AC 2007-1945: ACTIVE LEARNING THROUGH TECHNOLOGY (ALERT!); MODERN PHYSICS. AN UPDATE

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Abstract

In a previous ASEE presentation the author described first results in using some technological innovations in a one semester course in modern physics for sophomore engineering students. That paper compared results from two semesters before using the technology with one semester using it. In this paper results are given for two additional semesters. Data for 233 pre-project students and 298 project students are now available. Several important aspects of the conduct of the course were changed during this time, so the conclusions from the data are somewhat subjective. Nevertheless, others contemplating using similar technology might find the discussion useful. The technology has made it possible to increase conceptual understanding while making a small improvement in grades. The best students did significantly better. The most beneficial outcome provided by the technology was the in-class information about student misconceptions, making it possible to improve the teaching. Some examples are given.

Introduction

In the fall 2005 semester the author initiated project ALERT! to improve learning in a one semester lecture course in modern physics for sophomore engineering students. By increasing emphasis on active learning I hoped to improve conceptual understanding, improve attendance, and raise grades. A previous paper[1] presented the basis of this project in the body of educational research, described the software and hardware introduced, and discussed results from slightly more than one semester of operation. That discussion and references will not be repeated here. Those early results made for cautious optimism. The present paper compares three semesters with use of this project to teach 298 students and two semesters with 233 students before introducing ALERT! and gives some general results relevant to teaching modern physics. At the time this paper is being written, at the end of the fall 2006 semester, only slight improvements in grades have been achieved except, possibly, among the best students. This lack of significant enhancement is due in part to increased emphasis in tests on conceptual understanding, and to the freedom given to the students to learn outside of class, among other factors.

It is necessary first to give some background information. This course is the last in a three course sequence. Until now the sequence began in the first semester of the freshman year. Recently the start was shifted to the second semester, and these students will show up first in this course in spring 2007. The course is given each semester, until now to about 250 students per year. In the spring the class comprises coop students who have spent one semester off campus. Beginning spring 2007 the course becomes an elective and will have about 150 students per year.

The course carries two credits, whereas the previous two courses each carry three credits. Officially only two lecture meetings per week are scheduled, but a third, strictly voluntary recitation session immediately follows the second lecture. Topics fall into three groups: electromagnetic waves, including interference and diffraction; quantum mechanics, including models of atoms, molecules and solids based on one dimensional finite potential wells; and special relativity, including Lorentz transformations, applications of mass-energy to fission and fusion, and a brief introduction to general relativity as applied in the global positioning system.

An important aspect of the course is encouraging students to take responsibility for their own learning. A great amount of information is posted on our WebCT site so that a student does not have to come to every class. During lecture I write on a tablet computer in its journal mode instead of on the boards, and often write also on PowerPoint slides, which makes PowerPoint a livelier and more spontaneous lecture aid. Everything presented in class is saved as a pdf file and posted on our web site. In most classes virtual demonstrations are presented, and more than 50 such urls are posted. Some of the other materials posted are eight to ten practice problems each week with their solutions ---- homework is not collected ---- all past exams with solutions, and detailed lists of the topics students are responsible for in each chapter of the textbook. I do not take attendance, but I do emphasize the observed correlation between good grades and classroom participation.

Every student has a laptop computer and is provided with a software version of the well known hardware "clicker". The software keypad, called the vPad, and the corresponding course management software Turning Point[2], make use of wireless communication. In addition to having the capability of the clicker for sending answers to multiple choice questions, the vPad permits sending responses to questions requiring text and equations. It also enables students to send their own questions to the lecturer. When the project began in 2005 the use in lectures of wireless, the virtual keypad, and tablet computer were innovative, and still are for physics courses.

Results about Grades and Attendance

During the five semesters this course has been taught by me it has continuously evolved as a result of what I learned about student understanding. Three different textbooks have been used, the most recent being by Knight[3]. This is the one most clearly based on the results of educational research into teaching physics. Conceptual understanding has always been important in this course, but there has been a considerable increase in exam questions that require reasoning beyond selecting an appropriate equation. Gradually lecture time has moved to concentrating on illustrating concepts by examples and problems and away from introducing concepts treated well in the textbook. Thus, important variables were changed during the project to incorporate what was learned about how to teach the course better. These changes should be kept in mind when comparing data from different semesters. Few objective conclusions can be taken from the data, but these few might be useful.

Table 1 summarizes the grades of all students having taken the course, 233 before introducing the wireless technology and 298 after. At any one grade level the before and after results do not differ significantly. There is, however, a consistent shift of a few percent in grades from F and D to C and A. The grading scale is not curved, it is absolute, and the grade boundaries did not change during the project. The fact that grades have not declined, and might have improved slightly, despite the increased emphasis on concepts and increased reliance on the textbook is evidence of the benefits to me, the lecturer, of the new technologies. More will be said about this later.

Before ALERT!	With ALERT!	All Students
A=66=28%	A=95=32%	A=161=30(8)%
B=36=15%	B=44=15%	B=80=15(3)%
C=88=38%	C=117=39%	C=205=39(3)%
D=19=8%	D=15=5%	D=34=6(3)%
F=24=10%	F=27=9%	F=51=10(4)%
exc=15=6%	exc=48=16%	exc=63=12(6)%
Total 233	Total 298	Total 531

Table 1. Grade outcomes before and during project ALERT!. exc indicates students excused from the final exam with a grade of A. Numbers in parentheses are the average of the deviations of each semester's data from the mean of all five semesters.

To encourage the best students, those who earn ninety percent of the available points on the three one-hour exams are excused from the final exam and given a course grade of A. The increase in the percentage of excused students shown in table 1 is real, but the indicated change from six to sixteen percent is uncertain.

Attendance was not improved. In each semester attendance decreased to on average about forty percent. The attending students included most of the better ones as well as some of the weaker ones trying to improve their understanding. None of these students failed the course. Since I do not take attendance and, indeed, help students learn on their own outside of class, the low attendance might perhaps be expected. It seems to have been wishful thinking to expect the new technologies, and the changes in lecture they made possible, to make the course entertaining enough to attract most students. Every course I am aware of in which clickers or other devices similar to vPad have been used with positive outcomes, attendance has been taken or required, and few if any of the classes have been large lectures. Grade outcomes might be improved if attendance were required in my course also. This would be at the cost of not helping students become independent learners, a loss at least equal to the benefit of higher grades.

Those students attending class have an active role. Several virtual demonstrations are shown in most classes, and students are challenged through questions to reason about what they see and to provide text or multiple choice responses. Generally students work in small groups, typically of two to four. In every class rapid response questions and several problems similar to homework and exam problems are presented. Discussion follows the student responses. Classroom participation is essentially one hundred percent among those who attend. Pre- project experience was that very few students volunteered answers. An important advantage of the technology over show of hands or flash cards is the immediate quantification of responses. Students who choose to learn outside of class are active to some degree by the very nature of the process. However, few of those students manage to earn an A or B in the course.

There is a clear correlation between good grades and the extent of student participation in the various aspects of the course. The average number of times in a semester a student goes to the course web site is 150 to 180. The D and F students go about half this often. Most of the time students access the lecture notes and past exams. Students typically store the lecture notes on their computers and refer to them when answering questions in class. Typically they make use of no more than one or two of the more than fifty web sites having virtual demonstrations like those used in class. Students admit that, except when studying for an exam, they spend about 1.5 hours on the course per week, which is about one tenth of what I would like. I suppose it is evidence of their innate abilities to learn that they can perform on exams as well as they do with little regular study.

Results about Student Misunderstanding of Concepts

The most important outcome of this project has been to help me better understand student misconceptions, and through this knowledge to improve my teaching. This outcome by itself justifies the project. The students' understanding of concepts has improved as the course evolved. While examples of student understanding are somewhat interesting, examples of very basic misunderstandings perhaps are more useful. Some of these examples are given here taken from the just completed fall 2006 semester.

(a) Wave Motion, Interference and Diffraction.

One concept half the students never completely understood was the phase of a traveling wave. The following question is taken from the final exam.

"The displacement in a transverse traveling wave is given by $D_y = D_{oy}\sin 2\pi(x/\lambda + ft)$. If the wavelength is 2 m and the frequency is 4 kHz, what are the magnitude and direction of the velocity?"

The median score was 50 percent, achieved mainly by finding speed v from the formula $\lambda f = v$. Students can plot $\sin\theta$ versus θ, but they don't seem to accept that the phase $2\pi(x/\lambda + ft)$ is an angle, or that to follow the motion of a point of fixed amplitude requires that the phase be constant. Therefore, they could not find the direction of the wave.

It is not just that there are two variables, x and t, causing confusion. A multiple choice question asked in class and with a single variable is:

"An electron in an energy state with E = 10 eV moves in a one dimensional region where its potential energy $V(x) = 5\sin2\pi(x/1.0 \text{ nm})$ eV. What is the maximum kinetic energy of the electron?"

The results were 14 percent got the correct result 15 eV, and 43 percent each chose 10 eV and 5 eV. As always with a large fraction of incorrect answers, all answers were discussed carefully. Still, on the identical question on the final exam only about 40 percent got the correct answer. Students do not seem able to convert x, or x and t, into angles.

Yet the median scores on the following two interference questions from the final exam were each 100 percent. The reasoning given was correct also.

"Two sound waves from a common source come together at a point in space where a crest of one wave coincides with a trough of the other. Give all possible values of the phase difference between the waves."

"Suppose a double slit experiment is carried out with 800 nm light. A bright fringe appears at the center of the interference pattern on the distant screen. If now light of wavelength 400 nm is used instead, will the fringe at the center of the screen be dark, bright, or intermediate between dark and light?"

Students in class knew the conditions for constructive and destructive interference, and could express phase difference in terms of angle and path difference in terms of wavelength. That they found it difficult to conceive of $\sin2\pi(x/\lambda + ft)$ as a trigonometric function of phase angle suggests they accepted the conditions for interference on faith rather than from real understanding. I attempted to correct this situation by having students plot wave amplitude versus x or t separately. This is also done in the textbook. In the future I will exercise both aspects simultaneously.

Another misunderstanding related to trigonometric functions appeared in a multiple choice question about simple harmonic motion asked in class, which was a precursor to discussion of wave motion. In lectures preceding the question I discussed solutions to the differential equation for a mass on a spring and showed and discussed a virtual demonstration. I also posted a detailed discussion on our web site.

The question asked is:

"$d^2x/dt^2 = -\omega^2x$. The solution to this equation is: 1. $A\cos\omega t$; 2. $B\sin\omega t$; 3. $A\cos\omega t + B\sin\omega t$; 4. $C\cos(\omega t + \varphi)$; 5. $D\sin(\omega t + \varphi)$"

In fact, all choices are correct. However, 63 percent of the students chose only the cosine solutions 1 and 4. The other choices with sine functions were evenly divided at about 13 percent each. I believe the reason for this marked preference for the cosines is that Knight in his textbook uses only the cosine functions. The students seem to have read and learned from the text, which is a positive factor. However, they didn't absorb my discussion including the sine solutions, and apparently did not try for themselves substituting the sine functions into the differential equation. As a result of this discovery, as the course proceeded I spent extra time discussing matching solutions to initial conditions and to boundary conditions.

(b) Quantum Mechanics

As a test of student reading, before introducing the uncertainty principle in lecture I asked this question:

"One form of the Heisenberg Uncertainty Principle is: 1. $\Delta x \Delta t \geq h/2$; 2. $\Delta x \Delta p_x \leq h/2$; 3. $\Delta y \Delta p_x \geq h/2$; 4. none of the above."

The correct answer 4 was chosen by 17 percent, and 50 percent chose 2. Subsequently, after discussion and several examples, students were able to solve problems asking for the minimum uncertainty in a variable when given the uncertainty in the complementary variable. It was a surprise, then, that about 50 percent of the students could not satisfactorily answer this final exam question:

"Suppose an electron is known to be between x = 1 m and x = 1 m + 1 nm. What is the **largest** possible uncertainty in the x component of the electron's momentum?"

Although it was discussed in class, the significance of the inequality was not absorbed. Unwittingly, all of my examples had used the equality.

(c) Relativity

On the following question from the final exam the median score was only 25 percent:

"We observe a light turn on at x = 1000 m and t = 1.0 ns and turn off at x = 1100 m and t = 1001 ns. Another observer moving in the x direction at v/c = 0.6 measures the same two events. What does the second observer measure for the distance interval and time interval between the events?"

Ignoring the Lorentz transformation equations, nearly every student used the time dilation and length contraction formulas to answer the question. Yet the same situation was presented previously as an in-class question and 67 percent answered correctly that neither observer measured proper time. At least that many students showed also an understanding of proper length. Both time dilation and length contraction formulas were derived in class from the Lorentz transformation equations. And the Lorentz transformations were illustrated in lecture examples and in homework problems. Certainly it was simpler for students to incorrectly just plug numbers into the time dilation and length contraction formulas. I don't have an explanation for why students ignored the earlier in-class question and the Lorentz transformations. Having the students do more problems in class in the future will likely improve their understanding.

Conclusions

The effect of introducing wireless communication and using the vPad and associated software produced at best a small improvement in grades except for the best students, where the improvement was significant. During the five semesters the course has been taught the testing has evolved to put more emphasis on understanding concepts. That this change did not result in lower grades is evidence of the value of the technology in revealing deficiencies in student understanding so they may be corrected by the lecturer. This is the most important outcome of this project.

1. G. Rothberg, ASEE Annual Conference, June 18-21, 2006, Chicago Il, paper 2006-1215.
2. Turning Technologies LLC, 241 Federal Plaza West, Youngstown, OH 44503.
3. Randall D. Knight, "Physics for Scientists and Engineers: A Strategic Approach" (Pearson Addison Wesley, San Francisco, CA, 2004)