Clemson University's EXPerimental Engineering in Real Time (EXPERT) Program: Assessing the benefit of real-time sensors in the curriculum

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Abstract

EXPerimental Engineering in Real-Time (EXPERT) is a three-year NSF-sponsored project at Clemson University to study the benefit of using experiments with real-time sensors to improve student understanding of the graphical representation of various physical concepts and auxiliary benefit in understanding the concept itself. The project builds on successes by Physics education researchers (primarily with motion sensors) that combine the use of technology and hands-on engineering experiments to achieve visual analysis of phenomena in real-time in the classroom. The previous work is being expanded in two ways: a broader range of phenomena are being explored and a more controlled assessment of the benefit of real-time sensors is being conducted. A combination of multiple-intervention and switched replication assessment protocols will be used to determine the comparative benefit of curricula developed with and without sensors in either a laboratory or a lecture / demonstration mode. A pre-test / post-test design will be used to account for the effect of differences in the initial preparation of the different study populations.

While the primary objective of the project is to understand the benefit of the use of this educational technology, the sensor-based laboratories are designed to be accessible for use as modules by college faculty and by secondary school teachers and students as well so that, if the technology should prove effective, broader implementation will be practical. This paper introduces the methodology of the experiment and reports on the status of the development of laboratories. A variety of laboratory activities have been developed, including two that have been developed in sensor-based and non-sensor-based versions.

The use of technology in the classroom

Although there are many who assume that the use of classroom technology has significant potential to benefit the education of students, the body of evidence supporting that assumption is still small.[1] Even if it is assumed that most lecturers possess the necessary characteristics, research suggests that the exclusive use of the lecture in the classroom constrains students' learning.[2] To be effective, the use of technology in the classroom must balance the utility of technology with the ability of the instructor to incorporate it within a busy schedule. Despite the many innovations of the last several decades, it is evident that the chalk-blackboard-lecture format is still predominant. Various sources discuss the perseverance of this traditional method of instruction.[3,4,5,6] Since even many who continue to lecture exclusively admit that it is due largely to their comfort with the approach, we should not be surprised that even undergraduates who have been exposed repeatedly to this approach prefer it. Recently, a team of faculty in Civil Engineering at Clemson University had a series of meetings with small groups of students that included both males and females with a wide range of grade point ratios and backgrounds. Most students favored the traditional chalkboard approach, and clearly preferred it to lectures using overhead transparencies and PowerPoint slides. They had not experienced a sufficient number of instructors who incorporated active learning in the classroom to give an opinion. This is a bit disheartening, since the benefits of active learning experiences in the classroom are well documented, and include better attendance, deeper questioning, improved grades, and a lasting interest in the subject material.[7,8,9,10]

There are many technological innovations that would seem to have the potential to enhance the classroom experience beyond the chalk and blackboard, including: computer projection systems and videotapes that allow students to watch simulations of phenomena, laptop computers that improve students' access to information, and the use of real-time data acquisition, which helps students to more easily associate physical behaviors with their graphical representations. As time has passed, these techniques have become easier to use, as one might expect.[11]

The focus of this work is ultimately to integrate the use of advanced classroom technology—real time sensors in this case—into a sound pedagogical framework. This means using this technology along with cooperative learning and other proven, effective pedagogies.[12,13]

Pedagogical approaches to be 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.[14] Discovery learning is shown to have clear benefits in regard to deeper understanding and long-term retention,[15] but has never gained widespread use because many fear the potential time-inefficiency of discovery learning approaches.[16] 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[17] 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 (b) an ability to design and conduct experiments, as well as to analyze and interpret data and (i) a recognition of the need for, and an ability to engage in life-long learning.[18]

Lord Kelvin once said, "I am never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making one, I understand; otherwise I do not. The ancient Chinese proverb, *"I forget what I hear; I remember what I see; I know what I do."* suggests that the importance of active learning was known for centuries before Lord Kelvin's testimonial. The recent revival of interest in active approaches shows promise. Active learning methods are frequently paired with cooperative learning, where a group of students shares the responsibility for the education of each of its members.[19]

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 displaying phenomena is visually, including the use of simple graphs.[20] Recent advances in both software and electronic sensors allow the generation of such displays with off-the-shelf items. Furthermore, these products are easy to install and operate, requiring a minimum of training. Even more importantly, a wide variety of these sensors are now available so students can investigate many different principles.

Several recent studies indicate that students learning about the visual representation of phenomena and the underlying concepts is improved when they do it in a hands-on environment.[21,22,23,24] 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.[25] 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.[26] 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.

Modules are being developed consisting of activities that can be described in a short handout. The modules will address many engineering topics, but each topic will be addressed in a similar way. The basic approach is as follows:

(1) decide on phenomenon of interest
(2) select appropriate sensors (commercial sensors are available for motion, temperature, pH, dissolved oxygen, force, pressure, relative humidity, light, conductivity, voltage, etc.)
(3) students are guided through observation of some basic behavior for a particular phenomenon in a structured exercise; this behavior is displayed graphically in real-time
(4) teams then speculate what the response will be to a different input
(5) teams test their hypothesis to see if they predicted properly
(6) teams identify the graphical representation for other interesting input phenomena
(7) other teams speculate as to new graphs or new input phenomena given their previous exposure to the structured exercise.

Example #1: Motion

Use a motion sensor connected to the USB port of a microcomputer. Easy-to-use software allows display of a ***displacement versus time plot***. The subject (a member of a student team or the instructor if in demonstration mode) walks toward the sensor and the resulting plot is observed. The subject then walks away from the sensor and this plot is also observed. The teams are then asked to speculate on the type of motion that would be required to yield a plot of a particular shape—e.g., a constant velocity profile with rest stops. Students test their hypotheses, and the results are reviewed. Then each team is asked to produce a new plot in an attempt to stump the rest of the class. Alternatively, the instructor can ask additional questions: "If the displacement versus time plot looks like this, what is the corresponding velocity versus time or acceleration versus time plot?"

While this appears quite simple, students are generally not adept at these skills when they begin at the university. Several examples below indicate the misconceptions students have demonstrated in the face of an uncomplicated problem..

Monk on the mountain: Plot the movement of a monk (elevation versus time) moving in zigzags (over switchbacks) as he descends, finally arriving at the bottom (elevation=0). When faced with this problem, many students draw a plot similar to that shown in Figure 1.

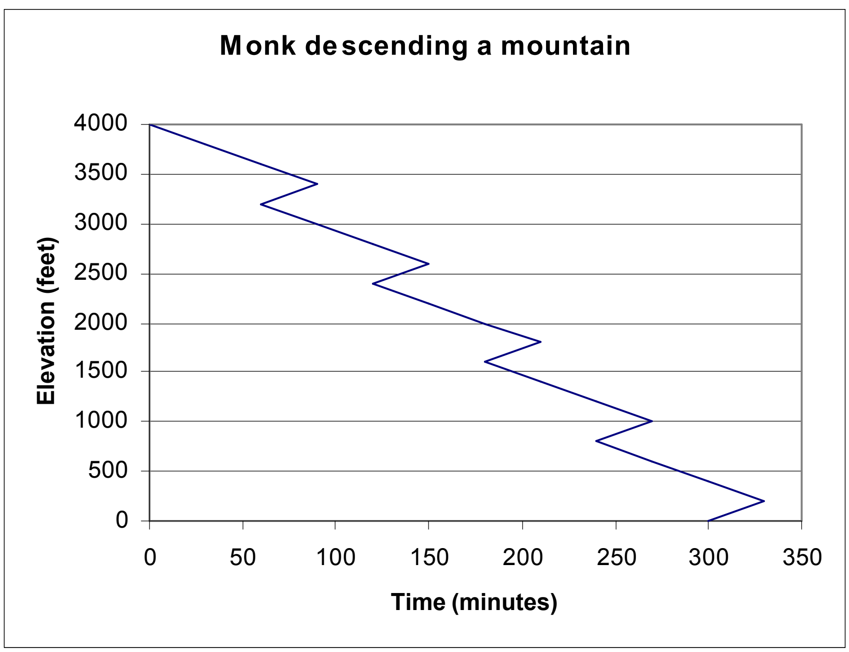

Figure 1. Student's graph of monk descending a mountain

On reflection, it doesn't seem reasonable that the monk can travel backwards in time, yet many students will produce this graph without realizing the impossibility it represents.

Skydiver: Plot the elevation, rate of descent, and downward acceleration of a skydiver if he opens his chute half way between the plane and the ground. A graduate student in his oral examination drew the graph of elevation versus time shown below. The student began by drawing a reasonably correct plot of elevation versus time, followed by reasonably correct depictions of the velocity and acceleration profiles. Upon noting the negative acceleration at parachute deployment, the student returned to the elevation plot and modified it to the graph shown in Figure 2. As a result, the student's plot indicates that the release of the parachute causes the skydiver to go up for a short time.

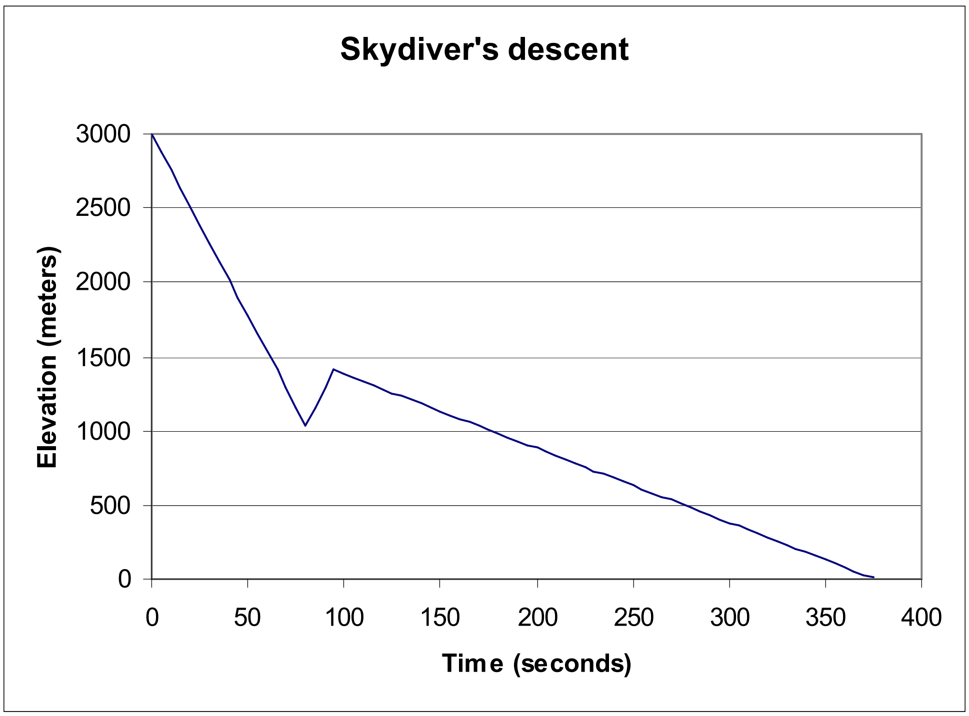

Figure 2. Graduate student's graph of a skydiver's descent

Similar experiences (such as graphing position / velocity / acceleration of a bouncing ball) indicate that students often do not fully grasp the connection between a particular phenomenon and the way it appears in graphical form. Since these problems uncover the misconceptions of students, problems such as these will be used to test student understanding in pre-tests and post-tests. Similarly, topics other than motion have characteristic misconceptions that will be the subject of experimentation and testing.

Project assessment

To provide meaningful evaluation of this new material, it is essential that it be evaluated in actual classroom situations, with more than one instructor, and compared on equal ground with other approaches to learning. The primary course selected for implementation has several advantages: (1) It is controlled by the General Engineering Program, (2) The three-credit-hour course includes one hour of lecture and two two-hour labs each week, (3) The topical material covered in the class lends itself to a variety of exercises, (4) It is an introductory class at the freshman level, and (5) Many sections (about 15) are offered every semester. While examining past grade distributions and course evaluations will help to develop a reasonable baseline set of data from which improvements (of both the student and instructor) can be judged, it is a multiple intervention study that will ensure sound assessment methodology. This protocol isolates the comparative benefit of different approaches. An example multiple intervention protocol is shown in Table 1.

Table 1. Multiple intervention protocol for testing EXPERT modules

Class section **Intervention**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Lecture presentation with examples	**x**	**x**						
Lecture presentation with think-pair-share collaborative learning			**x**	**x**				
Lecture presentation with instructor demonstration of sensors					**X**	**x**		
Lecture presentation with collaborative experimentation with sensors							**x**	**x**

The design above isolates the improvement of collaborative learning alone with sections C and D, the effectiveness of the sensor technology alone with sections E and F, and the value of the combination of the two by sections G and H. The baseline in this comparison is traditional lecture presentation (sections A and B) given the same amount of class time as other approaches.

Formative data used to guide program development will include student and instructor interest in the course, instructor effectiveness, and pre-test / post-test performance on concept questions such as are used on the Force Concept Inventory[27,28,29] and other concept tests as designed by Eric Mazur.[30] Such instruments test fundamental concepts as demonstrated by observed phenomena. Summative data will include the pre-test / post-test results as well as other measures such as student performance in follow-on classes, grade point ratios, and retention rates.

We will also make use of the College's student course evaluation forms since these are found to be reliable and valid assessment instruments.[31] Student's written comments on these evaluations will be monitored to assess both the plusses and minuses of the material. Other evaluations are routinely administered by the College's General Engineering Program to determine student interest and student desire to learn the material. Overall assessment of the instructor (in comparison with previous offerings of the same course) will be used as well.

We will elicit feedback from the students and instructors using them. Bi-weekly meetings of the instructors are a routine part of Clemson's ENGR 120 course, and will provide an excellent opportunity to solicit feedback regarding the EXPERT materials used. The faculty who teach the course usually includes a mix of first-timers with those who have taught it before. Assessment by these instructors will be very useful in a formative way to ensure the materials are accessible to a wide range of faculty. To make the assessment as robust as possible, dissemination to other test sites is planned.

Project status

A few pilot EXPERT modules were tested in Spring 2002, followed by a significant development effort in the summer of 2002. A large number of modules were piloted in Fall 2002 as a formative step. This formative assessment showed that

- the design of the module partially determines the robustness of the sensor output, and care must be taken to avoid situations where the sensor output is confusing.
- in the process of learning how to use the sensors and create EXPERT modules, the development effort drifted toward the creation of science labs rather than the engineering activities intended. We accept this as a step in the learning process, and plan to "reengineer" the modules early in the spring semester (in time to use the new activities in the spring of 2003).
- certain sensors are difficult to use. It is critical that the idiosyncrasies of a sensor not become an impediment to learning. If the modules cannot be redesigned to ensure robust performance, those modules and possibly those sensors will be set aside.

An update of the progress of the spring semester will be available for presentation by the time of the conference.

Author biographies

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