Tablet Computers Used for Teaching and Real-Time Assessment of Conceptual Understanding of Engineering Students

Frank V. Kowalski, Susan E. Kowalski, and Luke Campagnola
Colorado School of Mines

Abstract: The use of interactive teaching techniques has progressed dramatically with the advent of new technologies. This progress can be divided into two main categories. One is content enhancement while the other is feedback on student understanding. The latter is an important thrust of ABET in improving engineering education. Instantaneous assessment closes the feedback loop, associated with improving teaching, with the shortest time constant.

An important such technology, increasingly common nationwide, is the use of infrared transmitters used by the students to answer multiple-choice questions. The answers are computer-tabulated and displayed via projector to the class as a histogram, providing valuable formative assessment data to both students and instructors. Although the use of this technology is pedagogically sound, one shortcoming, particularly in engineering education, is the necessity of questions in the multiple-choice format. Students have a propensity to guess an answer from the menu given, thereby injecting noise into the feedback loop. This format also makes it more difficult to pose open-ended questions and those that require higher order thinking.

We use mobile technology to explore beyond the collection and tabulation of simple multiple-choice data, to that which includes equations, graphs, and short answers. Furthermore, we combine this technology with technological innovations in the content enhancement category, perhaps best illustrated by the development of applets. The number of available applets continues to increase while the conceptual level is diverse, typically covering high school to advanced undergraduate courses in science and engineering. These content-rich applets are appropriate in both the laboratory and classroom settings.

This combination of student-directed content enhancement and real-time feedback allows more meaningful active learning and a novel, sophisticated level of classroom communication. Instructors receive real-time feedback to questions that probe misconceptions and comprehension, reinforce main concepts and problem-solving strategies, and encourage higher-level thinking skills. This feedback, particularly written responses, increases student metacognition and guides the instructor in addressing student misconceptions.

Introduction

The pedagogical potential for interactive teaching techniques has increased dramatically with the advent of new technologies[1]. This progress can be divided into two main categories. One is content enhancement, such as the development of applets which allow students to utilize the power of computers to manipulate different variables and thereby visualize otherwise difficult concepts. The wealth of free applets available on the Internet continues to increase. The conceptual level is diverse, typically covering high school to advanced undergraduate courses in science and engineering. The other category of significant progress is the use of technology to

provide real-time feedback on student understanding. Feedback is an important thrust of ABET in improving engineering education[2]. Instantaneous assessment closes this feedback loop with the shortest time constant. It is an attempt to deliver a form of Socratic teaching to a group of students and strongly encourages active learning by every student in the group[3]. There is a solid body of research evidence showing that enhancing the practice of such formative assessment, with timely feedback to the students, can produce significant and often substantial learning gains[4].

The combination of student-centered content enhancement and real-time feedback allows meaningful active learning and a novel, sophisticated level of classroom communication. Students are engaged with the subject material and instructors receive real-time feedback to questions that probe misconceptions and comprehension, reinforce main concepts and problem-solving strategies, and encourage higher-level thinking skills. This feedback increases student metacognition and guides the instructor in addressing student misconceptions.

We discuss first some of the challenges of real-time feedback via student remote devices and then give an example of one application which intertwines the use of applets with more sophisticated real-time feedback. Our work is directed toward a vision of the classroom of the near future: one occupied by students with ready access to technology such as that currently available in tablet computers. Students will receive lectures, be able to annotate the distributed notes, have access to the web, and utilize classroom communications in a mobile environment. A major challenge is to develop pedagogy which takes full advantage of the technology and builds on our understanding of the learning process.

An initial step in classroom communication technology, increasingly common nationwide, is the use of infrared transmitters with which students answer multiple-choice questions. The answers are computer-tabulated and displayed via projector to the class as a histogram, providing valuable formative assessment data to both students and instructors.

Since this technology, referred to hereafter as clickers, is relatively mature (one product has been sold for over 20 years), one can focus on pedagogy. Clickers are particularly useful for single concept problems, definitions, numerical calculations, and can even be used to guide students (as in the Socratic process) through the problem-solving process using a series of questions. Questions with appropriate distracters give the instructor feedback on the methods of solution chosen by the students.

For non-homogenous classes (often the case in large classes) students will have multiple misconceptions. In this case the instructor must decide which to address in class and when to move forward. Nonetheless, even the minority of students whose misconceptions are not addressed are given immediate feedback that they need to receive additional instruction.

Although the use of clickers is pedagogically sound[5, 6, 7], one shortcoming, particularly in engineering education, is the necessity of questions in the multiple-choice format. Students have a propensity to guess an answer from the menu given, thereby injecting noise into the feedback loop. In addition, the author of the question must construct meaningful distractors. This may be particularly difficult for inexperienced instructors, but is often a challenge even for veteran

teachers. Another problem with this technique is that by giving the students a menu of answers to choose from, their thought process is directed toward eliminating wrong choices in the menu rather than solving the problem from first principles. This generates an environment often far removed from that in which the students are later expected to perform in industry. A further problem in assessing learning with multiple-choice questions is the response validity. Answers to similar open-ended and multiple-choice questions have been shown to differ greatly for certain students and questions[8].

Perhaps the most serious shortcoming of limiting real-time feedback to responses in multiple choice question format is that it shortchanges the students of an opportunity to improve their critical thinking skills through writing. Vygotsky[9] and others maintain that the use of verbal language supports higher cognitive functions. Emig's contention that "Writing represents a unique mode of learning" [10] acknowledges that when students write about content, they understand it better and remember it longer. This connection between writing and successful learning strategies has served as the basis of widespread educational reform movements such Writing Across the Curriculum, Writing to Learn, Writing in the Disciplines, and others. These reforms have positively impacted engineering education across the country, including at our institution[11]. Although one of the great strengths of clicker technology is that it actively engages students with their learning, formulating an original, written response requires an even higher level of engagement with the material. Furthermore, multiple-choice questions do little to help students attain an ability to communicate effectively, which is ABET's Criterion 3(g) for Accrediting Engineering Programs[2].

We want to explore beyond the collection and tabulation of simple multiple-choice data, to that which includes open-ended short answer questions, equations, and graphs. As a preliminary example, we describe a lesson in which students use mobile tablet computers for both independent, directed investigations using applets and a web-based real-time assessment tool we have developed. This utilizes a spectrum of tools enhanced by wireless technology.

Implementation

A lesson on phasors demonstrates how the classroom communication web-based software that we have developed can be used with applets to enhance conceptual learning. An abbreviated version of the instructor's web page is shown in figure 1. Multiple-choice, fill-in-the-blank, and written discussion questions can be constructed on this page as the instructor prepares for class. When the instructor activates a given question, the students then see the screen shown in figure 2 for the particular question activated. As the students submit their responses, the instructor can then monitor the responses in real time by clicking on "view response," which compactly reveals to the instructor an up-to-the-minute listing of all student responses (figure 3). Since this feature allows feedback to be gathered as the students work, it is particularly attractive in open ended/short answer questions. The instructor can address misconceptions in the way the question is framed before the whole class has responded, or use the time to devise a strategy to clarify the issue. The response page can then either be displayed to the whole class for discussion or viewed only by the instructor.

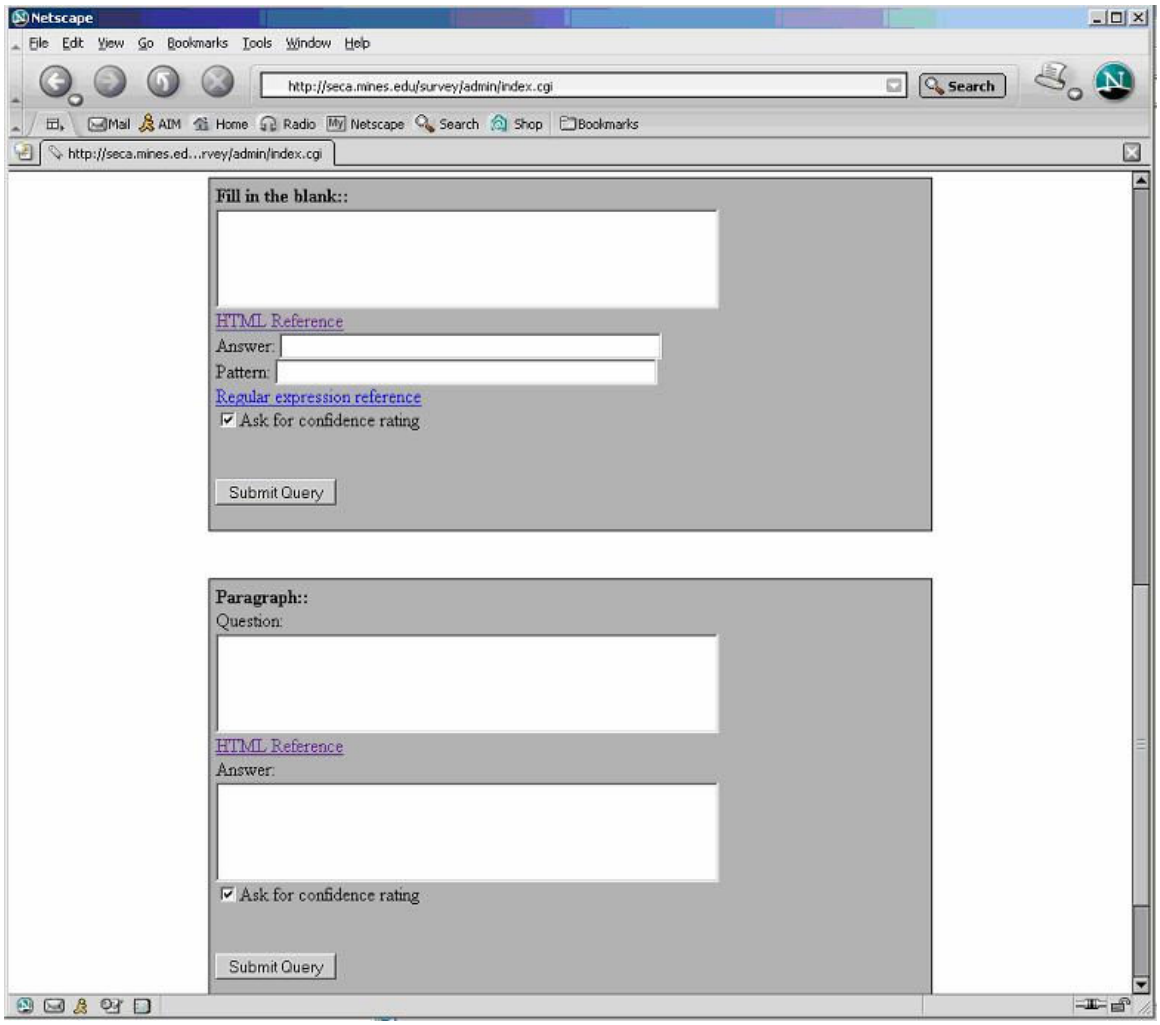

Figure 1: Abbreviated version of the instructors web page for question construction.

We begin the lesson with the short answer pretest question:

#1. Phasors are used to . . .

For most students, this is a refresher question over material they have covered in a prior electronics class. The answers to this question are not discussed, but serve as formative assessment information for both the students and the instructor. Next comes a mathematical discussion to demonstrate that the algebraic method of adding two harmonic waves of the same frequency and wavelength is tedious. Using Euler's theorem, the harmonic functions can be represented in the Argand plane as phasors. Harmonic waves can be added much more concisely and elegantly using this geometrical construction. For a detailed development see Griffiths[12].

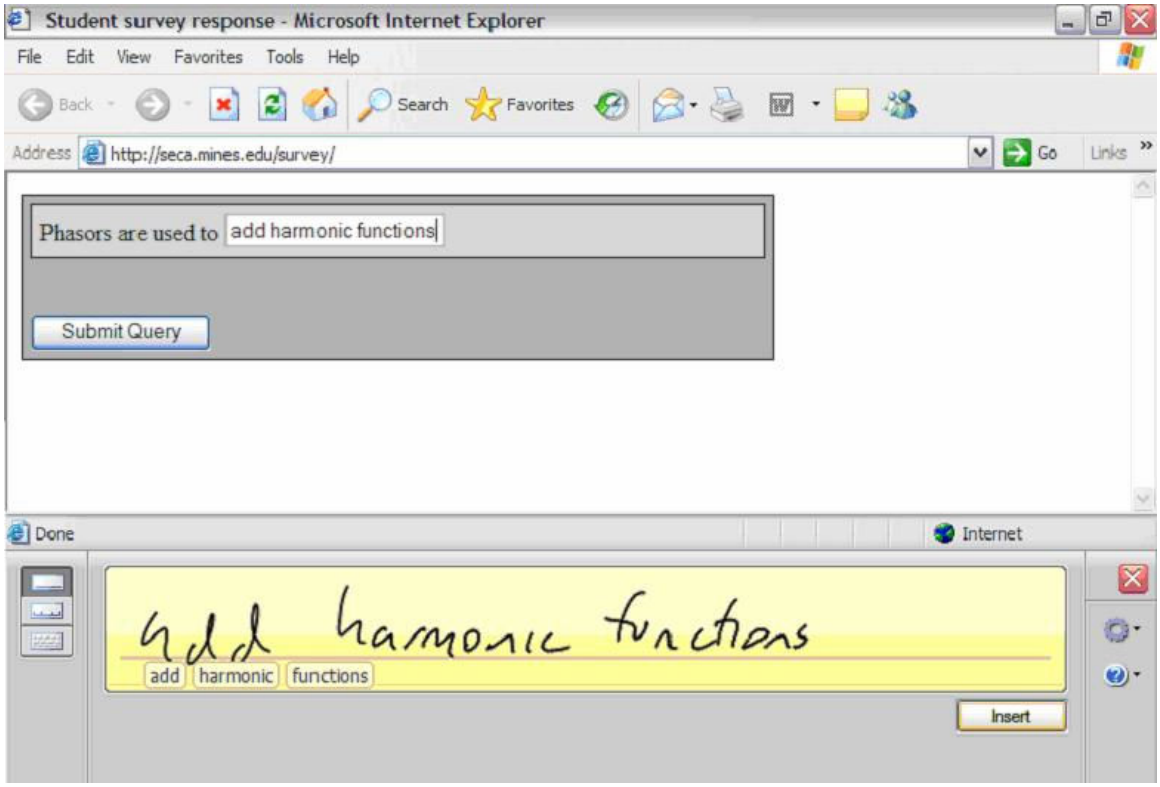

Figure 2: Student web page with handwritten response recorded.

Building on this abstract concept, specific applets are used to illustrate the breadth of the applicability of phasors. There are two ways the applets can be presented. The instructor can project and manipulate the applet and ask for student responses on the web-based software, or the students can run the applets and use the web-based software to respond to questions posed regarding the conclusions they form. The former, method A, allows the instructor more control of the pace and content while the latter, method B, allows more exploration by the student and the possibility of differentiated learning. For simplicity, our discussion that follows will be based on method A, but it can easily be modified for method B.

The first illustration is a one-loop circuit that includes a harmonic voltage source, a resistor, and inductor. Kirchhoff's law states that the sum of the voltages around the circuit is zero. This manifests itself as a sum of two harmonic voltages across the resistor and inductor equaling the voltage across the source. This is a sum of harmonic functions of the same frequency but with a different phase. In method A the instructor adjusts the phase relationship between the phasors and runs the animation found at:
http://www3.ltu.edu/~s_schneider/physlets/main/phasor1.shtml
with the voltage across the resistor being represented by phasor A (e.g. red and of magnitude 4) and the voltage across the inductor being represented by phasor B (e.g. green and of magnitude 3).

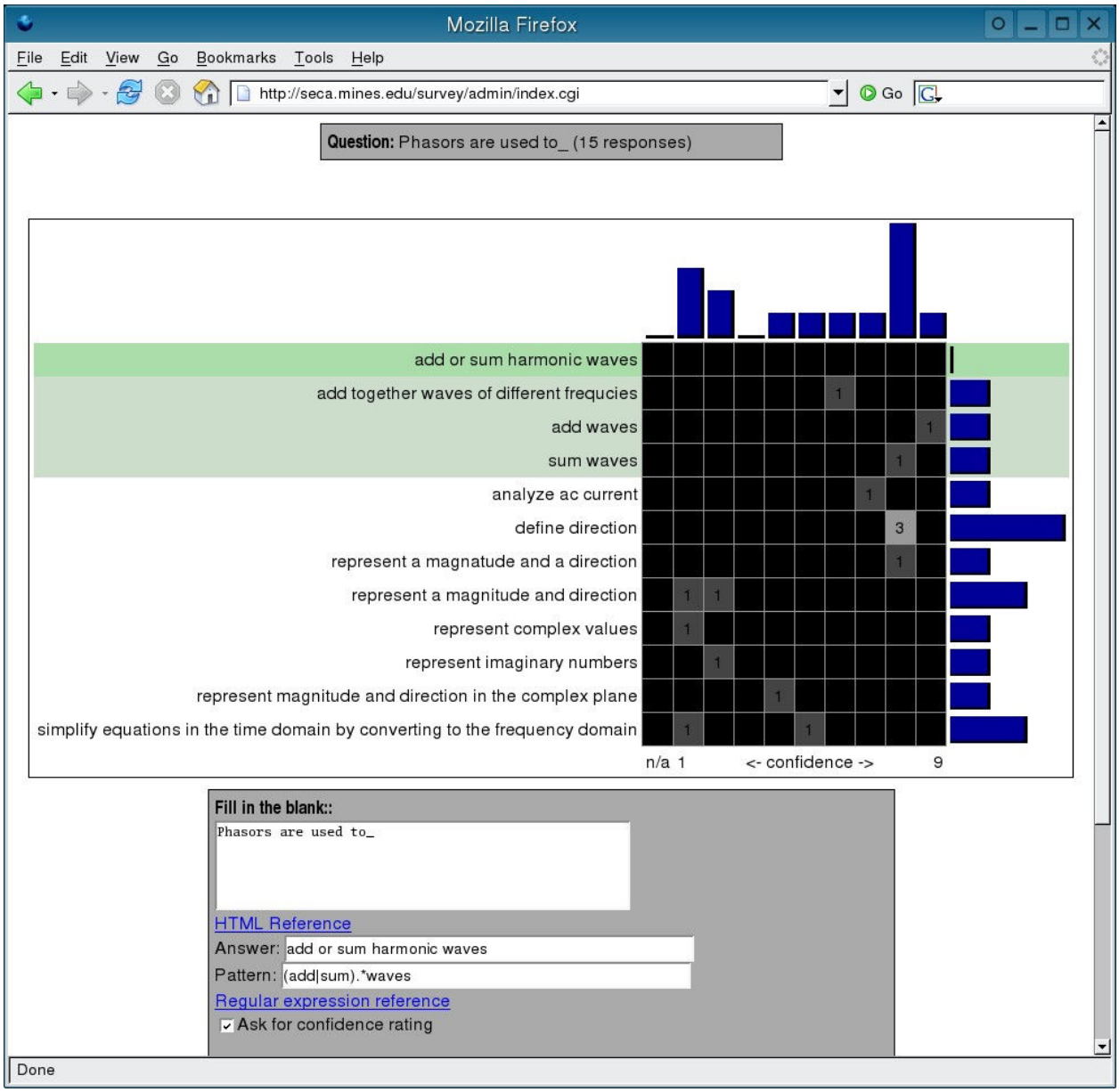

Figure 3: Instructors web page displaying student responses. The instructor has entered the response shown in green and the student responses are sorted according to how closely they match that pattern. Confidence level (optional) is displayed along the horizontal axis with the number in each box indicating the number of responses with that confidence level. The histogram along the top sums the confidence levels in each column and is indicative of the overall confidence students have in answering the question. The histogram along the right hand side sums the responses horizontally.

To test understanding of Kirchoff's law, the students are then asked:

#2. The blue phasor represents . . .

The expected answer is that it is the voltage across the source (from Kirchoff's law), which is the sum of the other two phasors. When the student responses are received, the instructor can reinforce the correct answer and address any misconceptions at this point.

Next, the instructor steps through the animation in time while asking the students to look at the time graph. The students are expected to draw the same conclusion as in the previous question but in the time domain. That is, they should conclude that the two harmonic voltages across the inductor and resistor add to yield the harmonic source voltage for every instant of time. This is assessed with the question:

#3. A conclusion that can be drawn about the three voltages, at any given time, is . .

Again, the data the instructor collects (open-ended student responses) drives the subsequent discussion.

After this, we move to an example of diffraction from a grating. This is a sum of harmonic waves of the same frequency but with different phases from each slit. Far away from the grating, the distance from neighboring slits to the observer differs by an integral multiple of the grating spacing times the sine of the diffracted angle with respect to the grating normal. This results in a progressive phase difference between phasors (each representing a wave from one slit) of 2 pi times this distance divided by the incident wavelength. The applet used is found at http://www3.ltu.edu/~s_schneider/physlets/main/phasorslits.shtml
First the phasor diagram for 2 slits with a phase angle of 60 degrees is set up. Now the angle of observation of the diffraction pattern is varied while watching the plot of the wave intensity, which is the square of the sum of the amplitudes from the two phasors.

Then, more slits are used and the phasor plot verses angle is repeated. To assess general conceptual understanding in this case, the following question is asked:

#4. This phasor plot differs from that of the previous applet by . . .

The students should understand that in this case the phase of the interfering waves is being varied by changing the angle of observation while in the circuit example the phase between the two waves was fixed and time varied.

A follow up question is:

#5. To make this animation look like the previous I would . . .

This should facilitate a discussion of the distinction between observing the waves from an observation point which varies spatially (and therefore the phase angle between phasors varies) and that of time variation at a fixed point which simultaneously rotates all of the phasors.

In the previous examples harmonic oscillations of the same frequency were added. However, phasors can still be used if the harmonic functions to be added have different frequencies. In this case the phase angle changes with time. An illustrative applet can be found at http://www.jhu.edu/~signals/phasorapplet2/phasorappletindex.htm

An impulse train composed of 3 harmonics is chosen. The animation is stepped in time. To assess the understanding that these phasors do not all have the same time dependence the following question is asked:

#6. This phasor plot differs from those of the previous two applets by . . .

As the students acknowledge the differences, this segues to an introduction to the topic of Fourier analysis and its relation to phasors.

Finally, the pretest question (#1) is repeated as the posttest. This final response serves the dual purpose of measuring student learning gains and reinforcing for the students the main, unified point of the lesson.

These lessons could be done with students working individually or in groups; we found it to be particularly effective when the students worked in groups of two, which allowed for a social component (peer instruction) in the learning process.

Results

This lesson was applied in three fall semester junior level modern physics laboratory classes with a total enrollment of 60 students. All students had two semesters of calculus-based physics, one in mechanics and the other in electricity and magnetism, along with one semester of analog electronics and concurrent enrollment in digital electronics. All of these courses are required in the engineering physics curriculum.

Evaluating the written responses, we conclude that for the pretest the incorrect and correct responses were 80% and 20% respectively. In the posttest the incorrect and correct responses were 28% and 71% respectively.

Many of the answers to these short questions were imprecise. This could be attributed to a lack of skill in verbalizing ideas or a lack of comprehension. Nevertheless, displaying these responses allowed the instructor the opportunity to give the students real-time feedback on what they wrote. For example, the question on what the blue phasor represented (#2), in the first applet, often had an answer involving addition of vectors. These responses lack the precision of describing what was being added, i.e. the voltages across the resistor and inductor at a given time. Such vague prose in an engineering report is not acceptable. Real-time feedback on this issue may have more of an impact on student learning than comments students receive weeks later from a written assignment.

Other responses indicated a lack of observational skills or an inability to consolidate the observations into a theoretical framework. As an example of the latter, consider the time series representation of the voltages across the source, inductor, and resistor in the first applet (#3). While most students were able to see that the sum of the voltages across the inductor and resistor always equaled the voltage across the source, some noted “all three voltages are never equal at the same point in time,” or “the frequencies of all the waveforms are the same.” While these two responses are correct, they do not address the consequences of Kirchoff’s law, which lies at the foundation of the problem.

Similarly, in relating the circuit applet and diffraction applet (#4), some students did not explain that different variables were being plotted. They noted, for example, that the difference between the two animations was that the independent variable in the first case was voltage while it was intensity in the other. Again, this is a true statement but misses the important point that the dependent variable in one case was time while it was the phase in the second applet. Real-time feedback about responses students give to such animations may help them to be more careful observers and place those observations in the context of some underlying principle. These are important problem solving and engineering design skills.

Conclusion

We have demonstrated a pedagogical technique for utilizing wireless tablet computers to provide open-ended feedback of conceptual understanding of applet simulations in an engineering context. The results indicate a strong learning gain. Real-time feedback guides the instructor in addressing student misconceptions on a time scale only slightly longer than in a one-on-one situation (Socratic teaching) while feedback increases student metacognition on a similar time scale. The open-ended feedback provides insight into the students thought process, deeper than that obtained with multiple choice questions.

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Bibliographic Information

1. Bransford, J.D., Brown, A.L., & Cocking, R.R. (eds.) (1999). "How people learn: brain, mind, experience, and school." Washington DC: National Academy Press.
2. ABET Engineering Accreditation Commission (2004). "2005-2006 Criteria for accrediting engineering programs." Baltimore, MD: ABET. Accessed online at http://www.abet.org/images/Criteria/E001%2005-06%20EAC%20Criteria%2011-17-04.pdf
3. Hake, R.R. (1998). "Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses." American Journal of Physics **66**, 64-74.
4. Black, P. and Wiliam, D. (1998). "Inside the black box: Raising standards through classroom assessment." Phi Delta Kappan, Nov.1998. Accessed online at http://www.pdkintl.org/kappan/kbla9810.htr.
5. Dufresne, R.J., Gerace, W.J., Leonard, W.J., & Beatty, I. (2002). "Assessing-To-Learn: Reflective formative assessment using a classroom communication system." Presented at Pathways to change: An international conference on transforming math and science education in the K-16 continuum, Arlington, Virginia, April 18-21, 2002. Accessed on-line at http://k12s.phast.umass.edu/~stemtec/pathways/Proceedings/.
6. Duncan, D. (2005). "Clickers in the classroom: how to enhance science teaching using classroom response systems." San Francisco, CA: Pearson Education, Inc.
7. Mazur, E. (1997)."Peer instruction: A user's manual." Upper Saddle River NJ: Prentice Hall.
8. Steinberg, R.N. & Sabella, M.S. (1997). "Performance on multiple-choice diagnostics and complementary exam problems." The Physics Teacher **35**, 150-154.
9. Vygotsky, L.S. (1962). "Thought and Language." Trans. E. Hanfmann & C. Vakar. Cambridge, MA: The M.I.T. Press.
10. Emig, J. (1977). "Writing as a mode of learning," College Composition and Communication **28**, 122-128.
11. Olds, B. M. (1998). "Technical writing across the curriculum: process, problems, and progress," 1998 Frontiers in Education Conference, Tempe Arizona. Available online at

http://fie.engrng.pitt.edu/fie98/papers/1359.pdf.
12. Griffiths, D.J. (1989). "Introduction to electrodynamics," second edition. Englewood Cliffs, NJ: Prentice Hall. See discussion, pp-348-349.

Biographical Information

FRANK V. KOWALSKI (Ph.D., Stanford University) is a professor of physics at CSM. As a strong proponent of using technology to improve engineering physics instruction, he uses both classroom communicators and applets on a regular basis in the courses he teaches. He encourages other teachers to explore the possibilities this technology facilitates.

SUSAN E. KOWALSKI (M.B.S., University of Colorado, Boulder) has been project coordinator for CSM's Classroom Communicator Project since its inception three years ago. She has extensive teaching experiences at the secondary, community college, and adult (teacher professional development) levels.

LUKE CAMPAGNOLA (B.S. Colorado School of Mines) is an instructor and research assistant for the Physics and Computer Science Departments at the Colorado School of Mines. He has worked on the development of 3-D imaging software and has also been involved in teaching physics laboratories and educational software development.