EXPERIENCES AND THOUGHTS ON STEMTEC-INSPIRED CHANGES IN TEACHING PHYSICS FOR LIFE SCIENCE MAJORS

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I have taught an introductory course for life science majors three times, each time introducing one or more teaching techniques discussed during the Science, Technology, Engineering, and Mathematics Teaching Education Collaborative (STEMTEC) meetings. Typical class size was 275 students. I cannot make quantitative statements about comparisons between the results of STEMTEC-type teaching methods and *traditional* teaching methods because I have never taught this course in a completely traditional lecture style. During the first year, I introduced conceptual questions into my lectures. The lecture would be interrupted several times with questions posed to the class. The students then had several minutes to discuss each question among their neighbors, then present their answers. During the second year, I switched from traditional homework to a computerized system which allowed instant feedback to the students, and the ability to resubmit solutions to problems they had not successfully solved. I also introduced an exam format that enabled the students to work individually, then redo the exam in groups and hand in a second set of solutions. The goal of each of these techniques was to increase the engagement of the students with the material of the course. Each of the techniques had both successes and limitations. The most serious problems I confronted were technical difficulties which diverted attention from the tasks at hand to the necessity of *keeping the system functioning*.

Introduction

Physics 131: Introduction to Physics I at the University of Massachusetts Amherst (UMass) is an introductory course designed for life science majors, exercise science majors, pre-medical students, and others who need a non-calculus based introductory physics course. There is an emphasis on applications which are important in the life sciences. The topics covered are mechanics, fluids, waves and acoustics, with a small amount of heat and thermodynamics.

Because it is a required course for a number of majors, the beginning enrollment in the fall semester is typically more than enough to fill the 290 seat lecture room in which it is given. The Department of Physics at UMass typically assigns a faculty member to teach a course no more than three or four times in a row. Thus, no faculty member *owns* a given course, and every faculty member teaches lower level undergraduate courses, as well as upper division undergraduate and graduate courses.

I was assigned to teach *Physics 131* for the first time in the fall of 1997, and I taught it

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during the two succeeding fall semesters as well. Each time I taught the course, I introduced one or more STEMTEC-type, student-active teaching methods, described below. Because I have never taught this course in a completely *traditional* lecture-only format, I cannot make quantitative comparisons of the results of *traditional* and *student-active* teaching methods of the material. However, I feel that I have enough experience with the course to point out both the advantages and disadvantages of these newer teaching methods.

The Goals in Using STEMTEC Techniques

The main goal of STEMTEC-inspired techniques I used is to increase student-active learning. More specifically, I wanted to:

- induce students to **think** about the physics under discussion **during class**
- induce students to **interact with each other** as a learning experience
- give students **immediate feedback** on the status of their activities, both their in-class student-active learning and their after-class homework assignments.

The Techniques Used

I attempted the first goal, getting students to think about the physics during the class meetings, by presenting them with conceptual questions during the lecture [1]. (Sample question may be found in the section, "A Conceptual Example.") The students were given several minutes to discuss each question with their nearest neighbors, then register their answers. The results were shown to the entire class. The first two times I taught the course, the students held up numbered sheets with their answers. In 1999, I switched to using the *Classtalk* electronic polling system described below [2,3,4]. Both methods enabled me to immediately see how the class was doing, and immediately address misconceptions that arose. The *Classtalk* system, however, made it easy to have a record of each student's activity.

In addition to interacting with each other during class, students were also encouraged to work together during exams, which were modified pyramid exams [5]. The students first worked independently on the problems and handed in their solutions. Then they worked on the same exam in self-selected groups and handed in another set of individual solutions. When it worked well, this interaction encouraged students to engage each other, forcing them to defend their viewpoints when conflict arose and increased their understanding of the material, their ability to manipulate the material, and the concepts to solve problems they had not previously encountered. The grading system for these exams is discussed below.

In the fall of 1998, I switched from the traditional homework system, with problems handed in once a week and graded by a graduate teaching assistant, to the On-line, Web-based Learning (OWL) system [6,7]. This system notifies the students immediately of their success in solving the problem at hand. If they do not succeed, the system gives them the correct answer and also the option of getting some *hints* and then trying the basic problem once more with a different set of numbers. Thus, the students can work the problems until they have solved them all.

Grading in the Course

The *Classtalk* conceptual problems counted for 10% of each student's grade. The OWL administered homework counted for another 20%. There were three evening "midterm" exams, worth a total of 50% of each student's grade: the exam on which the student got the lowest score counted for 10% and each of the others counted for 20%. There was also a final exam which counted for the remaining 20% of the student's grade.

Conceptual Problems and the *Classtalk* System

The purpose of the conceptual problems is to counter the idea that many students have that physics consists of inserting numbers into formulas for the sole purpose of getting a numerical result. The problems are designed to probe the basic understanding that the students have of the material. To the extent that numbers come into the picture, they usually come in as ratios. A good source of conceptual problems is reference [1]. In addition, many of the newer physics textbooks include conceptual problems either as separate sections, or along with the regular end-of-chapter exercises.

The *Classtalk* system consists of hard-wired connections between student calculators and a computer operated by a teaching assistant. Up to four students can sign onto a single calculator, each with their own unique ID. The students can enter the answer to a given question as individual answers, or as a group consensus answer with the possibility of dissenting answers from one or more members of the group.

When a question is posed to the class, the students are typically given three minutes to register their answers. In order to encourage both attendance and thought about the problems, one point of credit is assigned for an answer to each question, with an additional ½ point for the correct answer. At the end of the allotted time period, a histogram, generated by the computer, is displayed on the projection screen. This histogram tallies the answers to multiple choice questions, or numerical intervals to questions where a numerical answer was requested. The class and I immediately see what the response was to the question. If more than 90% of the answers are correct, I briefly comment on the problem. If more than about 10% of the students do not get the correct answer, I spend much more time going over the problem, stressing the concepts necessary to deal with it, and pointing out typical misconceptions that can arise. On average, a single problem takes a total of about ten minutes of class time. I consider a student getting 85% of the maximum number of points during the semester as having done enough to get full credit for the *Classtalk* part of their grade.

A Conceptual Example

To illustrate the type of conceptual problem used in the class, a problem involving motion in the vertical direction under the influence of gravity is outlined below. The students will already have understood the concepts of velocity, acceleration, and maybe the invariance of physical laws under the operation of time reversal.

A ball is dropped from the top of a building. It strikes the ground with a velocity v_f. At the instant the ball is released, a second ball is thrown upward with an ***initial velocity*** *v_f. Ignoring air resistance, where will the paths of the two balls cross?*

(a) At the half-height of the building.
(b) Below the half-height of the building.
(c) Above the half-height of the building.

There are several ways to approach solving this problem. One way involves asking (and answering) the following questions:

1. Will the thrown ball reach the top of the building and not go any higher?
2. Do the two balls take the same time to get from the top (bottom) of the building to the bottom (top)?
3. Will the balls pass each other half way in *distance* or in *time*?
4. If the time for the dropped ball to reach the ground is T, how far will it drop in T/2? (Note: The distance, d, the dropped ball falls in a time t is given by alignl d ~=~ 1 over 2 `gt^2, where g is the acceleration of gravity.)

This problem seems simple when asked, and the calculations involved are simple, but unless the students ask themselves the correct questions while solving it, they will be led astray.

For the curious, here is the solution to the problem:

1. The thrown ball will just make it to the top of the building.
2. The dropped ball takes the same time to reach the ground that the thrown ball takes to reach the top. Points 1. and 2. are intimately involved with the time reversal invariance of physical laws.
3. Because of 1. and 2., the balls will pass when *half the travel time* has elapsed, not half the travel distance.
4. If it takes the dropped ball a time T to reach the ground, in T/2 it goes 1/4 of the distance (because of the dependence of the distance traveled on T^2 rather than *T*). This means that the balls will cross paths above the half-height of the building (1/4 of the way down from the top of the building).

Homework and the OWL System

The ideal distribution of homework is to have problems based on material covered in a class due before the next class meeting. This way, the students are forced to think about the material as it is presented and not put off doing the homework for an extended period of time. In addition, I hear about questions on the homework at the beginning of the next class period and can address them immediately.

Under the *traditional* homework system, homework is due once a week, graded by a graduate teaching assistant and returned the following week during a discussion session. That system has several drawbacks:

- Many days pass between the material being covered in class and when the homework is due
- There is not much chance for help while a student is experiencing difficulty with a problem
- By the time the graded homework is returned, the student has forgotten what the problem was, how they tried to answer the problem, and what difficulties they encountered

The OWL system is an attempt to address these problems. I assign more problems than I did when all I had was a graduate teaching assistant to grade the problems (the computer doesn't get worn out grading homework of 300 students). Instead of being due once a week, the homework based on a class meeting is *due before the next class meeting*. This way, the students are continually doing work in the course. Typically, three homework problems are assigned after each class meeting.

To do their homework on the OWL system, the students sign on to a secure website (only registered students have access to the site). They can choose which problems to attempt and in which order. Each time a problem is presented, the numbers in the problem will change (but always consistent with the laws of physics). As soon as a student has entered an answer to a problem, they are told whether or not they have answered it correctly. If they did not answer the problem correctly, they are given the correct answer and the option of getting a hint on solving the problem. These hints usually consist of an indication of which physical principle(s) are applicable in solving the problem. The student is then given the option of trying to solve the problem again. Of course, the next time they see the problem, it is the same problem, but with different numbers. They may also elect not to try the problem again at that time and come back to it later, or in a different session. This process can be repeated as many times as the student wishes before the problems are due.

The advantages for students of the OWL system are instant feedback, some help if needed, and the ability to attempt the problem as many times as necessary until correctly solving it. The Physics Department maintains a Resource Room staffed by faculty and graduate students, open from 9AM to about 8PM, where the students can do their OWL homework (there are a number of computer terminals in the room) and get help on the spot if they need it from a living, breathing, person. Because the homework is web-based, the students also have the option of doing their homework in their rooms at any time of the day or night, as long as they have access to the World Wide Web.

During the course of the semester, more than 110 OWL problems are assigned. Students get full OWL credit for correctly solving eighty of these problems. This is done to lessen the burden on me of having students in my office every time they could not do an assignment because they did not have the time, or were sick, or had to attend a funeral, or were out of town, or . . .

The Pyramid Exam Technique

Evening midterm exams were multiple choice, two hours in duration. Each student worked on the exam individually for 1-1/4 hours, then turned in their answers. If they finished early, students were allowed to leave the room and discuss the exam with other students who had finished. At the end of this *individual* exam-taking period, the students formed groups of 3-5 (the group members were determined by the students themselves) and reworked the same exam for the remaining 45 minutes. Each student turned in an additional set of individual answers after the group effort. Thus, students got the benefit of interacting with each other on the material, but were not bound by any group decisions. In the best groups, the students vigorously discussed and argued about solutions to the problems over which they disagreed. In the unsuccessful groups, the students just copied the answers from a student who they considered better at the physics than they were.

The responses from the *individual work* were worth 80%, and the responses from the *group work* were worth 20% of the total exam grade. Thus, one correct answer on the *individual exam* was worth four correct answers on the *group exam*. The grades of students were raised by the group work, but not by much. However, the students learned from the group work, and at the end of the experience they understood the material much better. This was true even of the better students, who gained from giving explanations to the weaker students.

It was not possible to use the pyramid exam concept for the final exam because students from other courses were taking final exams in the same space at the same time as the students from my course; the noise from the group work would have been too disruptive to the students in the other courses.

The "Good Stuff"

I see a number of benefits from using the techniques described above:

- Attendance in class is much better. About 75% of the students are attending class even near the end of the semester. This is significantly more than the usual ~50% for large classes.

- Students are actively involved during lecture in thinking about the physics and interacting with each other.

- Students are learning from each other during class (*Classtalk*) and during the (pyramid) exams, and enhancing their knowledge of the physics.

- Homework is due in proximity to the class coverage of the material. Students can work on the homework problems until they understand them. They get instant feedback on how they are doing.

- Student interaction with the instructor (me) is greatly enhanced.

The "Bad Stuff"

There are, however, also some endemic problems:

- Attendance in class is much better. Students who really don't want to be there feel that they must attend class or they will lose credit on the *Classtalk* part of their grade. Uninterested students can be disruptive; they also are present during evaluation of the faculty at the end of the semester, with the obvious result.

- There is a problem of phantom students being signed into the *Classtalk* system by their buddies. This is easily dealt with, because the *Classtalk* system attaches the names of the students signed in to the seats they supposedly occupy. The teaching assistant then uses a seating diagram on the computer to find seats not occupied, but which have students signed in on them. An announcement to the class that we know who was signed in but not present, and also who signed them in (because we know onto which calculator they were signed in), and that both parties would lose credit for a week's worth of *Classtalk*, usually ends the problem.

- Not all students in groups during either *Classtalk* problems or during the pyramid exams are really interacting with their neighbors.

- With a class of 300, there are always a number of students who cannot take exams during the assigned exam time because of conflicts with other exams, work, etc. These students take makeup exams, but the timing of these makeup exams does not always allow each student to join a group.
  There are also a number of students, usually about half a dozen, who take untimed exams. Some of these students have documented learning disabilities and require extra time; others come to me after the first exam requesting extra time for subsequent exams. I usually arrange for these students to take their

individual exams earlier during the day of the scheduled exam and then show up at the main exam in time to take the group part of the exam. This is done in a way that minimizes the possibility of these students getting copies of the exam to others before the main exam is taken by the majority of students.

- Some students spend lots of time trying to "reverse engineer" the OWL homework. They will get a problem wrong and be given the correct answer (e.g., they may have said the answer was 5.2, and the correct answer is 10.4). Then they try the problem again, with different numbers, of course, and get it wrong again (e.g., they think the answer is 4.1, but the correct answer is given to them as 8.2). They will finally try the problem yet another time, but enter an answer that is different than the one they have calculated (e.g., if they think the answer is 3.7, they will not give the answer as 3.7, but as 7.4, assuming that the correct answer is really twice what they calculate). These students are not learning much physics when they do this, but it does happen (one group of students actually complained to me that many of the problems were taking too much time to reverse engineer—my response was that the point was to learn the physics, not just get the correct answer).

- Even though I allow the students ~30 "freebies" on the OWL homework, a number of students still pester me continually to extend the deadlines for the homework so they don't lose any possible credit.

- Some students just stop doing the homework after getting eighty correct problems.

Startup and System Problems

There were a number of what can be classified as startup problems:

- OWL — Students who register late for the class and hence cannot get onto the OWL system quickly are frustrated. In addition, if the main computer goes down, the students cannot complete assignments until the computer is back on-line. More frustration. This is a real problem if the computer goes down at 2AM (the homework is due at 4AM), while the student is trying to finish the assignment, and there is no way the computer will be brought back up until after 8AM.

- *Classtalk* — There is a logistical problem getting students signed onto the system in the beginning of the semester. Also, because the system is hard-wired to each seat in the lecture hall, sometimes the connections fail and the students cannot communicate with the main computer. This leads to more frustration and disruption of the class if not handled promptly.

- Pyramid exams — There are sometimes students who do not wish to share their knowledge with other students and refuse to join groups. As one student said to me: "I studied very hard for this exam. Why should I help someone else who has not put as much effort into preparation?" I try to convince such students that they will also learn as they teach someone else. If they still persist in refusing to join a group, I let them be a group of one for the second part of the exam. Usually, by the next exam, they have changed their minds about joining a group.

General Observations and Conclusions

- Students are *obsessed with credit.* This is especially true of students who feel they need good grades to gain entrance to competitive professional schools after college.

- Anything that prevents students from getting credit upsets them greatly. So, if the mechanics of the techniques being used are not in perfect working order (OWL downtime, *Classtalk* connection problems), the students are worrying about not being able to get credit instead of thinking about the physics.

- Most students really like the increased interaction with other students and the instructor fostered by the active learning paradigms.

- Students may actually learn and retain more compared to being taught in the traditional lecture style. I think the best way to check this would be by administering what I like to call the "Stop & Shop Test" to the students: You run into a student in Stop & Shop about a year after they have taken the course, and you administer an exam on the material to see how much they have retained. ■

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Bio

Monroe Rabin is Professor of Physics in the Department of Physics at the University of Massachusetts Amherst. In addition to an interest in improving teaching methodology, he does research in the areas of heavy-ion physics and medical physics.

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