have to engage in a lecture or whatever's going on in class… You can just sit there and do something else, do homework or whatever. But in that [computer-based] class, we didn't have any other papers around, we all had a terminal, and everyone else in the class was participating, and doing problems…and you couldn't do anything else but participate. So definitely more participation, definitely more.

Interestingly, the instructor also reported that his students were much more engaged than the typical section. When we asked him about his students' level of engagement he said that it was much more focused.

> In a normal group, I would lose some people. They would fall asleep. I think if they're not getting something, they'll just say, "I'm going home and study this." And you'd lose 10% of the people at any given time. This session was not, at all. Everyone was very engaged. Everyone was at full attention. When you work on a problem, everyone would be watching the problem solution very intently. When the problem was assigned, everyone would be really working on the problem. That was another very interesting point.

Students' Perception of Non-cognitive Outcomes

Finally, one of the most unexpected findings emerging from the student interviews was the impact the experience had on students' non-cognitive outcomes. That is, the issue of a caring professor emerged – one who creates an open and non-intimidating atmosphere to ask questions. All participants said that the instructor's attitude had been one of the main reasons that helped them learn. The instructor taking time to teach and to explain fundamental material was one of the most important factors cited as leading to students' increase in the level of engagement and understanding. It is essential to add that we did not prompt students for these comments on the instructor – all interviewees provided unsolicited feedback on the instructor.

> Professor [X], he helped us out with that it felt a little bit better getting it from a professor than a TA. I don't know why but it just did. But he was real kind, kind at answering everything pretty much. He was able to answer… all my questions. I was happy with this computer thing.

Monitoring Students' Performance

One of the most important benefits of the computer-based discussion section was the capability for the instructor to simultaneously observe students' problem-solving responses in real-time. Contrast this situation with the typical lecture class, where the instructor has little feedback about whether the students are comprehending the material. Thus, the instructor could determine how many students did or did not understand a concept and could address the situation immediately. In the instructor's words:

> What happens is that I get a chance to see exactly what people were doing, and if there was an error... what I would then do is spend discussion time speaking about that particular error, and instructing them about that particular problem, and I found that to be immensely more effective than the alternative. Now, in EE10… we were able to provide a…set of problems ranging from relatively simple to complex. And, at the beginning of the session, the success rate of the class might only be like one third… correctly solving the simple problems. But by the end of the class session, virtually the entire class was…working through the most difficult problems. So, the progress over a one-hour period was general. I would say, it could even exceed one-on-one office hours. Because, even at the one-on-one office hours, I typically don't ask a student to solve a problem. I'll do it for them, and ask them about it or they'll ask me how we move from step to step. And that's much better than a large group in terms of interaction and quality of interaction but even there we're not seeing what exactly the student does on their own. Because it's somewhat confrontational to ask them to solve a problem right there on the spot – they're nervous.

Interestingly, students also reported the benefits of the instructor's capability to observe students' responses. They reported the instruction being more targeted and individualized because the instructor was able to focus on what students were not getting correct. For example, in response to the question of what he had gained from the computer-based discussion section, one student remarked:

> I can say the most I gained was a little bit better problem-solving skill as far as analysis was concerned. I think that professors sort of looked at mistakes we were making along the way…So to get the idea at that exact moment where our mistakes [are] coming from and so he was able to more specify what he needed to teach, what the emphasis of learning should be on.

Discussion

The most effective form of assessment is one that is continuous, that occurs as close as possible to the scene of the action in teaching and learning (the classroom), and that provides diagnostic feedback to both teachers and students – to teachers on how they can improve their teaching, to students on how they can improve their learning (Cross, 1988, p. 3).

Our assessment perspective embraces this idea. This study directly attempted to address the issue of improving student learning via an online formative assessment that provided continuous feedback to instructors about students' learning progress, who could then provide feedback to students about their performance and provide remediation as needed. Effective feedback to students is consistently cited as one of the most important components of an effective learning environment, and it has been found to increase not only student learning, but also confidence and attitudes (e.g., Angelo and Cross, 1993; Black and Wiliam, 1998; Bloom, 1984; Chickering and Gamson, 1987; Cross, 1988, 1998; McKeachie, 1998; Tinto, 2002; Twigg, 1999).

Students overwhelmingly reported positive outcomes for the computer-based discussion section. When asked to compare their experience with traditional discussion sections, students indicated the computer-based discussion section had superior engagement with the content, had increased positive attitudes toward the course and engineering, and had increased learning of the material. Students felt they shifted from a passive role to a much more active and engaged role and felt they learned the material more thoroughly. Because students were required to solve problems step-by-step (vs. typical instruction where material was introduced broadly and students left on their own), students had to ask questions and "experience the equations." One of the most interesting findings was the bolstering of students' confidence in solving circuit problems and affective outcomes. The real-time feedback from the instructor, often individualized, was cited as critical not only to increasing content understanding but also because students felt they were receiving personal attention. Similarly, anonymity was critical because students felt comfortable asking "dumb" questions.

Limitations and Future Directions

The main limitation of this study was lack of an experimental design. This was intentional as we were investigating the feasibility and utility of the approach. The disadvantage of this tactic is that the findings of this study, suggestive as students' self-reports are, do not confirm the existence of a clear learning impact. Other limitations include a small sample size, a self-selected sample, and testing in only three courses from the same school of engineering. Also, while the instructional format appears useful for problem solving, it is unclear whether the format would be appropriate for non-problem solving-related topics. However, given the provocative findings of the current study, a clear next step is to contrast students' performance on various course outcomes between students randomly assigned to the computer-based discussion section and a control group, controlling for instructor effect. Such a study would need to be of sufficient duration to allow the intervention to have an impact.

The second line of future work is developing methods to allow scaling of the approach to large lecture classes. We have tested the system in classes with as many as 60 students (not part of this study); while still informative, attempting to observe all students' responses and to attend to individual questions or problems quickly becomes overwhelming. Thus, we are exploring techniques that blend automated reasoning approaches (e.g., Bayesian networks) and other formative assessment techniques (e.g., self-ratings of level of understanding; muddiest point) to allow students to engage and participate, while also providing a mechanism that will allow partial filtering of responses and automated detection and summarization of student responses.

The lecture format is likely to remain a large part of undergraduate instruction for the foreseeable future, and consequently its impact on student learning will be pervasive. Our work is one step toward developing online formative assessment methods intended to increase the level of engagement and interaction in the traditional lecture format.

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Author Biographies

Gregory K. W. K. Chung is a Senior Researcher at the National Center for Research on Evaluation, Standards, and Student Testing CRESST). His current work at CRESST involves developing computer-based assessments to measure problem solving and content knowledge in military and engineering domains. He has experience developing Web-based assessment tools for diagnostic and embedded assessment purposes using Bayesian networks, domain ontologies, and other advanced computational tools. Dr. Chung earned a Ph.D. in Educational Psychology from the University of California at Los Angeles, an M.S. degree in Educational Technology from Pepperdine University at Los Angeles, and a B.S. degree in Electrical Engineering from the University of Hawaii at Manoa. All correspondence should be sent to the first author, Gregory K. W. K. Chung, (greg@ucla.edu).

Tammy Shel received her Ph.D. in philosophy of education from UCLA. She also studied in Israel. She has focuses on the value of caring in education to promote learning and tolerance and to diminish violence. She links violence in the micro to the macro by focusing on students' social and emotional cognition and on students as individuals and as men and women. Her areas of interest are philosophy, ethnography, anthropology, gender studies, and international education.

Professor William J. Kaiser received his Ph.D. in Solid State Physics from Wayne State University. In 1994, he joined the faculty of the UCLA Electrical Engineering Department and served as Department Chairman from 1996 through 2000. At UCLA, he initiated the distributed networked embedded sensor field via many large collaborative programs across several departments. These combined UCLA research activities have now led to the creation of many new programs within DARPA, NSF, NASA, and in commercial technology corporations. Professor Kaiser has over 100 publications, 100 invited presentations and 21 patents and has received the Allied Signal Faculty Research Award, the Peter Mark Award of the American Vacuum Society, the NASA Medal for Exceptional Scientific Achievement, the Arch Colwell Best Paper Award of the Society of Automotive Engineers, and two R&D 100 Awards.

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