2006-1215: ACTIVE LEARNING THROUGH TECHNOLOGY (ALERT!): MODERN PHYSICS

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I. Introduction

Large, conventionally taught lecture classes typically suffer from poor attendance and weak student performance. This is the situation at Stevens and throughout the United States. "Even with an outstandingly effective and charismatic lecturer …. Lecture attendance at the end of the term in …. introductory courses hovers around 50%. No matter how strongly one feels about the intrinsic worth of the lecture format, it is hard to argue that it is broadly effective when half of the students do not attend the lecture. This lack of student engagement is arguably one of the major reasons for the failure rates (typically 15%) in these introductory courses." (emphasis added)[1,2]

Large lecture classes certainly make economic sense. We must find how to make them work well. "….. much research has shown the standard lecture-format class to be ineffective as a vehicle for learning. Effective learning requires the students to be active participants in the process, not passive listeners."[3]

In this paper I describe a project to significantly improve student learning in my one semester sophomore course in modern physics for engineers by introducing technologies to enhance active learning. None of the technologies is new; I only am describing my own experiences with a particular combination, a classroom response system in conjunction with a tablet computer, a combination which is also not new. The Physics Education Research Group, University of Massachusetts, web site provides many links to information about the technologies used here as developed by themselves and a number of universities and companies[4-6]. Another excellent source, emphasizing their own product, Classroom Presenter, is the Computer Science Department, University of Washington[7-10].

The course itself might be unique in that it carries only two credits, is scheduled to meet only twice per week in fifty minute sessions, and still is expected to educate students to a depth comparable to the typical preceding courses in mechanics, electricity and magnetism. To provide additional opportunities for problem solving, I hold an additional, strictly voluntary, recitation session each week.

The course was created by me in response to curriculum changes in the School of Engineering and taught for the first time in the fall 2004 semester. The population is about 180 sophomores in the fall and about 100 sophomores in the spring. The spring class consists of coop students who have had one semester of work experience. The project described here was initiated in the fall 2005 semester.

II. Basis in Educational Research

The project is based on the educational philosophy known as constructivism, and the methodology for carrying it out is active learning. The following quotation provides a good definition of constructivism in the present context. "We can briefly summarize the constructivist view of how knowledge is acquired as follows: All individuals must construct their own concepts, and the knowledge they already have (or think they have) significantly affects what they can learn. The student is viewed not as a passive recipient of knowledge but rather as an active participant in its creation. Meaningful learning, which connotes the ability to interpret and use knowledge in situations not identical to those in which it was initially acquired, requires deep mental engagement by the learner."[11] This contrasts with the standard lecture mode in which the student is passive while the lecturer transmits knowledge. The standard philosophy is called objectivism.

Considerable research now supports the constructivist view. " ….. in the introductory class, short periods of instructor-centered discourse can clarify difficult issues or provide background information. But extended lectures, particularly formal lectures of deriving results, appear to be the least effective mode of instruction."[12]

To help students construct correct concepts in modern physics active learning techniques are used here. "Active learning is simply that - having students engage in some activity that forces them to think about and comment on the information presented."[13] There is an extensive literature on the effectiveness of active learning and on many techniques that have been used to introduce it into classrooms, including large lectures.[3] One of the most prolific proponents is Richard M. Felder. His web site[14] is a large and valuable source of references and publications. The benefits of using technology along the lines described here are singled out in the National Research Council publication "How People Learn: Brain, Mind, Experience and School."[15]

Students are reluctant to answer questions or ask questions in large classes, perhaps for fear of revealing their ignorance. This makes it very difficult to get feedback during lectures. Having them discuss with their neighbors and return a collective response helps, but still not enough students volunteer. Before introducing this project my practice at the start of each class was to select several students whose responsibility was to hand me a written anonymous question at the end of class or a brief statement of one thing they understood. I answered the questions in the following class. The questions have been very helpful and sometimes startling in bringing out differences in understanding between me, the expert, and them, the novices.

It would have more impact on student learning if I could get anonymous questions and respond to them in real time during the lecture. The technology exists to do this, and one form of it is described here. The technology also makes it possible for me to ask snap quizzes, collect anonymous answers, and immediately summarize and display the overall class degree of understanding. These capabilities are invaluable aids to learning.

III. Software and Hardware

All Stevens students have their own laptop computers with wireless capability. It was decided to use this existing hardware to facilitate instructor-student interaction. Accordingly, a separate wireless subnet with three access points was installed in the lecture hall used by this course.

Course management software was evaluated in a simulated class setting with student and faculty volunteers. The software "Turning Point"[16] was selected for use in this project. The student software is "vPad", which is a virtual keypad permitting students to send and receive text and to respond to questions. The vPad was distributed via WebCT to the students registered for the course.

I believe we were the first to use this software in a wireless environment in which the computers are owned by the students. This presented problems unanticipated by the company that made it impossible for students to activate the software on their computers from an on campus site. For security, all student, on campus communications go through a proxy server. The activation process originally could not accommodate this situation. By mid semester the software was fully functional. The fall 2005 semester, consequently, was an intensive learning experience for me in the capabilities of the software and in ways to use it to promote student learning. There was no difficulty activating the vPad in the spring 2006 semester.

Turning Point with vPad can be operated with responses that are anonymous or attached to student names. I chose anonymous to encourage student participation. I do not take attendance, but with identified responses it would be straightforward to do so. It would also be possible to track the classroom participation of individual students. These are benefits that I forgo with the aim of getting students to take more responsibility for their own educations.

I also evaluated the use of a tablet computer in class. Turning Point operates within Microsoft PowerPoint. Normally, in the past I used PowerPoint only when delivering a scripted lecture and not in a classroom setting, where I prefer to be spontaneous so I can modify my presentation according to what I perceive to be student reactions. The tablet computer has greatly facilitated my ability to integrate PowerPoint into my teaching style. The tablet computer and the inking function of PowerPoint make it possible to write directly on a PowerPoint slide, so I can annotate figures in real time, integrating them more completely into my lecture.

With the tablet computer in its journal mode I write and project the highlights of my lecture in real time. These notes and copies of any slides are converted to a pdf file and made available to the students on our WebCT site. With the same computer I can switch to PowerPoint for presenting figures, for soliciting student responses to questions and for receiving and replying to the students' own questions to me, which functions are provided by Turning Point. The student software makes it possible for them to answer both multiple choice and essay questions and to send text to me. Turning Point displays responses to multiple choice questions as soon as the polling is closed. The percentage of responses to each choice is shown in a chart superimposed on the question slide.

At present text responses to questions can not be displayed in class; they can be saved for later examination. If a response is sent in the form of a question, however, by closing the text with a question mark, it can be reviewed and displayed in class. The parts of each class, or "session" in Turning Point jargon, that uses Turning Point can be saved in a proprietary Turning Point file for later examination, transfer to Microsoft Excel files and preparation of reports.

IV. Some Examples

At the second meeting of the fall 2005 class, which was the first voluntary recitation, a survey of preexisting knowledge was carried out to get insights into the students' math skills relevant to the course and into their pre-existing understanding of some key modern physics concepts. No modern physics topics had yet been discussed. The survey results as generated by Turning Point are given in the appendix. About half the class of 185 attended. Twelve had managed to activate their software in the two day interval after the first class meeting. To get responses more nearly representative of the entire class I had them work in groups of two to four and to agree on a response before sending it to my computer. Since they worked in groups, I believe the survey responses represent 15 to 20 percent of the total population. The results are informative and guided later class discussions, but for the most part can not be considered fully representative. It is conceivable that the survey results are skewed towards the better students, that is, those motivated to come to the recitation and to get the software to work. Hence, a strong percentage of incorrect answers is probably a valid indicator, but correct answers might not be representative of the entire class.

Again in the spring 2006 semester a survey was conducted in the first recitation class, this time emphasizing knowledge relevant to electromagnetic waves. Because the vPad activation was straightforward, many more responses were obtained, representing about 50 percent of the class of 100. The first four questions are identical to the first four of the fall survey discussed below and confirm the fall results.

Before beginning the survey a warm up question was asked just to familiarize the students with the software. The first four questions of the survey are on math skills and the last four relate to modern physics course topics. Each question offered three choices. Turning Point displayed the responses as soon as the polling was closed for each question. A short time, two to three minutes, was allowed for each answer. At the end of each question I briefly explained the relation of the question to the content of the course and discussed the correct and incorrect responses before presenting the next question.

Q1 is basically an example of expressing a verbal statement in algebraic form. The correct answer is #1.

Q2 is a test of partial derivatives, which students often find mysterious. #2 is correct. Students did well on Q1 and Q2 and similarly well on these aspects of math throughout the course.

Q3 requires reading a verbal statement and carrying out a calculus integration. It does relate to course topics, but that is incidental at this point. #1 is correct. #2 would be the result if the question were misinterpreted as dN/dt = - aN0 or if the integration process were misunderstood. Very few students answered this question within the allotted time. In earlier sophomore courses I found that students differentiate readily but have more difficulty with integration, consistent with the present result. This deficiency was addressed several times during the present course.

Q4 is a test of vector addition. #2 is correct. Most students got this answer. Later observation suggested that students do not have a clear understanding of the physical significance of a scalar product of two vectors. This point was questioned explicitly in question 5 of the spring survey, shown in figure 1. The figure shows the typed, multiple choice question, the three answer choices, and the percentage of students who made each choice. The written notation illustrates the inking capability of the tablet computer within PowerPoint. Only 35 percent of the students answered correctly. After the brief explanation shown on the slide, 80 percent of the students answered correctly the next question about the vector product, which is not discussed here.

Q5 is an example of relativity in classical physics. #2 is correct. Students did better than I expected.

Q6, 7 and 8 are definitely modern physics topics, and here the students revealed the expected lack of understanding. The correct answer in each case is #2. The predominance of incorrect answers to Q7 and Q8 is pronounced enough that the results may be considered truly representative of the entire class. Q6 was split about 50-50 between correct and incorrect answers. In view of the almost completely incorrect responses to the related Q8, the Q6 result could represent just guesswork. These knowledge deficiencies were corrected when these topics arose in the course.

The course is divided into three broad topic groups, not always in the same order: relativity, mainly special but including some general relativity as required for discussing the global positioning system; electromagnetic waves, including interference and diffraction; and quantum mechanics, including basic concepts and simplified applications. At the beginning of each major group of topics I made a survey of prior student knowledge. It was quite useful to learn what students did not know. Later exam results showed significant improvement in knowledge. During lectures I created snap multiple choice questions to test student understanding. Turning Point makes it possible to insert standard question templates into the PowerPoint presentation. Often, however, while using the tablet computer's journal mode to record lecture notes, I found it more convenient to write a question and multiple choice answers directly in the notes and switch to Turning Point to collect responses and instantly display the percentage of students making each choice. Figure 2 shows such a question about traveling waves taken from a journal page, and figure 3 shows the corresponding Turning Point display. This question was preceded two days by a class showing web based demonstrations of longitudinal sound waves and transverse water waves. Electromagnetic waves were discussed following this question. Each response was discussed with the students to explain why it was correct or incorrect. This procedure definitely was helpful for me, but it will require further study to know if and how it benefits students. As discussed in the next section, there is some evidence that student performance was improved.

V. Preliminary Evaluation

My previous experience with this course closely parallels that referred to in the introduction.[1,2] By midterm attendance was 50 percent or less. In the fall 2005 semester student attendance dropped similarly and seems to be happening in the spring 2006 semester also. The low attendance is partly the result of the fact that I put the lecture notes, supplemental materials and weekly quizzes on WebCT so that students do not have to attend lectures provided they study the textbook and discuss with fellow students.

I intentionally give students responsibility for their own learning, ideally with myself serving as a guide and resource. Unfortunately, many sophomores are too immature to bear this freedom. I get along well with most of them, and they talk fairly freely. They readily admit they don't read the text until a few days before an exam, and likewise they usually don't discuss the course with others. One consequence is that after the second of the three hourly exams a significant fraction of students are failing. At the same point in the fall 2005 semester the number failing was 50 percent less than in the two previous semesters. Student surveys in the spring using Turning Point show that up to the first exam only about 40 percent of the students were participating fully in the course outside of class. It would be relatively straightforward to force students to participate by removing the anonymity of in-class responses and giving them course credit. I prefer, though, to help them learn how to study.

In recognition of different learning patterns among students I make it possible to get good grades in several ways. Since the students are intrinsically bright, many significantly improve their grades on the third hourly exam and on the final exam, which covers the entire course. I grade on an absolute scale, and about 50 percent earn As or Bs. However, the failure rate was 14 percent in fall 2004, which is twice as large as I expected at the beginning of that semester based on my earlier results with first semester sophomores in other courses. In fall 2005, perhaps as a result of using Turning Point to make the course more interactive, the failure rate was reduced by 50 percent and the number of Ds, Fs and withdrawals was reduced by 57 percent. I believe it is too early to know if it is justified to attribute this improvement to the new technologies.

Another significant improvement in fall 2005 is that 16 percent of the students were excused from the final exam and given As because they had accumulated at least 90 percent of the possible hourly exam points with no exam score less than 80 percent. This possibility is intended to encourage the better students. In fall 2004 not one student achieved this level of performance, though after the final exam about the same overall percentages of As and Bs were earned. The number of spring 2005 excuses was essentially the same as fall 2005. Perhaps these data indicate the value of Turning Point in educating less mature, first semester sophomores. At this time this is just speculation.

In conclusion, Turning Point with vPad in a wireless classroom has definitely helped me to detect and correct student misunderstandings of course materials. The tablet computer fit well into my teaching style and, because of its easy to use inking capability, made the use of PowerPoint satisfactory. Finally, there are indications that student performance was enhanced, but it is too early to know how much is attributable to use of the technologies applied.

<u>Appendix. Knowledge Survey</u>

Turning Results by Question Created 9/1/2005

1.) Is today Thursday?

	Responses (percent)	(count)
Yes	54.55%	6
No	9.09%	1
Abstain	36.36%	4
Totals	100%	11

2.) Q1. At Stevens there are 15 students for each professor. Let S = number of students and P = number of professors. As a mathematical expression this statement is

	Responses (percent)	(count)
1. S = 15P	72.73%	8
2. P = 15S	27.27%	3
3. S*P = 15	0%	0
Totals	100%	11

3.) Q2. Consider a function f = 2(x^3)y. The partial derivative of f with respect to x is

	Responses (percent)	(count)
1. 0	0%	0
2. 6(x^2)y	100%	10
3. none of the above	0%	0
Totals	100%	10

4.) Q3. A substance containing N radioactive nuclei decays at a rate dN/dt = - aN, where a is called the decay constant. If N0 is the number of radioactive nuclei present at t = 0, the number present at a later time t is

	Responses (percent)	(count)
1. N = N0 exp(-at)	66.67%	2
2. N = N0 (1 - at)	33.33%	1
3. N = N0 (1 - ln(at))	0%	0
Totals	100%	3

5.) Q4. An electric field vector E1 has magnitude 3 V/m and points in the +x direction. A second electric field vector E2 has magnitude 4 V/m and points in the +y direction. The sum of the two fields has magnitude

	Responses (percent)	(count)
1. 7 V/m	8.33%	1
2. 5 V/m	83.33%	10
3. 2.65 V/m	8.33%	1
Totals	100%	12

6.) Q5. I'm standing on the sidewalk tossing a ball straight up in the air. My friend drives by and observes me and the ball. From his point of view, the path of the ball is

	Responses (percent)	(count)
1. a vertical straight line	8.33%	1
2. a parabola	75%	9
3. a tilted straight line	16.67%	2
Totals	100%	12

7.) Q6. According to relativity theory, if I heat a solid its mass will

	Responses (percent)	(count)
1. be unchanged	36.36%	4
2. increase	45.45%	5
3. decrease	18.18%	2
Totals	100%	11

8.) Q7. In a solid at absolute zero temperature all motion of the atoms ceases.

	Responses (percent)	(count)
1. true	75%	9
2. false	25%	3
3. don't know	0%	0
Totals	100%	12

9.) Q8. Under the right conditions two hydrogen atoms can be brought together to form a helium atom. As a result of the process the final energy of the helium atom is greater than the sum of the energies of the two hydrogen atoms. This statement is

	Responses (percent)	(count)
1. true	90%	9
2. false	10%	1
3. don't know	0%	0
Totals	100%	10

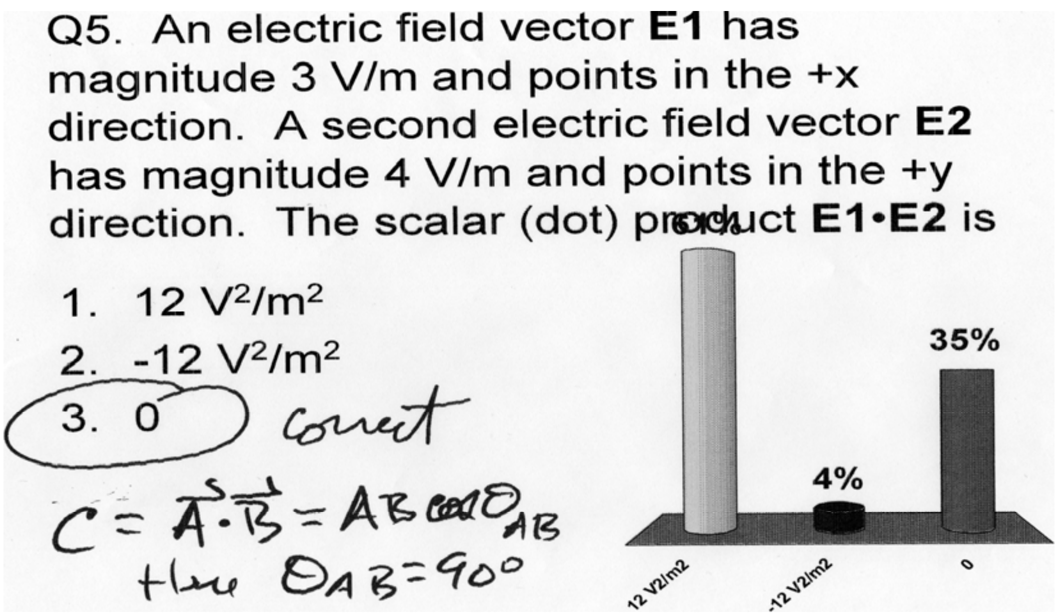

Figure 1. Question from knowledge survey. Turning Point slide with inking.

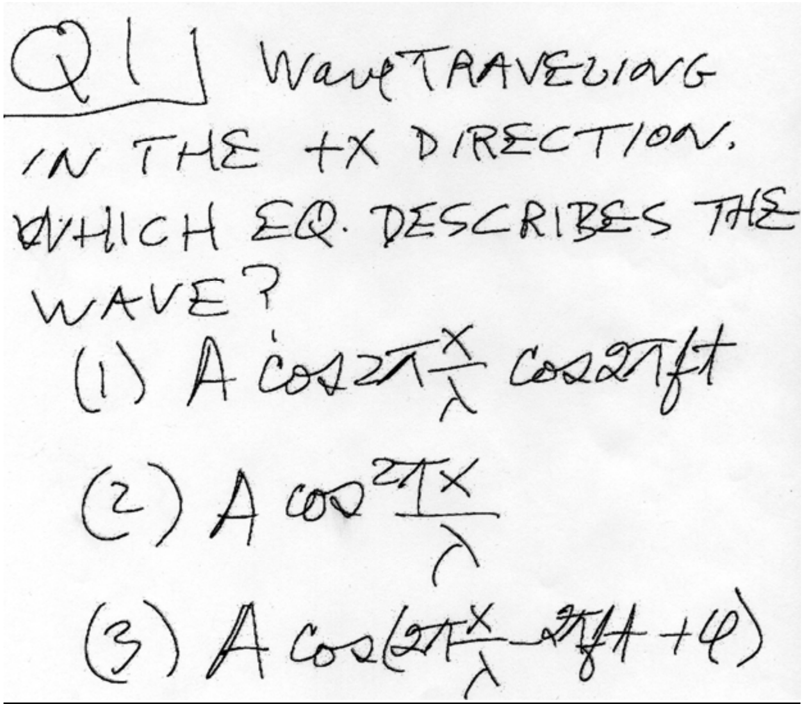

Figure 2. Question to class written in tablet journal mode.

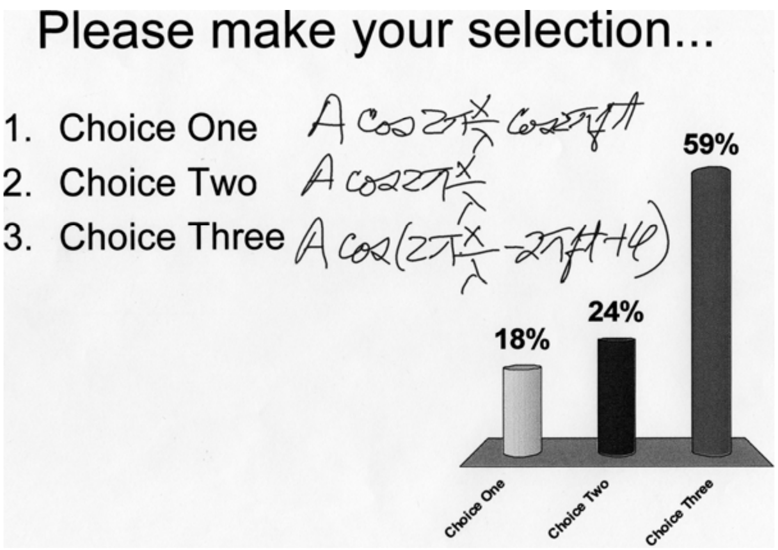

Figure 3. Response to question of figure 2. Turning Point slide with inking.

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