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Teaching first-year engineering students in a laptop environment requires carefully choosing and then adapting teaching methods. This chapter describes how laptops were used, how the students responded, and what the group of participating faculty learned in the process.

Using Laptops in Engineering Courses for Real-Time Data Collection and Analysis

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Although it is commonly assumed that the use of computer technology in the classroom has significant potential to benefit the educational process, evidence supporting the assumption is still modest (Neal, 1998). A growing body of literature on strategic management of technology in higher education asserts that technology is increasingly, inevitably, and ubiquitously a part of education. Katz and Associates (1999) ascribe learning benefits to technology, yet they present no evidence of its benefits to student learning. The Alfred P. Sloan Foundation, which has invested nearly $50 million in the Sloan Program in Anytime, Anyplace Learning, presents highlights of a recent survey focusing mostly on increasing enrollment rather than enhancing student learning (Sloan, 2004). Bates (2000) enumerates "How Technology Is Changing Teaching" yet refers to no studies

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supporting his assertion that new technologies improve the teaching of higher-order learning skills.

Bates and Poole (2003), however, put the issue of educational technology in the proper perspective. They identify the most significant challenge in studying how technology affects learning: the media is typically confounded with the message. Thus, in comparing technology-enhanced learning to traditional methods, it is difficult to design an experiment in which all other things are equal. Bates and Poole also point out (2003) that gaining a better understanding of how technology enhances learning requires that we use it even though the effect is not completely understood.

This chapter focuses on how we used laptops in combination with sensor-based technology and other pedagogical approaches that are known to improve student learning. In the process, we created a classroom environment in which the technology was enabling, creating educational experiences that would not be possible otherwise. Here we present our preliminary results from an ongoing study of student learning.

The Learning Environment: Our Students, Courses, and Classrooms

Clemson University is a rural land-grant institution in upstate South Carolina. It has technical foundations and still maintains a technical focus; the College of Engineering and Science is the largest college of five in the university. The General Engineering Program has coordinated a common first-year engineering curriculum since 1985.

About one in eight of Clemson's General Engineering students has not taken high school physics, 80 percent start the mathematics sequence in Calculus I, and about one in ten is not calculus-ready at matriculation. The average SAT score of first-year students in the College of Engineering and Science is about 1250.

The first-semester course, Introduction to Engineering Disciplines and Skills, enrolls eight hundred mostly first-time-in-college students. It provides detail on the various majors in the college and introduces elementary engineering material, including units, dimensions, estimation, graphs, spreadsheets, and experimentation. This course is a descendant of Introduction to Engineering and Science, which is described in greater detail elsewhere (Ohland and Sill, 2002; Ohland, Sill, and Crockett, 2002). One of the course objectives is to acquaint students with the design process; a variety of design projects have been used to meet this objective (Sill, Ohland, and Stephan, 2003).

The second-semester course, Engineering Fundamentals, offers multiple sections with different disciplinary emphases. It helps students confirm their choice of major and develop skills more specific to their interests. This course is a descendant of Introduction to Engineering Problem Solving and Design, which is described by Sill, Ohland, and Stephan (2003). This course

enrolls approximately six hundred students per year, including some transfer students.

In both semesters, students meet each week for a one-hour lecture and a two-hour lab. The lecture typically meets in a large theater-style lecture hall equipped with continuous tables and movable chairs. The labs typically meet in a small-group classroom equipped with oval tables and movable chairs, or in our project lab, which has workbench-style tables and stools. Our entire building is wireless, and the college has required all entering students to have a laptop since 2002. Undergraduate teaching assistants attend class to facilitate instruction and hold evening office hours.

We assign project teams to be of heterogeneous academic ability using predicted grade point ratios computed by the Admissions Office. We try to ensure that women and minorities are not outnumbered on a team (Felder and Brent, 1994).

The Approach to Learning: Desired Pedagogies

Research suggests that exclusive use of the lecture in the classroom constrains students' learning (Bonwell and Eison, 1991), but use of technology does not guarantee improvement. Its effectiveness depends on both the advantages of the technology itself and the ability of the instructor to incorporate it into a busy schedule. The benefits of active learning experiences in the classroom are well documented, notably better attendance, deeper questioning, higher grades, and a lasting interest in the subject matter (Johnson, Johnson, and Smith, 1998; Bonwell and Eison, 1991; Felder, 1992; McKeachie, Pintrich, Lin, and Smith, 1986; Wankat and Oreovicz, 1993). Of particular interest is evidence highlighting the benefits of active and cooperative learning in engineering and science classes (Felder, Felder, and Dietz, 1998; Hake, 1998; Springer, Stanne, and Donovan, 1997; Bowen and Phelps, 1997; Caprio, 1993; Carpenter and McMillan, 2003; Cooper, 1995; Felder, 1996; Kogut, 1997; Mourtos, 1997; Redish and Steinberg, 1999; Rosser, 1999). Another form of active learning is discovery learning; the research finds that it promotes deeper understanding and long-term retention (Travers, 1982). Similarly, learning improves when students are coached but not directed to a solution (Tribus, 1971). Unfortunately, discovery learning has never gained widespread use because of its potential time inefficiencies (Jacobs, 1992).

With the university laptop mandate, we were able to introduce a powerful, discovery-based instructional technology that depends on students using laptops in class. This technology has been well researched. The literature on microcomputer-based learning shows that students demonstrate improved understanding of physical concepts and their graphical representation when electronic sensors are used to gather and display data in real time (Thornton and Sokoloff, 1990; Brasell, 1987; Redish, Saul, and Steinberg, 1997; Beichner, 1996). It is no surprise that seeing graphical output from

electronic sensors in real time makes for effective learning; these techniques are discovery-based and active.

To study whether this approach has an educational benefit beyond other active, discovery-based learning, Clemson received a grant from the National Science Foundation (Ohland, Stephan, and Sill, 2003; Ohland, Stephan, Sill, and Park, 2004). While controlling for other learning-related variables, the experimental study compares student performance in sensor-based lab activities to student performance in parallel lab activities that do not use sensors (Yuhasz, Ohland, and Stephan, 2004).

Adapting Proven Pedagogies to the Laptop Classroom

As Bates and Poole (2003) predict, managing this educational experiment has been a challenge. We frequently had to adapt our teaching approach to accommodate the limitations and potentials of the laptop and sensor-based technologies.

Group Size. Prior to the laptop mandate, all faculty in Clemson's Department of General Engineering divided their classes into groups of four for interactive, in-class learning activities. These four-person groupings functioned well in all our teaching settings. In our theater-style lecture hall, movable seats permitted student pairs from adjacent rows to face each other. In our smaller classrooms, four-person tables fostered this same kind of interaction. In our project laboratory, four students shared a workbench.

But the introduction of laptops rendered this configuration unacceptable. If four students in any of those configurations work on a laptop, the student whose laptop is in use and the one on the same side of the table are able to see the laptop, but the other two students see only the back of the laptop. Three students can see a laptop from the same side of a table, *if* the laptop is in front of the center person. In settings with relatively large tables, then, groups of three are acceptable. But in a setting with shorter tables (which describes our laboratory set-up), we hypothesized that students would have to work in pairs on laptops to ensure universal engagement and adequate visibility.

We tested this hypothesis on our 438 General Engineering students at the end of the spring semester of 2004. We surveyed their opinion of the pair arrangement with this agree-disagree item: "When using the sensors, someone else in my group always operated the computer, and I wasn't involved." Fewer than 10 percent of the students agreed with the statement, giving us confidence that the pair arrangement fostered student engagement.

Student Maturity. In a theater setting, General Engineering faculty commonly used active learning techniques suitable to that environment, such as think-pair-share (Lyman, 1987; Kagan, 1994). In this large group setting, our first-year students were significantly distracted by the use of laptops. So we chose to eliminate laptop use in lecture and required students to put their laptops away. However, more mature students, such as those in

junior-level computer science classes using the same theater, did make proper use of laptops in the lecture setting.

The Pace of Learning. The use of electronic sensors connected to laptops automated data collection, making many laboratory exercises move more quickly. Unfortunately, this seemed to encourage students to rush through the lab and leave early, jeopardizing their ability to comprehend the data collected and assimilate meaningful conclusions. To slow down the labs a bit and foster deeper processing, we introduced structured reflection.

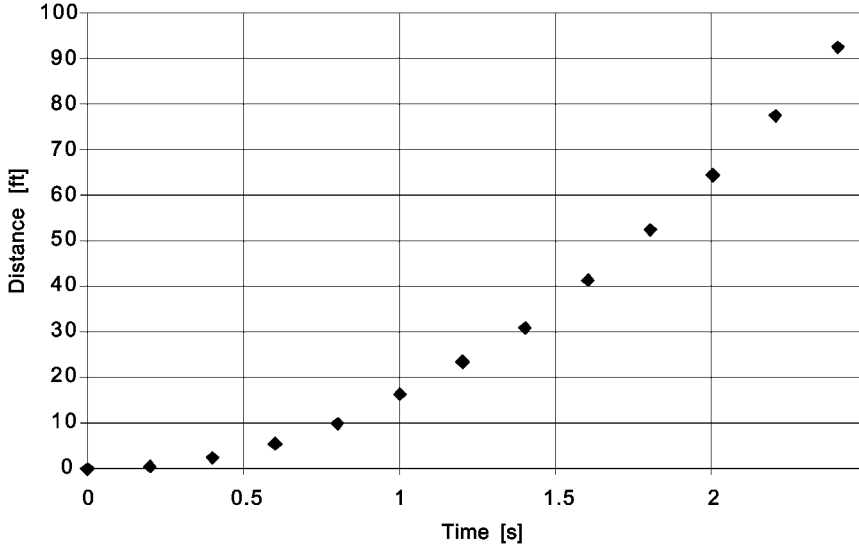
The reflection process complemented the discovery methods we were using, because both shift some control over the learning process to the learner. The benefits of doing so are well documented by Goforth (1994) in his meta-analysis of the effectiveness of learner control in tutorial computer-assisted instruction. The use of mastery-based activities and self-paced problem solving in a resource-rich environment (with peers, the instructor, and the undergraduate assistant available to help) gives even more control to the student. This approach was particularly useful in allowing students who had already mastered the material through prior experience to demonstrate their mastery in that area.

Positive Interdependence. Automation of data collection in the labs also reduced the workload of the group, leaving some group members idle, distracted, and disengaged. Our initial response was to increase the workload to ensure positive interdependence. But since each student was responsible for understanding the additional material, the heavier workload could not be divided among group members; the workload increased for *all* students. We then faced the additional challenge that some laboratory procedures were either conceptually sequential or required the same equipment for execution, so the laboratory activities could not be conducted in parallel. Ultimately, the reduction in group size discussed earlier restored positive interdependence.

Individual Accountability. Although tests and quizzes accounted for individual mastery of the material, we wanted to encourage students to master the material before leaving class, so that homework could address extensions to the material. We established checkpoints during class activities at which the instructor or an undergraduate teaching assistant examined the material before the student continued in the activity. This approach was particularly useful when teaching computer skills with software such as Excel and Matlab; students worked on solving a problem with the help of other students, the instructor, and undergraduate assistants.

Figures 8.1 and 8.2 illustrate the approach taken in class. Students were given a small table of position-and-time data and asked to produce a properly formatted plot of the position data as a function of time. Figure 8.1 shows a successful result, modified from the default format in Excel (whereas Excel commonly shades the plot frame, the shading has been removed; similarly, since raw data are plotted, the data points are represented by unconnected symbols). Once students created a properly formatted graph of

Figure 8.1. Position Graph Produced During In-Class Exercise

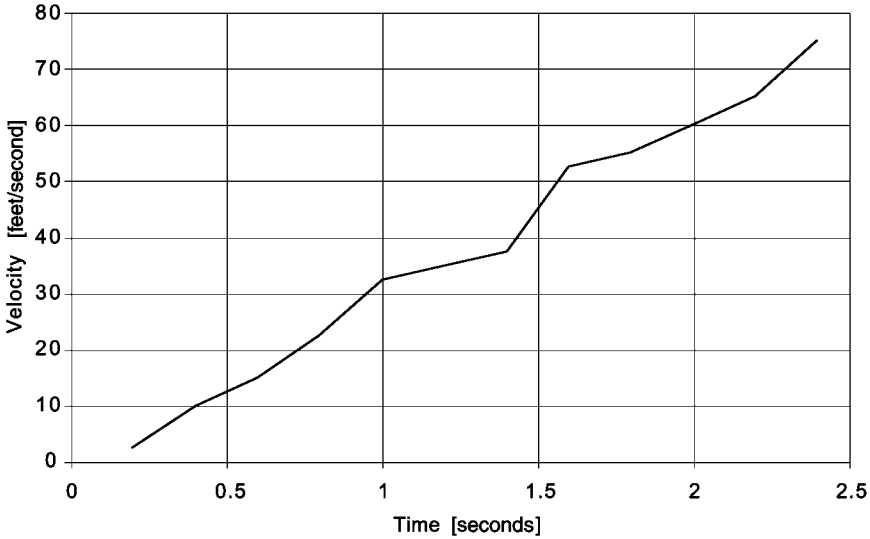


position and time, they needed to calculate and plot a velocity profile; Figure 8.2 shows the resulting profile. The questions accompanying these in-class exercises asked students to struggle with important concepts. In this case, for example, students had to explain why the position curve was smooth but the velocity curve was much less smooth. Their subsequent calculation and graph of acceleration departed even further from the smooth appearance of the position versus time graph. Thus, even though the class activity focused on learning how to use Excel, students discovered the sensitivity of derivative quantities along the way.

Gathering Data from the Internet. On several occasions, students used their laptops to gather Internet data in class, including the values of problem parameters. Students searched reliable sources for physical parameters, background material, and the effect of problem constraints.

Sharing and Integrating Data. Students performed several experiments that required sensors and laptops to collect and analyze the data. Examples of these lab exercises are studying vibration (Figure 8.3) and pH response (Figure 8.4), which happen too quickly for manual data collection, and collecting relational data of force versus displacement (Figure 8.5) or voltage versus current on the same time baseline. With the data in electronic form, we had student groups share their data with other groups so they could compile a more complete data set and acquire a fuller, more accurate understanding of the phenomenon. Figure 8.6 shows a summary of data collected by various groups investigating how the time at which

Figure 8.2. Velocity Graph Produced During In-Class Exercise



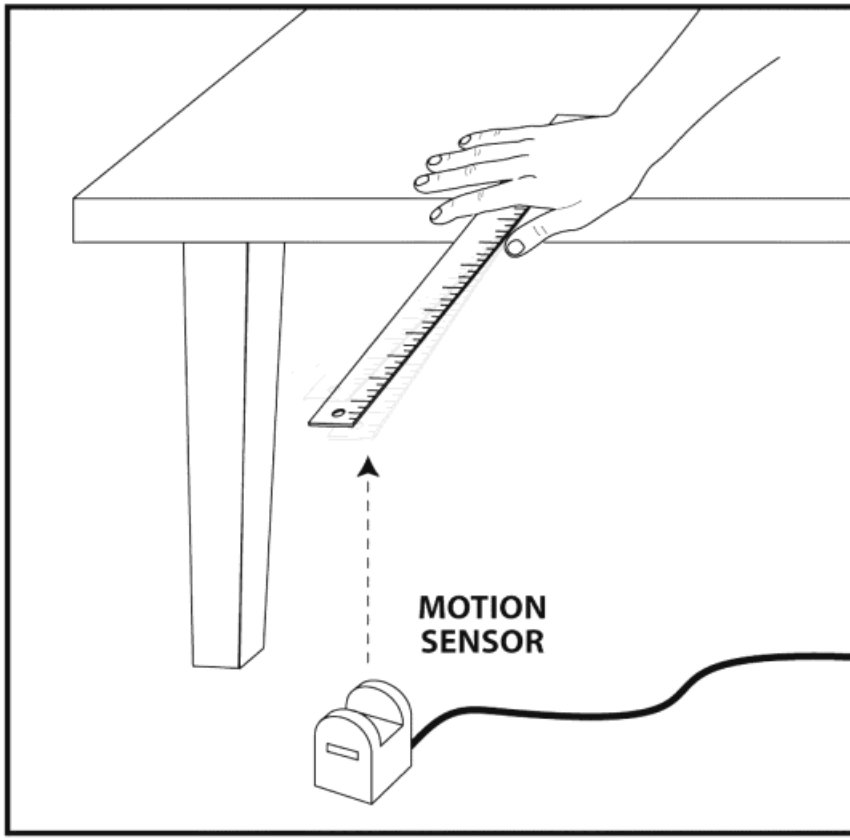
creamer is added to coffee affects the time it takes for the coffee to reach a drinkable temperature.

Efficient Use of Equipment. Placing students in pairs for lab activities as opposed to a larger group required an additional investment in the real-time sensors that attached to student laptops. In fact, switching from four-person groups to pairs required *twice* as many sensors; double this figure *again* if the laboratories of two course sections are scheduled simultaneously. We managed the high cost of the smaller groups by diversifying the lab activities and rotating students through stations around the room.

Diversification required that the day's activities use different sensors and be independent as to their order of completion. In this way, all students in the class could conduct the same activities. In a modified version of the arrangement, groups completed different activities, which worked well when we allowed groups to select from a set of activities typical to various disciplines. This approach also lent itself well to the "jigsaw" method of teaching, in which various students or groups of students construct partial knowledge and then teach each other what they have learned to complete their knowledge (Aronson and others, 1978; Johnson, Johnson, and Smith, 1998).

Our other strategy was establishing stations around our laboratory with the real-time sensors already attached to the equipment. Here we took advantage of the portability of the laptop. Student groups proceeded around

Figure 8.3. Measuring Vibration of a Ruler Using a Motion Sensor



the room to visit each station, sequentially if necessary. In addition, this approach saved set-up time and reduced the cost of auxiliary equipment needed for conducting activities.

Establishing an Environment for Success in a Laptop Classroom

We made varied adjustments to the classroom to support both classroom management and cooperative learning, such as installing movable seating (even in our theater space). To help students get their laptops ready for classroom use and keep them that way, we developed a handout of frequently asked questions (FAQs) with solutions to problems students commonly encountered. An early mastery-based assignment ensured that all students had properly installed software on their laptops. We assessed students a grade penalty for not bringing a working laptop to class unless

Figure 8.4. Fast Response Times of pH Measurement Prohibiting Manual Measurement

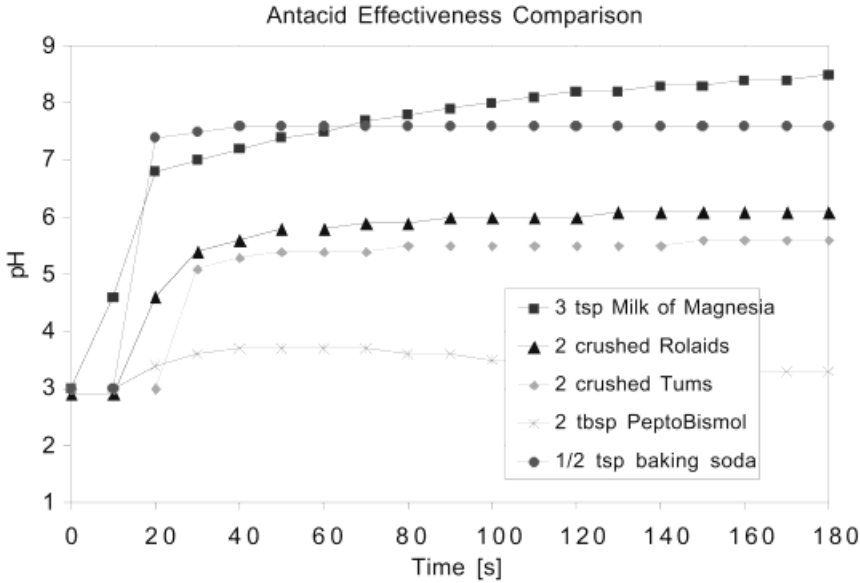


Figure 8.5. Measuring Force and Displacement of a Spring Simultaneously

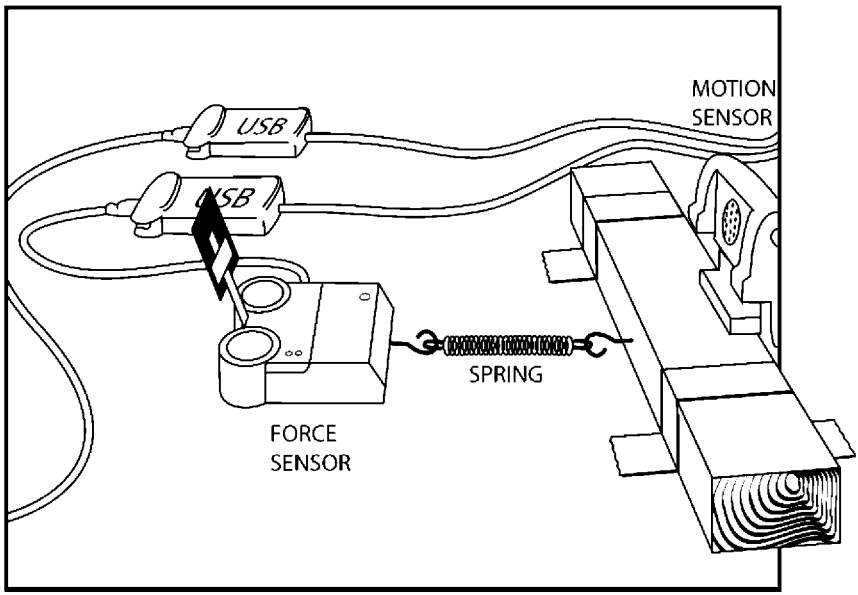
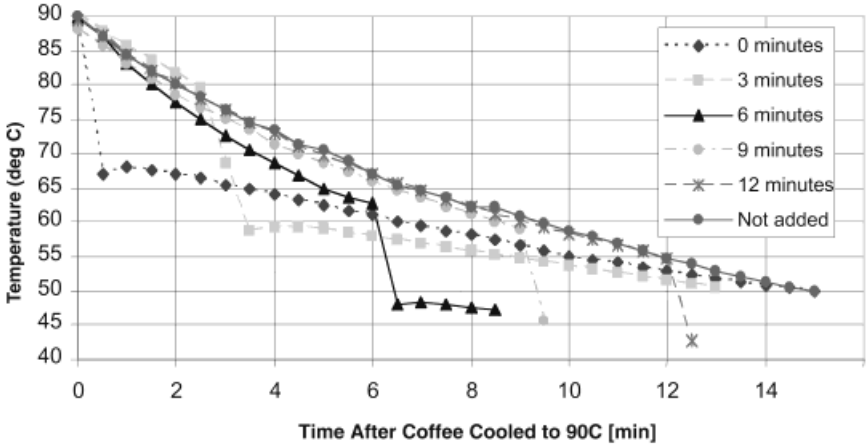


Figure 8.6. Data Collected by Student Groups Investigating Coffee Cooling to Drinkable Temperature (When Creamer Should Be Added)



they presented a written excuse for laptop repair from the campus computer facility.

We were forced to make certain adjustments to our teaching because of technological difficulties we experienced. DataStudio, the software that collects data from the Pasco PasPort sensors we used, conflicted with certain spyware programs, so we taught students how to remove them. Personal online activities such as instant messaging interrupted real-time data collection, so we forbade use of such programs in class. We also struggled with overloading the wireless network with network-intensive processes, the worst of these being network installation of software such as DataStudio and particularly Matlab. So we require students to install these applications prior to class for part of their in-class grade. We even struggled as a number of students attempted to connect to another wireless network service, a commercial operator in downtown Clemson.

Summarizing Our Experience with Laptops in the Classroom

Our experience using laptops in the classroom, particularly in conjunction with real-time sensors, helped us understand how to manage in-class use of the technology and adapt cooperative learning and other teaching methods to it. We also learned how to enable students to take advantage of the unique features of the medium. We gave students the opportunity to collect and process data, learn visually by generating and displaying graphs and diagrams, gather and review information in varied locations, research infor-

mation on the Internet, and share and integrate experimental findings to gain a fuller and clearer understanding of physical phenomena.

We were particularly pleased with the ingenious problem-solving approaches we saw some students initiate, so pleased that we started awarding prizes for original thinking in class activities. For example, one student pair made innovative use of the laptop-sensor combination in an outdoor lab exercise where the technology was not required. The object of the exercise was to determine the velocity of a rubber chicken (a simulation of the University of South Carolina Gamecock mascot) launched by a large slingshot. The standard equipment was usually a radar gun. But the innovative pair used two synchronized motion sensors to measure the time it took the chicken to pass those two points. From this time measurement, the students easily calculated the velocity of the chicken; they obtained an answer comparable to that given by the radar gun.

Although we could observe only the increase in student creativity, we were able to survey student opinions of the technology and the learning benefits they perceived. In our end-of-spring-semester survey, 44 percent of our 438 students agreed with the statement "When using the sensors, it was exciting to manipulate a process variable and see its immediate effect on the graph output of other process variables." In addition, 60 percent agreed with "Using the sensors helped me learn to interpret graphs"; 59 percent agreed that "Using the sensors improved my ability to predict the appearance of a graph."

In view of positive student reactions like these, we plan to continue teaching General Engineering with the winning combination of student laptops and real-time motion sensors. We also expect to refine and expand our use of the technology and extend our research on its effects on student learning.

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