Applications of Real-Time Sensors in the Freshman Engineering Classroom

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Abstract

Clemson's NSF-sponsored EXPerimental Engineering in Real-Time (EXPERT) project is designed to assess the efficacy of using real-time sensors in freshman engineering classes. We wish to determine if use of these devices enhances student understanding of both physical concepts and graphical representations of those phenomena.

Where parallel activities can be designed (one set with and one set without real-time sensors), the relative performance of students conducting sensor-based laboratories will help isolate the pedagogical benefit of using the sensors. It is also clear that the sensors are particularly useful in cases where no parallel educational design can be devised—situations in which it is either not possible to collect enough data quickly without sensors or in which dynamic measurement can be used to provide additional information regarding even an apparently static problem. The use of sensors to measure rapidly changing quantities is well known, and marked the widespread introduction of computer-based instrumentation into the curriculum decades ago. The measurement of quantities that are difficult to measure without sensors is also well documented.

This work focuses on documenting a number of creative ways in which sensors have been used to illustrate concepts to students. There is particular emphasis on ways that the sensors elucidate concepts that defy other types of teaching aids such as models and computer simulations.

Pedagogical approaches used in these curriculum materials

Too often students are given too much direction in the learning process. For best results, students must be coached, but not "directed" to the solution.[1] Discovery learning is shown to have clear benefits in regard to deeper understanding and long-term retention,[2] but has never gained widespread use because many fear the potential time-inefficiency of discovery learning approaches.[3] Our proposed format, however, incorporates structured reflection to achieve some of discovery learning's benefits without making a major commitment of time. The introduction of discovery methods shifts some control over the learning process to the learner. This approach agrees with Goforth[4] who, in a meta-analysis of the effectiveness of learner control in tutorial computer assisted instruction, found that *"it is important that the learner have some control rather than none."* If we wish our students to learn and to be creative, they must be given that opportunity—at least some assignments must be open-ended. Students must learn to think about the problem, to ask questions, and to design an experiment to test their hypothesis. This also directly addresses a number of ABET EC 2000 Criterion 3 Outcomes, with special emphasis on outcome (b), an ability to design and conduct experiments and analyze and interpret data, and outcome (i), a recognition of the need for, and an ability to engage in life-long learning.[5]

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Demonstrations also have pedagogical benefit beyond traditional lecture methods because demonstrations engage the observer in seeing as well as listening. Lord Bertrand Russell is quoted as saying, “Aristotle maintained that women have fewer teeth than men; although he was twice married, it never occurred to him to verify this statement by examining his wives’ mouths.” This underscores the importance of observation—both in an experimentally controlled situation and during a demonstration in class.

The use of real-time sensors in the curriculum

One of the most important means of communicating information about phenomena is visually, including the use of simple graphs.[6] Recent advances in both software and electronic sensors allow the generation of graphs from real-time data using off-the-shelf items. Furthermore, these products are easy to install and operate, requiring a minimum of training for both students and faculty. Even more importantly, a wide variety of these sensors are now available so students can investigate many different principles. The sensors described throughout this research are from Pasco’s PasPort line. These sensors connect easily to a USB port and are hot-swappable.

Several recent studies indicate that student learning about the visual representation of phenomena and the underlying concepts is improved when the learning occurs in a hands-on environment.[7,8,9,10] They use discovery-based lab curricula, are active and also witness the behavior right in front of them. The work by Brasell showed that exposure for as little as a single class period using a microcomputer-based motion sensor was enough for high school physics students to improve their comprehension of distance and velocity graphs.[11] Other studies have showed similar improvements. Of particular interest is the fact that no improvement was observed when the activity was limited to a single teacher-led demonstration.[12] The assessment protocol used in this project will allow the investigators to confirm or refute this finding at the same time the newly developed materials are being evaluated. Particularly, the multiple intervention study design will allow us to investigate our hypothesis that the real-time nature of this method is essential to its efficacy.

Lab modules developed

The lab modules developed are presented in the remainder of this paper. Designing parallel sensor and non-sensor versions that were otherwise equivalent required a significant curricular design effort in the preparation of the laboratories. Cases where a parallel non-sensor version was developed receive special focus, because the pedagogical equivalency of the sensor and non-sensor version is an assumption that underpins the research design.[13] Each laboratory features a pre-lab activity in which students speculate as to what will happen or background material on the laboratory and questions for the students to answer. Each laboratory also has a post-lab activity in which students synthesize the “big picture,” sometimes integrating other course material to better understand the laboratory.

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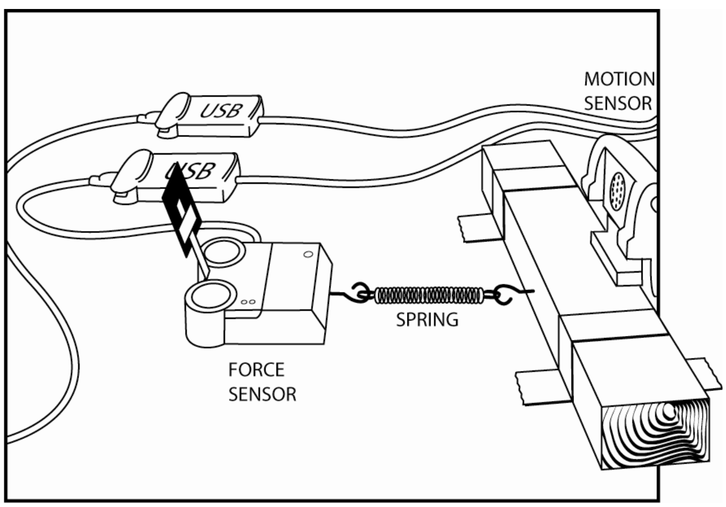
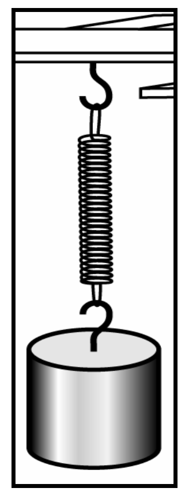
Springs / stiffness laboratory

The lab begins by linking the subject to the Physics (mechanics) class and textbook. Experimental sections that used this laboratory in the fall semester in the experiment will have few students who are concurrently enrolled in Physics. Most (about 85%) have taken Physics in high school. This laboratory introduces students to a force-based perspective and introduces stiffness in a general form that addresses how various systems resist the forces that act on them (force/deflection of a spring, force/acceleration of a mass, voltage/current in a circuit).

Figure 1 shows the experimental setup—a force and a motion sensor are each attached to a USB port on the laptop, and the motion sensor is aimed at a small target attached to the force sensor. In this configuration, there is a length offset. Note that the student who pulls the force sensor to stretch the spring has the added pedagogical benefit of actually *feeling* the force as it is applied. The only way for all students to gain this benefit is to ensure that all students take a turn at pulling the force sensor.





Figures 1 and 2: Determining a Spring Constant—Sensor and Non-Sensor Laboratories.

In the non-sensor version, the force sensor is replaced with hanging weight sets, and students measure the resulting deflection with a ruler. The time to take the data is comparable, because only a few data points are needed to reliably find the spring constant for each spring.

Temperature laboratory

In this laboratory, students study a typical heating curve for water, measuring room temperature, initial water temperature, and tracking the water temperature while heating.

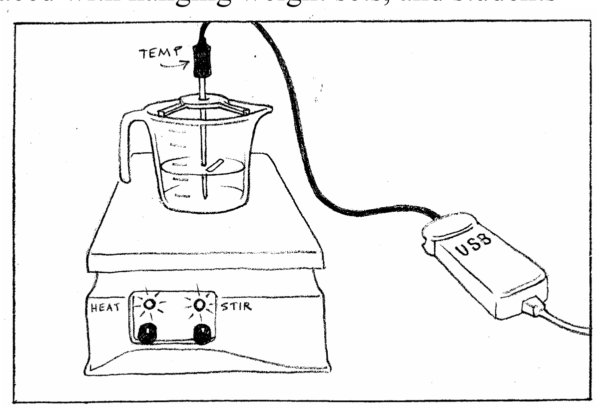


Figure 3. Temperature probe setup.

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Students then study the effect of mixing two liquids of different temperatures using the scenario that they want to be able to drink coffee as soon as possible, so they need to figure out the optimum time to add cream to the hot liquid to get the temperature to reach 50º C as soon as possible. Should the cream be added immediately, or is it better to wait? Combining data from various groups, students are able to generate the graph shown in figure 3. Sensor groups use the temperature sensor while non-sensor groups use a thermometer and a stop watch.

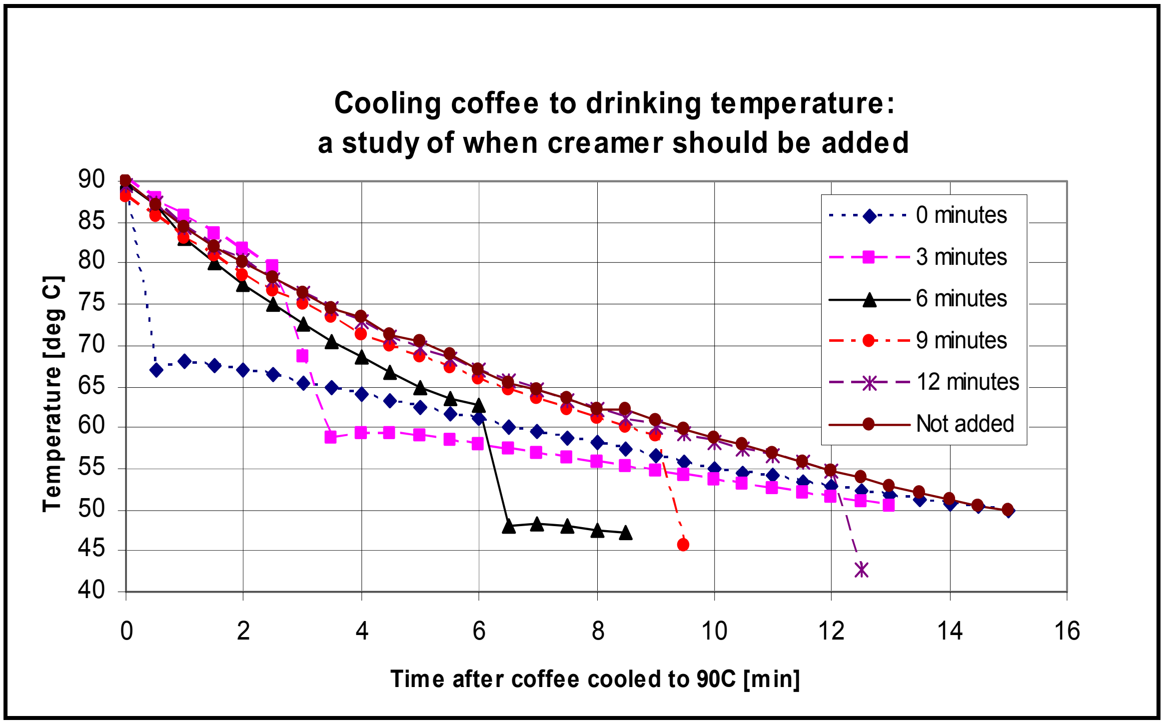

Figure 4: Graph of temperature lab data.

From this exercise, regardless of which laboratory version students used, students learned a variety of thermodynamic concepts:

- cooling curves are exponential
- the introduction of creamer causes a step change
- the temperature recovers slightly after creamer addition as mixing occurs and because the container reheats the coffee
- adding creamer immediately results in a cooling time that is as long as or longer than if no creamer was added
- the added thermal mass of the creamer itself slows the cooling process after the creamer is added.
- Excel's "smooth" feature shows false behavior if used on this graph.
- how to develop envelope and "minimum time" curves and use each to predict system behavior.
- it is better to wait to add the creamer because coffee cools more quickly the hotter it is.

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pH laboratory

In this activity, two different types of pH measurements are taken using a pH sensor. First, static measurements of various unknown household substances are recorded. Using these measurements and sensory observations, students identify these substances.

In the second procedure, dynamic measurements of pH versus time are recorded to study the effectiveness of antacids in neutralizing acid. Students are given the recommended dosage and cost of each of 6 antacids, and use this information to discover which has the most neutralizing power (total pH change), which has the fastest response (pH change per second), and which is the most cost effective ($ / pH change).

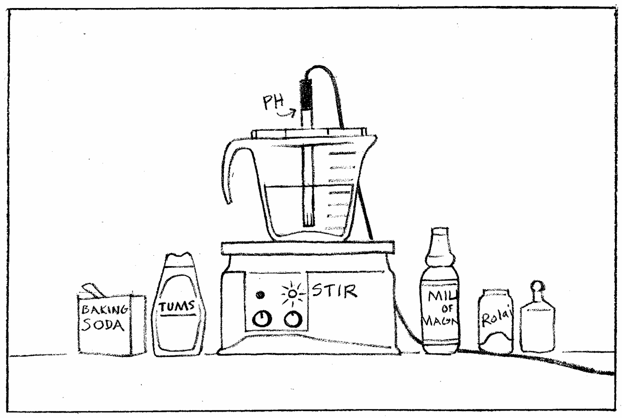

Figure 5. Measuring antacid response.

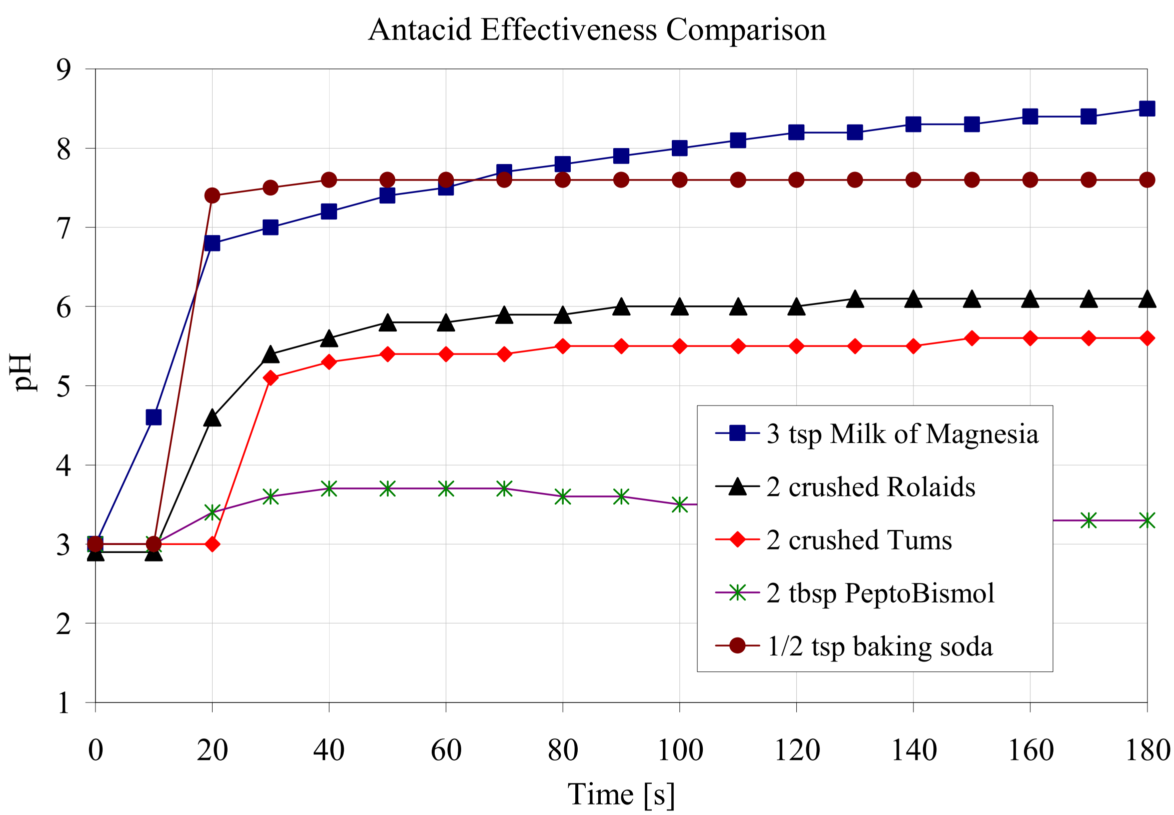

Figure 6. Study of antacid effectiveness.

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Humidity laboratory

Humidity is very important in industry. In the process of drying, humidity and temperature are the two most critical variables. For this reason, companies such as brick makers need to carefully regulate the humidity; if the atmosphere is too dry or too wet the brick will either crack from drying too fast or it won't dry at all. In this laboratory, students learn about dew point, relative humidity, absolute humidity, dry bulb and wet bulb temperature, and how to read a psychrometric chart.

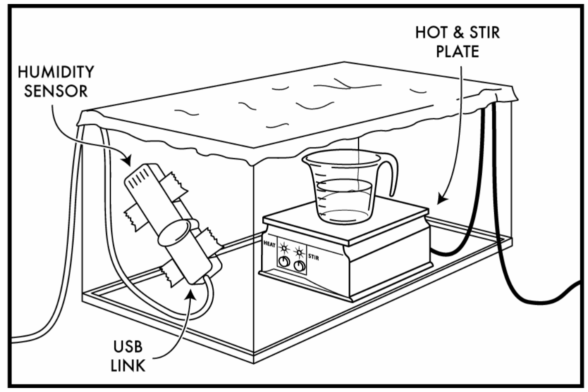

Figure 7. Taking humidity measurements.

Pendulum laboratory

In this laboratory, students explore the different pendulum characteristics of a hollow plastic ball and a lead weight using rotary motion sensor. They speculate as to how each will change if the pendulum makes contact with water near the bottom of its swing, and test their hypotheses. The experiment is extended by having each pendulum nearly submerged at the bottom of its swing. Students observe the effect on the graph output when a finger is placed in the path of the string of the pendulum on one or both sides of the swing—allowing the pendulum to swing, but causing it to have a shorter length when the string is caught on the student's finger.

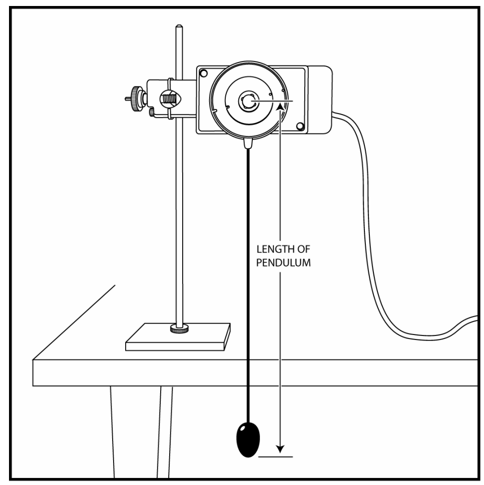

Figure 8. Pendulum laboratory.

Vibration laboratory

Students fasten a yardstick to a workbench and then depress and release its end in order to measure the way it oscillates up and down with a motion sensor on the floor. This experiment is done in several arrangements with several independent variables. In each case, students speculate as to how the graph will change. Students study the effect of mass (attached to the end of the yardstick) and protruding length (which determines system stiffness) on the vibration characteristics. Students also investigate the effects of measurement point and sampling rate on the resulting graph. The motion of the yardstick is measured with a motion sensor on the floor pointing up.

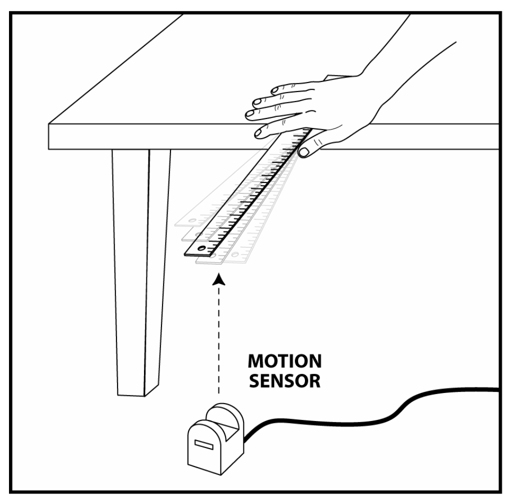

Figure 9. Vibration laboratory.

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Electric circuits laboratory

Students learn to use a breadboard, investigate Ohm's law and Kirchhoff's voltage and current laws, and observe the time-dependent characteristics of a circuit with a capacitor. Students speculate as to how intermittent windshield wipers might use capacitors for timing. Students explore the underpinnings of resistance by determining the resistivity of various pencil leads and evaluating the effect of length on resistance. This experiment uses the voltage-current sensor.

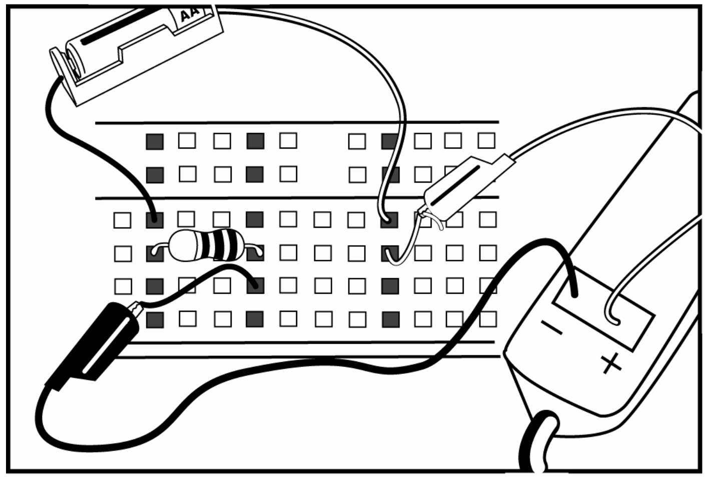


Figure 10. Measuring current in the circuits lab.

Soil buffering laboratory

Students collect soil samples from various campus locations and identify two plants growing in each soil condition. Evaluation of the soil characteristics begins by analyzing differences among the location, plant types, plant health, and type of wildlife characteristic of the soil. Students then measure the pH of the soil. Diet cola is then used to add acid to the soil. Students discover that the soils differ in their ability to handle sudden doses of acid—the samples have different buffering capacities. Repeated additions of diet cola then simulate the effect of acid rain. Students research the purposes of adding fertilizers and lime to soil.

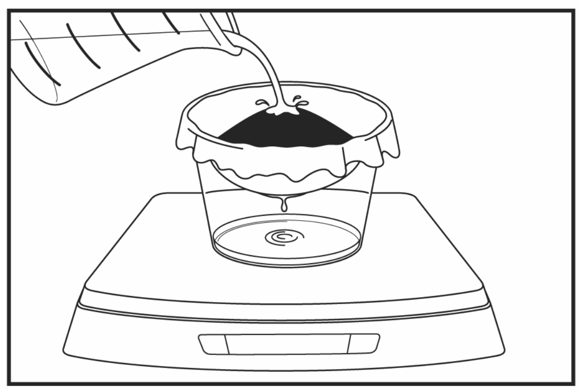
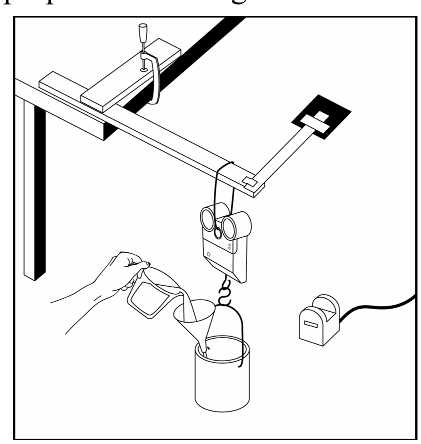


Figure 11. Repeated addition of soda to soil.



Cantilever beam laboratory

This laboratory allows students to continue their investigation of stiffness begun with the springs laboratory, again using force and motion sensors. After confirming that the cantilever exhibits the same proportionate response to increases in applied load, students determine the effect of cantilever length, beam width, and beam depth on stiffness. New materials are being added to the laboratory to enable students to see how material properties affect the beam stiffness.

Figure 12. Cantilever laboratory.

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In an effort to use the sensors to their full advantage, this laboratory has undergone a significant modification recently that permits monitoring deflection *while varying the length of the cantilever beam continuously*. This new feature significantly improves the pedagogical value of the sensor version, which suggests that this laboratory should be included in the educational experiment. Prior to this modification, much of the laboratory, even when sensor based, required discrete measurements. As a result, there was concern that the use of the electronic sensors provided little educational advantage. Drawings of the redesigned apparatus are not yet available.

Conclusions

We face a number of challenges in the development of parallel laboratories that can be used in the educational research project. The most significant is that laboratories such as ***electric circuits, vibration,*** and ***pH***, involve the measurement of processes that are so dynamic that it is not possible to conduct the experiment without electronic sensors of some sort. This confounds the measurement of the educational benefit of using the sensors. There are additional laboratories under development that may provide a stronger comparison base—a concurrent forces laboratory under development is nearly a replication of an experiment done in statics classes using spring scales. In the sensor version, multiple force sensors (two or more) can all be used to support a weight by strings. The advantage of using the sensors in this experiment would include an increased data acquisition rate, time synchronicity among the sensors, increased precision, and ease of reading data. We hope to compare this lab with the non-sensor approach already in use.

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Author biographies

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References

[1] Tribus, M., "Education for Innovation," *Engineering Education*, p. 421 ff., February, 1971.
[2] Travers, R.M., *Essentials of Learning: The New Cognitive Learning for Students of Education*, 5th Edition. New York: MacMillan, 1982.
[3] Jacobs, G., "Hypermedia and Discovery-Based Learning: A Historical Perspective," *British Journal of Educational Technology* **23**(2), 113-121, 1992.
[4] Goforth, D., "Learner Control = Decision Making + Information: a Model and Meta-analysis," *Journal of Educational Computing Research* **11**(1), 1-26, 1994.
[5] http://www.abet.org/images/eac_criteria_b.pdf
[6] Felder, R.M., "Reaching the Second Tier—Learning and Teaching Styles in College Science Education," *Journal of College Science Teaching* **23**(5), 286-290, 1993.
[7] Thornton, R.K. and D.R. Sokoloff, "Learning Motion Concepts Using Real-Time Microcomputer-Based Laboratory Tools," *Am. J. Phys.*, **58**(9), 858-67, September, 1990.
[8] Brasell, H., "The effect of Real-Time Laboratory Graphing on Learning Graphic Representations of Distance and Velocity," *J. of Research in Science Teaching*, **24**(4), 385-95, 1987.
[9] Redish, E.F., J.M. Saul, and R.N. Steinberg, "On the effectiveness of active-engagement Microcomputer-Based Laboratories," *Am. J. of Physics*, **65**, 45-54, 1997.
[10] Beichner, R.J., "The impact of video motion analysis on kinematics graph interpretation skills," *American Journal of Physics,* **64**(10), 1272-1277, 1996.
[11] Brasell, H., "The effect of Real-Time Laboratory Graphing on Learning Graphic Representations of Distance and Velocity," *J. of Research in Science Teaching*, **24**(4), 385-95, 1987.
[12] Beichner, R.J., "The impact of video motion analysis on kinematics graph interpretation skills," *American Journal of Physics,* **64**(10), 1272-1277, 1996.
[13] Yuhasz, A.G., M.W. Ohland, and E.A. Stephan, "The Benefit of Using Real-Time Sensors in the Engineering Classroom: Experimental Design Considerations" submitted to *Proc. Amer. Soc. Eng. Ed.*, Salt Lake City, Utah, June 2004.

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