Incorporating Technology into a First Course in Physics for Engineers

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Abstract

A variety of new teaching tools have come into existence in recent years because of advancements with computers and the worldwide web. At Clemson University, we have spent the last two years using a variety of these tools to "modernize" the three credit course *Introductory Physics with Calculus*. This course is innovative, not only because of its wide use of technology, but because we have adopted some of the latest techniques developed by experts in the field of physics education. Student interviews find that these techniques improve the course.

Introduction

Currently calculus based physics is a requirement for all engineering majors. This will not be a requirement within six years because of new criteria implemented by the Accreditation Board for Engineering and Technology (ABET).[1] Instead, depending on the engineering field, students will need to demonstrate "proficiency in" or "ability to apply knowledge of" physics. The purpose of these changes is to increase flexibility within degree programs, which should help promote innovation at the university level. In all likelihood, calculus based physics will remain a requirement for most engineering majors at most universities, but the new ABET criteria should compel universities to become more efficient in the education of their students.

Physics faculty members often come away from teaching a college-level introductory course astonished at how little their students have apparently learned.[2] At Clemson University approximately 25% of the students receive a D or F in the course *Introductory Physics with Calculus*. From discussions with colleagues elsewhere, these numbers are typical at most large universities. Clearly this course is one of the largest hurdles engineering majors face. Besides the high failure rate, we believe it would be difficulty to convince an outside review board that many of the students that pass the course are "proficient in" physics. Students pass the course by adopting a variety of strategies. Many of these strategies involve misconceptions of the physical world, and problem solving skills void of any critical thinking.[3,4,5]

Given the changes in ABET criteria, physics departments and engineering departments need to open a better line of communication. We need to address several questions. "What are we teaching?" "How can we improve our product?" "What are the students learning?" "How do we make sense of what they do?" "How do students develop problem solving skills?" "How do we effectively assess what students have learned?" Only then can we make sense of how students learn physics in a way that helps us improve their engineering education.

Over the last two years, the Department of Physics and Astronomy at Clemson University has "modernized" the first semester of *Introductory Physics with Calculus*. This is a three credit hour course taught in either a lecture/recitation (2/1 hr.) or pure lecture (3hr.) format. Some students are required to take the accompanying 1 credit hour lab course, but not all. Typical lectures consist of 150 students; a typical recitation group has no more than 30 students. This course serves about 700 students per year.

Currently, the course is nearly 100% on-line. The only exceptions are that the students still meet for lectures, and the major exams are on paper. We have introduced on-line homework, and on-line quizzes. Students can access their professors and recitation instructors via email and bulletin boards. Lectures have been modernized, using both the latest ideas in peer instruction, and multi-media PowerPoint presentations. Our modules (lecture notes) our available to the students on-line. Short movies and other multimedia are now incorporated into almost every lecture.

In this paper we discuss the advantages, difficulties, and limitations of introducing advanced technology in the classroom. First, we will look at the background of the students entering this course. Second, we will review a variety of course designs. Third, we will show how we implemented various teaching tools. Fourth, we consider assessment of these changes. Finally, we will consider future directions.

Student Background

There are three background areas that are of primary concern: the students' physics background, the students' math background, and the students' computer literacy.

About 80% of the students entering this course took physics in high school. In principal this should allow us to quickly move through the introductory material in the course. In practice this is not the case. Interviews with the students reveal that most of the training in high school centers around solving problems by substituting numbers into given formulae. Many often refer to this as the *plug and chug* method of science instruction. Most students entering this course have never been required to think critically, and reason through a given problem. As will be discussed in the next section, high school training does little to change the students misconceptions of the physical world.

The second semester of calculus is a co-requisite for Physics 122. During interviews with the students, most said that setting up the problem was their greatest hurdle, not the math. As instructors, it is apparent to us that at least 25% of the students possess serious mathematical deficiencies. We have not investigated this area beyond student interviews.

We find that computer literacy is not a problem. Even students with no computer background quickly master various skills such as surfing the web, email, bulletin boards, etc. On the first day of class we hand out a sheet of paper with the web address for the course. We also include the location of all the computers on campus. During the first two weeks of the course, the anxiety level of the students who are unfamiliar with the web is quite high. After this introductory period, everyone settles down, and the course operates very smoothly. As of yet, no one failed the course because of computer illiteracy. With computers fast becoming an integral part of high school education, computer illiteracy should be a non-issue in a few years.

Possible Course Designs

Ideally, older professors who have been recognized as model teachers would transfer their knowledge and techniques to new professors. In reality this hardly ever occurs. Professors, old and new, are assigned teaching responsibilities. They decide on a book, read the book and other course material, assign problems, and outline the important topics in lecture. In practice, professors have little time to research the effectiveness of different teaching methods for a specific course. Each professor is left to reinvent the *teaching wheel.* Progress is not passed down from generation to generation. If a research professor started their scientific explorations from scratch without first reviewing the relevant scientific literature, they would be laughed out of their field. Yet most research professors adopt this behavior when it comes to instruction.

In the 1980's Halloun and Hestenes[3,4] published a series of landmark papers that revealed most students enter a first physics course possessing strong beliefs, many of which are misconceptions about common physical phenomena. These notions arise from personal experience. Halloun and Hestenes showed that instruction does little to change these "common sense" misconceptions. Researchers found this to be universal, even for an introductory physics course at Harvard.[5] Subsequent, research revealed that professors who concentrate on conceptual understanding, even if it reduces the number of traditional problems worked during lecture, increases the students ability to solve problems, both conceptual and conventional.[5]

There are a number of ways to increase students' conceptual understanding of the physical world. Making conceptual questions a regular part of the homework and putting conceptual questions on exams is a good starting point. Probably the most effective way to force students to learn the material is to have them work a problem, then describe in 200 words or less using no equations the basic ideas and concepts employed to solve the problem. Most students who successfully solve even simple problems have a difficult time expressing themselves, and many times use incorrect reasoning when arriving at the correct solution. Forcing the students to write allows an instructor to correct misconceptions early. The advantage of this is that bad reasoning skills can be corrected before they become bad habits. The "downfall" of this technique is that it is labor intensive. For this reason we have not implemented this method on a regular basis. Until class size is reduced to 20 or less per instructor, this technique is not an option. This is not even an option during recitation. Most teaching assistants teach a few sections, and have other time constraints on their schedule. Employing this method would also involve a massive teaching assistant training program of incoming graduate students.

A man stands on a scale in an elevator. If the elevator is in free fall, what does the scale read?

a. 2mg

b. mg

c. mg/2

d. zero

Figure 1. An example of a conceptual question.

Another popular method that increases students' conceptual understanding is peer instruction.[5] Here the instructor poses a question (see Figure 1). Students are given time to think, and then students show their answers using flash cards (or vote electronically if the classroom is wired as a smart classroom). Students then spend a minute or two to convince their neighbors that their answer is correct. Students show their answers again. Finally the professor gives the correct explanation.

We were amazed to discover how many students had difficulties with conceptual questions that seem on the surface trivial. It is a humbling experience to discover your students do not understand the basic material.

At the time, Halloun and Hestenes findings were eye opening. Today, many professors at a variety of universities lecture solely on the concepts using the method of peer instruction. We have decided not to adopt such a radical approach. We ask conceptual questions one or two times a lecture, and make it a point to emphasize concepts at other moments during lecture where appropriate.

Instructors face other practical problems. Students spend most of their time learning the material outside of class. Therefore it is important to help the students use this time efficiently. Lectures are much more effective if students are not introduced to the material cold. However, motivating the students to read ahead is not easy. Also, grading homework is time consuming. For a traditional course, assignments are typically returned weeks after they are handed in, if they are graded at all. By that time many students ignore the corrections because they are busy studying for the next exam. Under these circumstances their misconceptions are never addressed, and they carry their incorrect line of reasoning into later courses.

Tools and Implementation

Modern computers and the World Wide Web provide instructors with a variety of educational tools. On-line course management programs allow instructors to give on-line quizzes, give on-line homework, post grades, use bulletin boards, and make lecture notes available. Many course management programs exist. For this course we use WebCT (see Figure 2). (For more information regarding WebCT, visit their page at http://www.webct.com/webct/.)

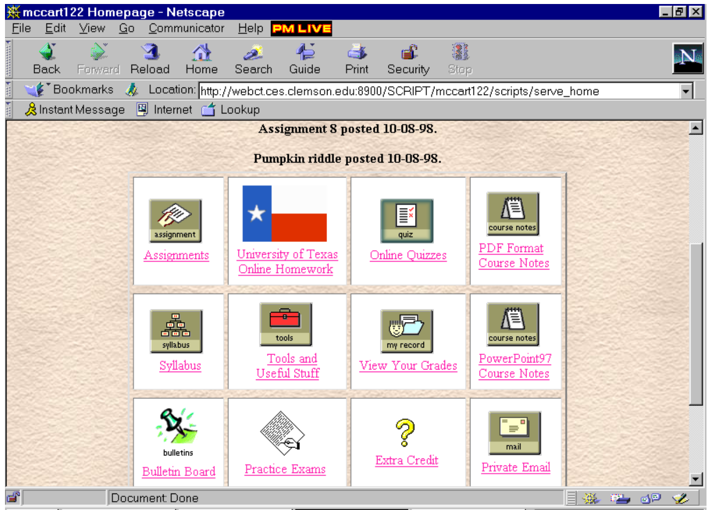

Figure 2. Portion of the Physics 122 Homepage.

Before Lecture

To introduce the students to the course material before lecture, we give on-line reading quizzes. These quizzes are given almost every week (see Figure 3).

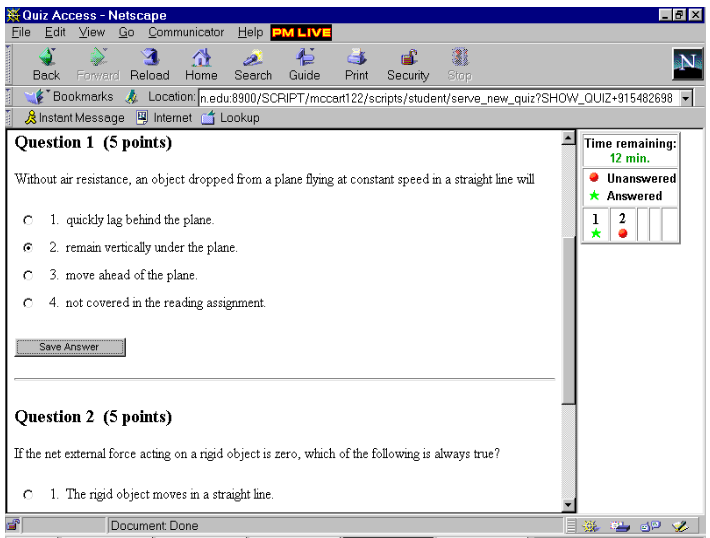

Figure 3. Part of an on-line quiz.

Lecture

Lectures consist of demonstrations and PowerPoint Presentations. The modules (PowerPoint Presentations) are made available to the students via the web. During interviews, we find that 55% of the students print out the lecture notes before class. During lecture they fill in the missing details in the margins. This allows the professor to cover more material than with a traditional board lecture.

One of the major advantages of PowerPoint is the ability to incorporate short movies. Showing NASA trainees inside a plane in free fall drives home the point that the weight of a man standing on a scale in an elevator is zero if the elevator is in free fall. The true power of multimedia is that it helps the students connect the lecture material with real world situations.

After Lecture

Students submit homework electronically using a service provided by the University of Texas. (For more information, visit their website at http://hw.ph.utexas.edu/fm.html.) Part of a typical assignment is shown in Figure 4, and the submission interface is shown in Figure 5. Problems are graded immediately, so students receive instantaneous feedback. To compel students to perform their own work, each student is given a unique set of parameters, so answers are not identical. To make sure that each student understands the material, in addition to the three regular exams and the final, we give three homework exams, where the problems are taken directly from the homework.

At our web page, there is a bulletin board where students can post questions about the homework. The instructor and the teaching assistants check the bulletin board daily, and offer tips on how to get started on various homework problems.

Each student can view his or her grades using WebCT. For each assignment, quiz, and exam, a histogram of the course as a whole is available. This allows students to view their class progress, and compare their performance to their peers. Students who are struggling are encouraged to seek help, either during office hours, or by hiring a tutor.

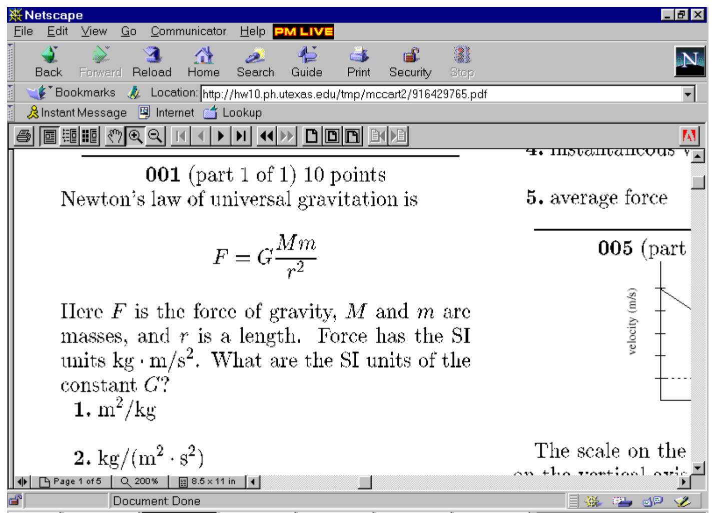

Figure 4. Part of a typical on-line homework assignment.

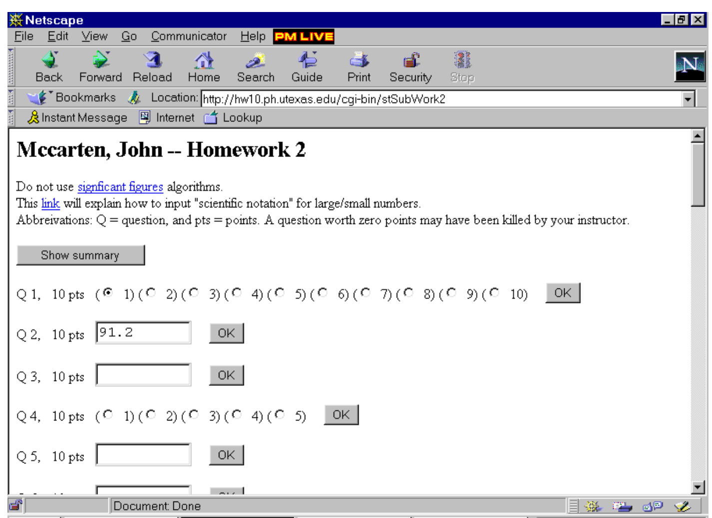

Figure 5. Interface for submitting homework through the University of Texas.

Assessment

Assessing general physics knowledge is difficult. Standardized exams do exist.[5] However, we did not use any of these exams to assess the impact of our changes. In hindsight we should have pre-tested and post-tested two sets of students, where one set takes the traditional course, and the other set the "modernized" course. At this time this is not practical since we have already implemented the changes. There is no incentive to return to the ways of old.

Instead, five weeks into the fall semester of 1998, we interviewed 176 of the 218 students taking the class. 81% said the on-line quizzes force them to read ahead. 81% said they prefer the on-line homework to the traditional method. 87% prefer the PowerPoint Presentations to a traditional board lecture. 97% said the short in-class movies are worthwhile. 99% thought the conceptual questions help them learn the material. 55% print out the lecture notes before class. 93% refer to the lecture notes at some point in time. To our surprise, 92% of the students look at the bulletin board for tips on how to start some of the homework problems.

From these interviews, we also identified a problem that is present for all introductory physics courses. About half of the students spend less than 3 hours per week studying outside of class. At the beginning of the semester, we tell the students to expect to spend 4.5 to 7.5 hours per week. Most students have no excuse. Only 22% of the students work at a job 10 or more hours per week. In our opinion, the lack of time spent by students on the material outside of class explains in part the high drop out/failure rate for this course.

Future Directions

The power of technology as a teaching tool is that it helps students visualize problems, and helps them realize that physics concepts apply to real world situations. We believe this greatly enhances the learning process.

At Dickinson College in Carlisle, Pennsylvania, Priscilla Laws and her collaborators have developed Workshop Physics---a set of instructional materials for a nontraditional learning environment in which lectures, recitations, and laboratories are combined into three hour long sessions.[6] Students work in groups of two to four, with sophisticated computer equipment that permits them to obtain high quality data quickly and efficiently. Studies find that students learn more, and have a more favorable attitude towards science after taking a Workshop Physics course in comparison to a traditional physics course.[2] The downfall to Workshop physics is that it is labor intensive and equipment expensive.

Following the Workshop Physics lead, in the future we would like to implement a series of on-line projects that would accompany the current on-line homework. Using shock-wave movies, Java-enabled computer simulations, and commercial programs like Interactive Physics, these projects would force students to analyze real world situations, and see how different phenomena are affected by a change in parameters. While working through these on-line virtual labs, they would answer a series of questions (using WebCT) about their on-line virtual experiments. If written properly, these virtual labs have the potential to address and correct common misconceptions students have about the physical world, while reducing the labor involved for the instructor.

Besides labor costs, the problem with introducing these on-line projects into the course is one of student time. This is only a 3-credit hour course. The extra time spent on these projects has the potential to overwhelm the students. At Clemson University, the engineering majors are not required to take the accompanying lab. Many of these computer projects belong not in the course, but in the lab because it is in the lab where the students discover that simulations can describe the real world. This is an issue that will have to be dealt with amongst the curriculum committee with attention paid to the new ABET criteria.

Conclusion

In our opinion, using technology wisely greatly improves the introductory physics course for engineers. However, implementing an electronic course page, on-line quizzes, on-line homework, and PowerPoint lecture notes requires much more planning than for a traditionally taught course. Before the first day of the course, we find that a new instructor spends between 20-40 hours familiarizing themselves with all these features. (This does not include course material preparation and the infrastructure development of the PowerPoint lecture notes.) Much of this time investment is quickly recovered with the on-line grading. We should note that the creation of this "modernized" course occurred over the period of five semesters. Features were added each semester. Once the infrastructure is in place, teaching the course requires about 10-15 instructor hours per week during the semester. Most of this time is spent checking the bulletin board, answering student email, and creating quizzes, assignments, and exams. We find that a major advantage of this infrastructure is that it provides a natural mechanism for new professors to learn successful teaching techniques from more experienced professors.

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