Enhancing the Student-Instructor Interaction Frequency

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The number of students attending universities has exponentially increased over the past several decades. In response, departments have systematically converted many introductory service courses from small to large lecture settings. In this environment, a teacher may be instructing hundreds of students at a time, which diminishes his or her ability to provide personalized attention to every student. Worse still, basic teaching activities, such as grading homework and administering in-class quizzes, are usually too difficult to implement on such a large scale.

Without reinforcement provided through daily practice from quizzes and homework, students often fail to develop a comprehensive understanding of the material. This lack of knowledge may remain undiscovered until after the first exam. Poor student performance may leave them demoralized, sometimes enough to drop the course. If the entire class does poorly on the exam, both the students and teacher rightly question the value of such an educational environment.

A stopgap measure introduced by many departments was to create multiple drill or recitation sessions as a supplement to the large lecture classes. Although a smaller class size can be beneficial, this environment is typically designed for the transfer of knowledge instead of interactive personalized attention.

Other innovative strategies for solving the large-lecture dilemma have been developed; however, they have not yet been commonly adopted by universities.[1–4] One strategy uses student-issued flashcards to engage them in question-and-answer sessions during the regular class period.[1] By asking multiple-choice questions and visually tallying the handheld flashcard answers, the teacher determines the knowledge level of the class while the students get feedback about the accuracy of their comprehension. An electronic version of the flashcards, called Classtalk, was introduced about 15 years ago.[3,5,6] Classtalk requires hardwiring each desk with a calculator and tracks each student response using a central computer system. A major advantage of Classtalk over the manual flashcards is that the responses can be graded, thus mandating student participation. Other innovative approaches utilize the Internet to enhance the educational process. One such method, Just-In-Time Teaching (JITT), requires students to answer pre-class questions, which the teacher uses to appropriately plan the upcoming lecture, allowing the students to have some limited control over the pace of the course.[4]

In this article, we describe a teaching technology that is an all-digital, cost-effective solution to the problems described above. Generally, this technology provides a vehicle for mandatory, personalized student

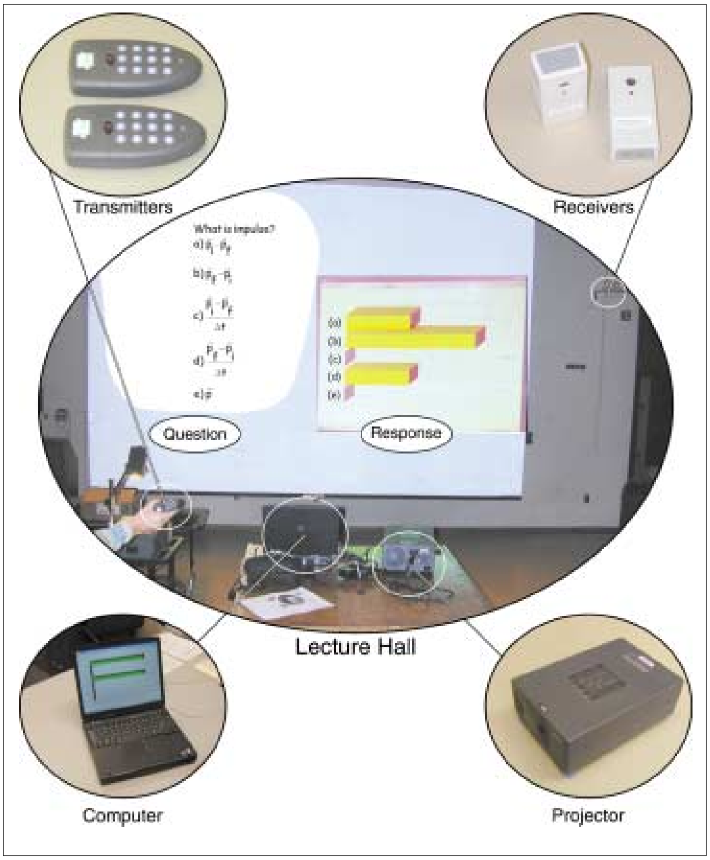

Fig. 1. Classroom layout and hardware necessary for implementing the teaching technology. (Center) Classroom setup with question and responses. (Upper left) Handheld transmitters. (Upper right) Infrared receivers. (Lower left) Laptop computer. (Lower right) Projector.

engagement, and we report that it also creates a better learning environment in a large-lecture setting while simultaneously reducing operating costs.

Experimental

The goal of this article is to illustrate the mechanics of this technology and to show that it is an efficient method for significantly increasing the personalized student-teacher interaction frequency. This article is *not* intended to show that increasing the interaction frequency results in a better education; however, this is an underlying assumption.[7]

This study was carried out over two semesters on approximately the same 200 undergraduate students enrolled in an algebra-based physics course sequence. The first semester, covering Newtonian mechanics, was used as the control group (i.e., the teaching technology methodology was not integrated into the course). The second semester, covering electricity and magnetism, used the technology as part of the course grading scheme. Thus, we were able to compare with-and-without results on the same set of individuals. Over two semesters, we tracked the following activities, which are considered core factors in determining student performance: attendance, pre-class preparation, in-class participation, homework completion, and exam scores. The following paragraphs discuss the data-collection method for the control semester, as well as the experimental setup and data-collection method for the technology-based semester.

For the control semester, we quantified attendance by counting the number of students in the classroom and dividing by the number registered for the class. The exam scores reported represent an average score based on four exams given during the semester. To measure pre-class preparation, in-class participation, and completion of the homework, we used two polling methods. First, anonymous, voluntary questionnaires were distributed at the beginning, middle, and end of the semester. Second, throughout the semester, voluntary personal interviews were conducted with the students.

For the second semester using the teaching technology, the lecture portion of the study was performed in an auditorium with a seating capacity of 450; the in-class setup is shown in Fig. 1. To administer the in-class quizzes, an overhead projector was used to display a multiple-choice question. Students responded by pressing the appropriate number on their commercially available, handheld transmitter while aiming at a wall-mounted receiver.[8] The receiver collected the signal, and a computer displayed the transmitter's unique ID. When all the responses were received, a histogram showing the class response was displayed. To track the percentage of students attending class, we tallied the number of electronic responses and divided by the number registered for the class. To monitor pre-class preparation, before starting a new chapter students were asked one question that could be answered only if they had read the material prior to class. Percentages were calculated by counting the number of correct responses and dividing by the number of students attending that particular lecture. To examine the percentage of students participating, we tallied the number of electronic responses and divided by the number of students attending that lecture.

In order to encourage participation, we tethered each transmitter's ID to the student's ID and graded their quiz responses. Specifically, two points were awarded for a correct answer, one point for an incorrect answer, and zero for no answer. In order to ensure accurate data collection, students were not allowed to use any transmitter but their own. To encourage students to adhere to this policy, they were repeatedly warned that having more than one transmitter constituted cheating, which is a violation requiring referral to the university's judiciary board. In addition, headcounts were randomly performed throughout the semester to confirm that they corresponded to the same number of recorded transmitter responses.

With a goal of fostering peer instruction, special attention was given to the manner in which we asked in-class questions. On occasion, the students were asked a multiple-choice question and required to come up with an answer on their own. After the student responses were received, the teacher displayed the histogram. Depending on the results of the histogram, the teacher would either move on to the next topic or ask the students to reconsider their answers and try to convince their neighbors to agree with their responses. This algorithm of student-to-student teaching, or peer instruction, has been shown to be an extremely effective educational tool.[9] Note by showing the uniformly distributed histogram to the students before implementing peer instruction, one communicates that the majority of students have an erroneous thought process, consequently triggering a mindset in the students that they must critically reconsider their answers.

The study also utilized the Internet outside of class.[10] On the class website, students access general class and grade information, as well as answer quiz questions (as shown in Fig. 2). Chapter homework sets were assigned to the students, and the answers (not step-by-step solutions) were posted on a public web- site. Three multiple-choice qualitative questions and 10 fill-in-the-blank quantitative questions were assigned per chapter. These same problems were then modified and used as a web quiz as a way of collecting homework. The qualitative problems were reworded, while the quantitative problems used a random number generator to give each student a unique set of input parameters (see upper-right panel in Fig. 2). For this study, only the percentage of students who submitted the web quiz is reported. To encourage participation, the answers to the homework questions were graded and used as part of the overall course grade. Each correct answer was worth one point, while wrong or missing answers were worth zero points. After the allotted time period for taking the quiz expired, the students were able to retrieve complete solutions (see lower-right panel in Fig. 2) and practice other randomly generated quizzes on the public website, with no impact on their grade.

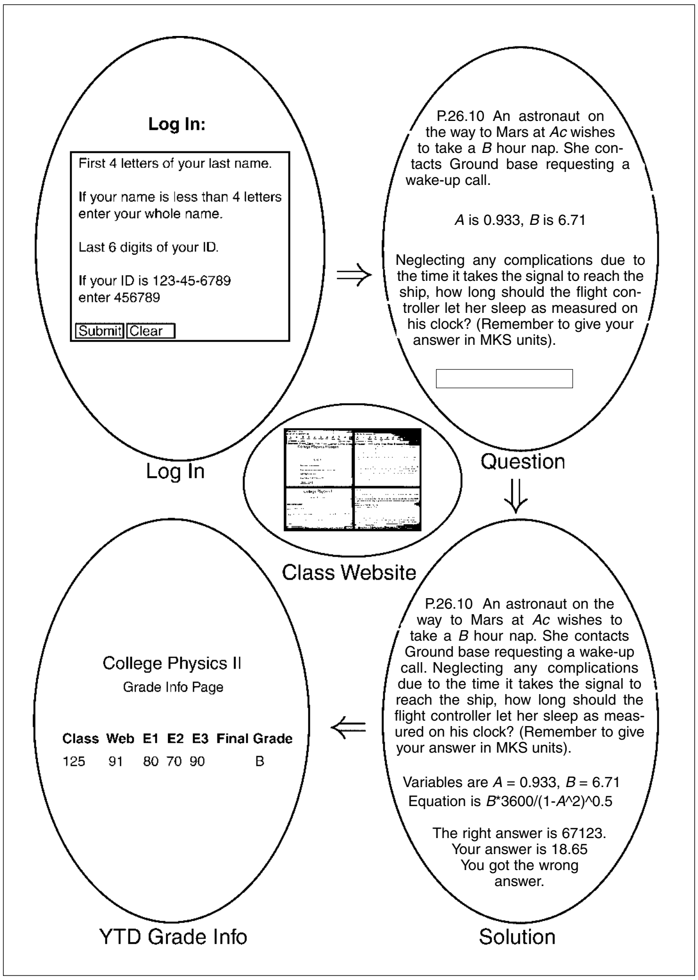

Fig. 2. Schematic diagram showing the class website layout and features necessary for implementing the teaching technology. (Center) Photograph of computer monitor with various webpages displayed. (Upper left) Student log in webpage layout. (Upper right) Example web quiz question. (Lower right) Solutions to the example web quiz question. (Lower left) Personalized year-to-date grade information.

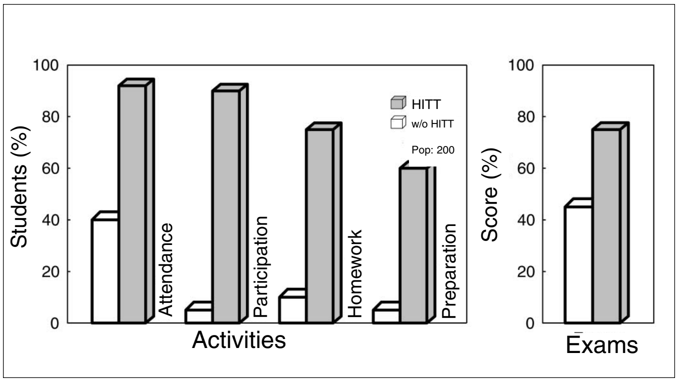

Fig. 3. Results of tracking student activities. (Left) Percentage of students participating in core course activities both with and without the technology. (Right) Average exam scores with and without the technology. We estimate all errors to be ~10%.

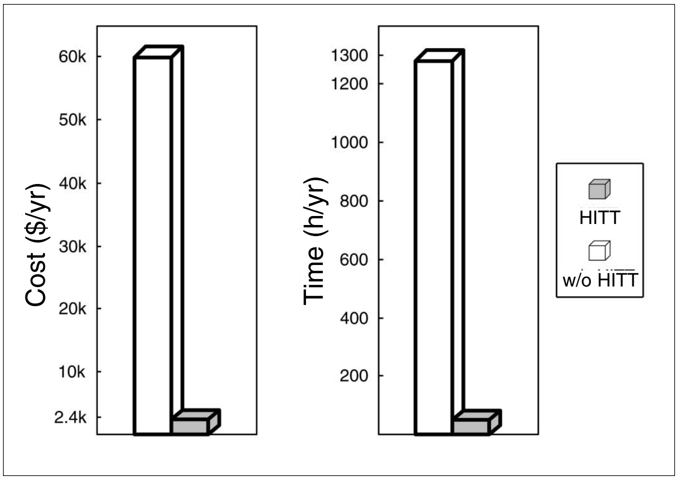

Fig. 4. Results of tracking expenditures. (Left) Monetary expenditure comparisons with and without the technology. (Right) Time expenditure comparisons with and without the technology.

The monetary and time expenditures for both semesters were also tracked, as these are crucial in considering whether or not to implement any curriculum. In general, our large lecture class is allocated two graduate teaching assistants (TAs) per year, which cost the department ~$60,000. The all-digital nature of this approach allowed us to teach the course without requiring graduate TAs for grading purposes. Instead, these TAs could be utilized in different roles to help the students (i.e., one-on-one tutoring, homework help sessions, etc.). The in-class technology approach required hardware (computer, projector, receivers, and cart) at a cost of $8,000 and a web server with supporting software at a cost of $4,000. Note most institutions currently provide a web server and software for teaching. The transmitters cost $50 each, so for 200 students, $10,000 is required. By negotiating with the university bookstore to sell and buy back the transmitters (in a manner similar to that of textbooks), we were able to relieve the department of the financial and administrative burdens associated with purchasing and distributing the transmitters. This approach was very effective and reduced our setup costs considerably.

Results

The results of tracking the five student activities are shown in the left panel of Fig. 3. Each category compares the percentage of students both before and after implementation of the technology. Across all five categories, significant improvements were realized as a result of implementing this technology. For example, attendance increased 130%, class participation increased 1,700%, and pre-class preparation increased 1,100%. Equally important to the in-class activities are the out-of-class activities. Here, we observed that the number of students now completing the homework has increased 650%. Finally, the average exam score improved significantly. The average increased from a score of 45% to a score of 75%, a 70% gain.

Monetary and time investment comparisons are shown in Fig. 4. The annual monetary and time costs to run a large lecture class taught in the traditional manner is $60,000 and 1,280 hours, respectively (due to graduate teaching assistant personnel costs). The annual monetary cost for the technology-based approach is $2,400 (we estimate the lifetime of the hardware at five years). The annual time investment for the technology-based approach is primarily due to web database management (i.e., data entry and error testing), which is estimated at 50 hours per year. The monetary and time cost differences resulted in significant savings. Over a five-year period, an estimated monetary savings of $300,000 will be realized, as well as a time savings of 6,150 person-hours.

Discussion

Previous studies have shown that increasing the student-teacher interaction frequency enhances student performance.[1,2,7,11] Traditionally, the method most commonly used to achieve this frequency enhancement has been to decrease the student-to-teacher ratio, which can be expensive or even unfeasible. The use of flashcards is an inexpensive way to increase the student-teacher interaction frequency; however, due to its voluntary design the participation is limited and the responses can be inaccurate. In contrast, the all-digital approach mandates student participation because the responses are graded. This is critical to realizing significant increases in student participation and accurate feedback.

A flowchart showing the relative weight and frequency of the three student-teacher interaction forums is shown in Fig. 5. A large lecture class taught in the traditional manner typically relies solely on periodic exams for providing feedback (lowest forum on flowchart). These exams are usually administered every four weeks and worth 100 points. Often the feedback received from these exams is too late and too harsh to be of benefit. The remaining two forums, in-class quizzes and homework, are major components of the technology-based semester, and their frequency is specified relative to the exam. The frequency of the in-class component is approximately 100 times greater, and we made the point total equal to the exam. This provides interaction without severe grade consequences, shifting the student's focus from grades toward learning. The frequency of the homework is four times greater than the exam frequency, and again we made the point total the same as the exam. These added feedback elements result in an increase in the interaction frequency by more than 100 times, or two orders of magnitude. Note, without the technology the students only get one graded response (i.e., the exam) every four weeks, whereas with the technology they're getting at least 100 graded responses.

During the semester without the teaching technology, the students were repeatedly encouraged to read the book and do the homework so they could perform well on the exams. Nevertheless, the students consistently demonstrated that they were unmotivated to do these activities, and would only put time into the course just prior to an exam. This is consistent with the exam scores being very low without the technology. After implementation, a significant increase in the exam scores was recorded. We interpret this to mean

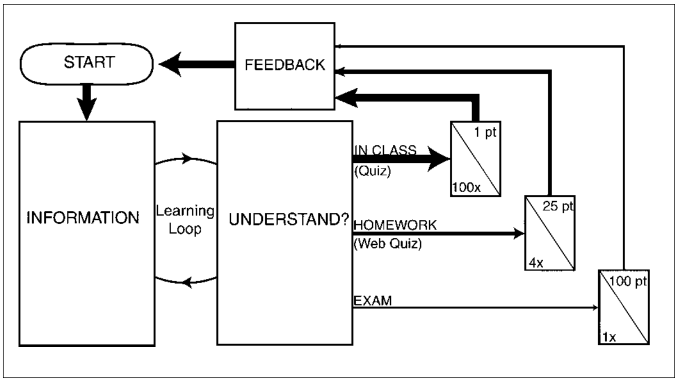

Fig. 5. Flowchart showing the introduction of new material, questioning process, and three possible forums for providing feedback, along with their frequency and grade value.

that without the technology, the students were in fact not reading the book and doing the homework (as reported by the limited number of students polled). The significant gains in all the student activities are assumed to be a direct consequence of placing a portion of the students' grades on each activity. Another major problem with a class of this size is a lack of attendance. Worse still, a majority of the students that are attending passively take notes rather than actively engaging themselves in the material. Both of these problems are naturally solved with this technology by giving students a reason to attend class and participate (i.e., the point values assigned to these activities). More significantly, to answer the in-class quiz questions correctly, the students must engage themselves with the lecture in order to solve problems in the classroom. Furthermore, the teacher can enhance learning by asking questions that test whether the students have read the material before class, or whether they have a qualitative or quantitative understanding of a particular concept.[12]

With a class of this size, it is also difficult to monitor whether or not the students are solving the homework problems. This technology addresses this issue by requiring the students to log onto the website, answer the homework questions, and receive points based on the number of correct answers. In addition, a surprising consequence of the Internet-based homework collection was that the students were forced to revisit each homework problem. Often students may struggle to find an answer to a problem, yet never rework it to find the most elegant or simple solution.

By knowing that this question will be given to them again, but with new numbers, the students naturally revisit the question. We believe this was a critical consequence of the technology-based methodology. Furthermore, since the quantitative quiz problems are the same as the homework problems, except for the random numbers, there is also a strong motivation to solve the problem algebraically.

Probably the biggest benefit of this technology, from the students' perspective, is that they gain control of the general pace and direction of the course. The pace at which topics are covered is a direct result of the feedback the students give the teacher. For example, if half the class gets the wrong answer during an in-class quiz, the teacher is alerted that more time must be devoted to that topic. If a large majority of the class answers the question correctly, the teacher can spend less time on that topic. Therefore, the teacher is forced to utilize the class time efficiently and naturally address student comprehension problems. These attributes were realized by JITT and hailed as a major breakthrough.[4] This technology reaps these same benefits without the time delay between the student-generated responses and the teacher's feedback. As the students and teacher interact more frequently, the learning process becomes less dependent on the experience and poise of the teacher. Furthermore, the anonymity of the technology allows students to participate without concern of being embarrassed. These features are important in effective communication; therefore, we believe this technology should be implemented in courses regardless of their size.

It is true that a significant increase in the student-teacher interaction frequency can be achieved by employing more people. However, we estimate that without this technology, one teaching assistant for every five students would be necessary for managing, collecting, and grading the multiple daily quizzes and weekly homework sets (although even with this increase in personnel, the live reporting of the distribution of answers would not be possible). This additional labor would increase the annual monetary and time costs to ~$2.5 million and 7,680 hours. Clearly, despite the benefits, such an expense is not feasible. The all-digital nature of this technology results in an overall enhancement in productivity and allows an institution to provide a better educational environment while reducing personnel costs.

Most people would agree that the best way to learn something is to try and teach someone else. This technology makes peer instruction more effective by mandating participation. That is, since each student's grade is involved, there is naturally a sincere effort applied to the student-to-student teaching.[9]

The large amount of data made available by this technology creates a powerful tool for studying the pedagogical process. Many opportunities become available, including studying the time required for the students to answer in-class questions. A histogram of the number of right and wrong answers in time may provide insight into properly coaching the students on how to enhance their learning process. In addition, one can study the responses when answered individually or after a group discussion. Furthermore, one may determine the proper time during a lecture series to inject new information, which yields maximum educational gain. This allows one to quantifiably compare various teaching strategies, such as linear information injection versus spiral, and determine the effectiveness of each method.

Conclusion

By integrating in-class and Internet technologies into a large lecture course, attendance, in-class participation, pre-class preparation, and the number of students attempting the homework increased dramatically. Furthermore, the overall average exam scores increased significantly. The implementation of these technologies also resulted in a net monetary and time savings. Overall, the all-digital nature of these teaching tools was responsible for these enhancements and savings.

Acknowledgments

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References

1. D.E. Meltzer and K. Manivannan, "Promoting interactivity in physics lecture classes," *Phys. Teach.* **34**, 72–77 (Feb. 1996).

2. R.A. Burnstein and L.M. Lederman, "Using wireless keypads in lecture classes," *Phys. Teach.* **39,** 8–11 (Jan. 2001).
3. R.J. Dufresne et al., *J. Comput. High. Educ.* 7, 3 (1996).
4. G.M. Novak, E.T. Patterson, D.G. Andrew, and W. Christian, *Just-In-Time Teaching: Blending Active Learning with Web Technology* (Prentice Hall, Upper Saddle River, NJ, 1999).
5. J. Poulis, C. Massen, E. Robens, and M. Gilbert, "Physics lecturing with audience paced feedback," *Am. J. Phys.* **66,** 439–441 (May 1998).
6. A.L. Abrahamson, in *International Conference of the Teaching of Mathematics* (Wiley, New York, 1998), p. 2.
7. R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64–74 (Jan. 1998).
8. There are several manufacturers of in-class polling systems, and the authors do not wish to advertise any one of them.
9. Eric Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, Upper Saddle River, NJ, 1997).
10. The web software used for this study was developed by an independent contractor; however, there are several commercial products available.
11. P.W. Laws, "Calculus-based physics without lectures," *Phys. Today* **44**, 24–31 (1991).
12 B. Thacker, E. Kim, K. Trefz, and S.M. Lea, "Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses," *Am. J. Phys*. **62,** 627–633 (July 1994).