2008-2009 Alumni Class Funds Project: Bringing Interactive Learning to 8.012 Lectures

Adam Burgasser

Associate Professor

MIT Kavli Institute for Astrophysics and Space Research

Department of Physics

I describe the implementation and assessment of interactive learning techniques incorporated into the Fall 2008 8.012 Physics I (Classical Mechanics) course. Roughly 30 new mechanics concept questions and modules for peer instruction were developed as part of this program to match to the advanced level of the 8.012 students. These modules, intermixed with traditional lecture, were paired to personal response systems (PRS) that allowed anonymous voting and provided both the students and the instructors real-time assessment of conceptual proficiency. Questions polled more than once in a given session demonstrated an average improvement in short-term conceptual understanding, albeit positive conversion (net gain of correct over incorrect responses) was not universal. I also find a weak but positive correlation between PRS participation and improvement in exam scores. Assessment of overall conceptual gain using the Mechanics Baseline Test proved ambiguous due to the high initial scores of the students, comparable to post-peer instruction proficiency in the literature. The concept modules developed as part of this program have been packaged for easy adoption by future (typically junior and inexperienced) instructors, although it is suggested that alternative polling methods, such as paper flash cards, may address student's cost concerns and improve class participation without loss of instructor assessment.

Background

Traditional lecture—a single instructor presenting material to a class of students—is a well-established, widely-utilized and generally popular format for undergraduate education, particularly in introductory physics. Yet its fundamental flaw is its lack of interactivity between instructors, students and the course material. The generally passive learning environment of traditional lectures leads students to disengage or simply not attend class. Instructors find it difficult to assess the level of comprehension and retention of students' knowledge in real-time and adjust lecture accordingly ("contingent teaching"; Wood et al. 1978). These problems are exacerbated for junior instructors who are generally inexperienced and often unfamiliar with modern teaching methods; and for first-year students who may feel uncomfortable or intimidated in their new university environment. Even simple methods of engagement in a lecture environment, such as posing general questions to the class, cold-calling and show-of-hands or flash-card polling, can be ineffectual and difficult to quantify if students feel negative social pressure or are simply unmotivated.

In recent years, innovations in introductory physics education have focused on peer instruction techniques and technology-enabled learning methods. Peer instruction is a method by which students "teach each other" through collaborative in-class projects and peer discussions, thereby reducing periods of passive lecture (Lyman 1981; Mazur 1997, Crouch 1998). These activities can be facilitated by technology-enabled learning techniques, such as computer-aided/internet-based exercises and quizzes and/or in-class student personal response systems (PRS; e.g, Novak et al. 1998; Draper & Brown 2004). At MIT, peer instruction and technology-enabled learning have been combined with specially-designed teaching laboratories in the *Technology Enabled Active Learning* (TEAL) program, now encompassing the mainstream 8.01 and 8.02 introductory physics course. TEAL has demonstrated measurable improvements in students' conceptual learning of mechanics and electricity and magnetism (Dori & Belcher 2003).

Despite its obvious success, TEAL is not—and indeed should not be—the sole teaching format available for students in introductory physics. Multiple teaching formats cater to a broader range of student abilities and learning skills, and traditional lecture classes provide important venues for training junior instructors. It is nevertheless essential to address the fundamental lack of interactivity present in a traditional lecture, and any solution to this problem should be easily adoptable by junior instructors with limited teaching experience.

In 2008, I was awarded funding from the MIT Classes of 1951, 1955, 1972 and 1999 to incorporate interactive teaching methods into the first-year MIT introductory physics course, 8.012 (classical mechanics). This advanced, calculus-based course, part of the MIT curriculum for nearly 40 years, is designed for the brightest and most engaged first-year students at MIT who score sufficiently high on the Physics placement exam and/or AP Physics exam to qualify for enrollment. This course is also commonly taught by junior Physics faculty as part of the department's demonstration teaching requirements. As junior faculty (including myself) frequently come to MIT with little or no teaching experience, and are under concurrent pressure to build up their research groups, apply for grants, and generally meet expectations for tenure, it is no surprise that we tend to revert to traditional and familiar lecture-style formats. It was therefore my goal to introduce interactive teaching methods to 8.012 that could function in a lecture environment and be easily adopted by future instructors.

Implementation

Educational Objectives

The 8.012 interactive teaching project was motivated by four education objectives:

- Increase interactivity and engage 8.012 students in lecture through the use of concept questions coupled with PRSs;
- Facilitate student self-assessment in lecture through instant feedback and peer instruction;
- Facilitate contingent teaching through real-time feedback on students' conceptual problems and supplementary example modules; and
- Make lecture enhancements easily adoptable and adaptable for future junior (and senior) instructors of 8.012.

These objectives were fulfilled primarily by introducing concept question modules matched to PRS voting systems into the 8.012 lecture. I describe the design of these modules and their implementation below, along with steps for assessing the students' gain in conceptual understanding.

Concept Questions

TEAL and other introductory physics courses employing interactive learning techniques have developed vast concept question libraries, notably the ConcepTests designed by Eric Mazur and presented in *Peer Instruction: A User's Manual;* and Project Galileo (http://www.seas.harvard.edu/galileo). However, based on my experience teaching 8.012 over 2005-2007, it was clear to me that most of these ConcepTests were too basic to sufficiently challenge the students. I therefore set out to design a suite of more advanced concept questions and series of questions (modules) targeted for 8.012.

The design of these questions was based on two methodologies; first, the three-question modules described in Raey et al. (2005), in which a students' understanding of a given concept is evaluated by asking three related questions of increasing complexity. The first question in a sequence is used as a warm-up and, assuming the students are prepared, should be relatively easy and result in near-universal agreement. The second question is considerably more challenging and designed to create an impasse to preconceived ideas, a technique that has been shown to enhance conceptual learning (VanLehn et al. 2003). The third question is increasing more difficult but reinforces the impasse, providing a gauge as to whether the concept has been successfully learned. Raey et al. (2005) have demonstrated that this method is particularly efficacious for introductory physics courses.

The second methodology are challenge questions targeting a concept discussed during lecture. These are meant to reinforce the lecture, but are aimed to be sufficiently challenging to produce a broad range of initial responses, which the students will resolve through peer discussion. Challenge questions are not meant to be "trick questions": explicitly misleading, obtuse or algebraically complex. As emphasized in Crouch & Mazur (1991), they should push the limit of a student's perceived understanding of a newly acquired concept.

The purpose of concept questions in class is to stimulate peer instruction, whereby the students—with minimal direction from the instructor—validate their conceptual reasoning and argue their perspectives with their peers. A typical sequence employed in the 8.012 lectures is as follows: a concept question is poised and the students are polled. If the results show near-unanimity for the correct response (say >65-75%) then the lecture moves on to the next topic. If there is a broader mix, then students are instructed to “convince their neighbors” of their solution by explaining their physical reasoning. The students are then re-polled to see if there is a change in the overall consensus. If a disparity remains, additional tactics such as advocacy (having individual students advocate for their given answers), ruling out incorrect options (if votes are split between three or more choices) and as a last resort guided discussion (steering students to the appropriate concepts) are used. As described in the Assessment section below, the students by and large arrive at the correct conceptual idea with little or no input from the instructor. In some cases the polling is coupled to a demonstration to provide a visual proof of concept (Mayer et al. 1996).

In addition to the in-class concept discussion questions, concept questions were incorporated into the three semester quizzes and final exam, typically accounting for 10-20% of the overall exam grade. These exam questions frequently reflected or reproduced the in-class discussion questions.

The concept questions and modules developed in this program and deemed successful for in-class discussions and exams are provided as a supplementary document to this report; their implementation is discussed in further detail below.

PRS System

The PRS technology selected for this program was the TurningPoint “clicker” developed by Turning Technologies (http://www.turningtechnologies.com). This system incorporates radio frequency (RF) wireless response cards purchased by the students ($50 at the MIT COOP), which transmit data to a single USB base station receiver ($99) connected to the instructor’s laptop computer (Figure 1). Each student's card is uniquely identified by an ID number, which can be associated with the student's name for tracking attendance and performance diagnostics, or left anonymous for the type of analysis presented below. Software running on the instructor's laptop is used to initiate polling, maintain voting lists, and produce reports, and is independent of the software used to display course material (e.g., Powerpoint, PDFs, etc). Results are shown in real-time after every poll, allowing instant feedback to the class and instructor while keeping individual responses anonymous. The Turning Technologies system has been used in

Figure 1: Turning Technologies wireless response card model RF (right) and receiver base station (left).

introductory courses in the Sloan Business School, Aero/Astro, Chemistry and Physics (TEAL) over the past few years time, and was also implemented in 8.01L (lecturer Paul Schechter) concurrently with 8.012 during the Fall 2008 term. The common usage of TurningPoint has allowed us share implementation strategies, and students were able to use their RF cards for multiple classes.

One of the drawbacks of portable electronic PRS systems such as TurningPoint is the tendency for students to lose their response cards or forget to bring them to class; prior studies have noted a 25-35% "non-participation" rate on any given day (e.g., Draper & Brown 2004). Some educators have solved this problem by providing PRS cards in class or having response units mounted to the seats. For this implementation, the former solution was prohibitively costly (~$3500 for 100 students at bulk rate purchase) while the latter even more costly and unlikely to be permitted in the near term. So students were responsible for purchasing their own cards and incentivized to bring them to lecture by making response attendance (but not accuracy) 2.5% of their final grade, equivalent to one problem set. As discussed below, this strategy did not appreciably increase the participation rate over prior years, and despite its small contribution a point of contention with some of the students.

Evaluation and Assessment Tools

In addition to the concept questions and modules and end-of-term student evaluations (see below), I planned to use the *Mechanics Baseline Test* (MBT; Hestenes & Wells 1992) to assess to efficacy of interactive elements introduced into 8.012. This standard test of classical mechanics concepts is slightly more advanced than the commonly used *Force Concepts Inventory* (FCI; Hestenes et al. 1992; Halloun et al. 1995), specifically testing concepts that require some formal knowledge about mechanics. The MBT was administered in the first week of the term to assess the students' baseline understanding, and students were obliged to take the test in order to remain enrolled in 8.012 (this requirement was later relaxed as it became evident enrollment was well below previous semesters). The MBT was also administered during the final exam in order to assess gain in conceptual understanding. Incidentally, the MBT was concurrently administered in 8.01L and 8.01, allowing for a (future) cross-comparison of MIT introductory physics learning performance for students over a range of ability levels.

Assessment of Program

The Fall 2008 8.012 Class

Before examining the impact of the interactive teaching techniques on 8.012, it is worth reviewing the general characteristics of the class during the Fall 2008 term. A syllabus is provided in Table 1. There were 22 full lectures interspersed with 3 in-class quizzes and a final lecture period devoted to the presentation of class projects (an additional interactive element not discussed in this report). Lectures were conducted 9:00-10:20am on Tuesdays and Thursdays in the 6-120 lecture hall. Students also attended one-hour recitation sections

Table 1: Syllabus of 8.012 in Fall 2008		
Lecture	**Date**	**Concepts covered**
1	4 Sep	Intro, vectors, superposition, change in vectors, coordinate systems
2	9 Sep	Position->velocity->acceleration, ballistic motion, rotating coordinate systems
3	11 Sep	Newton's Laws: concept of inertia, F=ma, action-reaction, application of laws (static vs mechanic)
4	16 Sep	Application of Newton's Laws, atwood machine, types of forces, strategies
5	18 Sep	Spring force, pendulum (approx), friction
6	23 Sep	Friction, viscosity, gravitation
	25 Sep	QUIZ
7	30 Sep	Definition of momentum & Newton's laws, system center of mass, p conservation, impulse
8	2 Oct	Elastic & inelastic collisions, mass flow, momentum transport
9	7 Oct	Rocket equation (approximation)
10	9 Oct	Energy definition, work-energy theorem, conservative & dissipative forces, conservation of energy
11	14 Oct	Energy diagrams, stability and small oscillations
12	16 Oct	Collisions and center of mass formalism, power
	21 Oct	QUIZ
13	23 Oct	Angular momentum (motivation), torque, conservation of L
14	28 Oct	Total angular momentum, moment of inertia, parallel axis theorem
15	30 Oct	Rotation and energy, rotation and translation, gyration radius
16	4 Nov	Angular velocity vector, skew rod, I tensor
17	6 Nov	Gyroscopic approximation
	11 Nov	NO CLASS
18	13 Nov	Precession & nutation, Euler's equations
19	18 Nov	Review of rotational motion
	20 Nov	QUIZ
20	25 Nov	Cavendish experiment
	27 Nov	NO CLASS
21	2 Dec	Fictional forces, translationally accelerated reference frames, rotationally accelerated reference frames
22	4 Dec	Equivalence principle, Mach's principle, nature of gravity and inertia, Kepler's Laws
23	9 Dec	Review central force motion, class project reports

Table 1: Syllabus of the 8.012 course in Fall 2008

on Mondays and Wednesdays led by George Benedek, Saul Rappaport and Martin Zwierlein. In addition to exams and class projects, students were required to turn in weekly problem sets drawn primarily from the course's main text, *An Introduction to Mechanics* by Kleppner & Kolenkow. There is no lab currently associated with 8.012. A total of 88 students were enrolled in 8.012 at the end of term, down from 96 at the time of the first exam (prior to Add day) and roughly 30%-50% below previous two semesters.

Note that the introduction of concept modules and peer instruction, which typically occupy 5-15 minutes of lecture time per question depending on the level of discussion, reduced the total time available for lecture through the semester. Hence, some topics covered in prior semesters (e.g., central force motion, special relativitiy) were not covered in Fall 2008. This is an important consideration for anyone planning on introducing concept questions into their lecture-based curriculum.

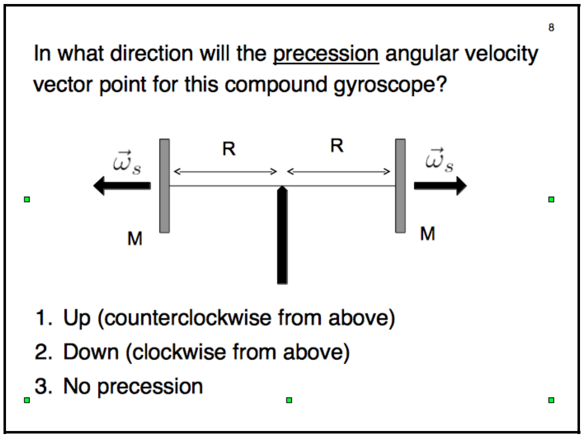
Conversion Rates in Concept Modules

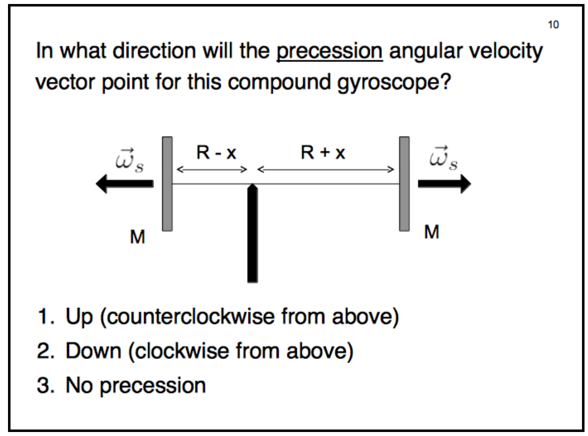
An important component of conceptual learning for students is the effectiveness at which they are able to recognize gaps in understanding and confront these in the framework of peer interactions. Conversion between incorrect conceptual thinking to correct understanding (or vice versa) is a proxy for assessing the short-term efficacy of concept questions (e.g, Raey et al. 2005), and can be measured as conversion rates for questions polled multiple times. For many of the questions used, a large majority of students chose the correct answer on the first poll, obviating the need for additional discussion (note that no question was answered correctly by 100% of the classroom). However, eleven of the concept questions had sufficiently mixed responsse on initial polling to warrant peer discussion, and it is these questions that allow assessment of conversion rates.

Before delving into these rates in detail, I first describe a couple of case to illustrate how students converged (or didn't) on the correct conceptual result. A question posed in Lecture 11 is shown in Figure 2, and is a ConcepTest originally from Mazur's *Peer Instruction*. The purpose of this question was to test the students' understanding of dissipative energy loss as it relates to kinetic motion. Upon first polling, 68% of the students chose answer 2 and 16% choose answer 3. The class was then instructed to discuss their answers with their peers without any further input from me. A second poll showed a shift of the majority to answer 3 (52%). The students were then asked to advocate for their answers, resulting in a lively debate during which the concept of dissipative energy loss was brought up. A third poll showed that the vast majority of the class (79%) had switched to the correct response, answer 3, corresponding to a conversion rate of 65% of the class from incorrect to correct response. Importantly, at no point in this exchange did I provide any input on the science concept or correct response..

> A stone is launched upward into the air. In addition to the force of gravity, the stone is subject to a frictional force due to air resistance. The time the stone takes to reach the top of its flight path is
>
> 1. larger than
> 2. equal to
> 3. smaller than
>
> the time it takes to return from the top to its original position.

Figure 2: Sample concept question, based on a ConcepTest developed by Mazur (1997).





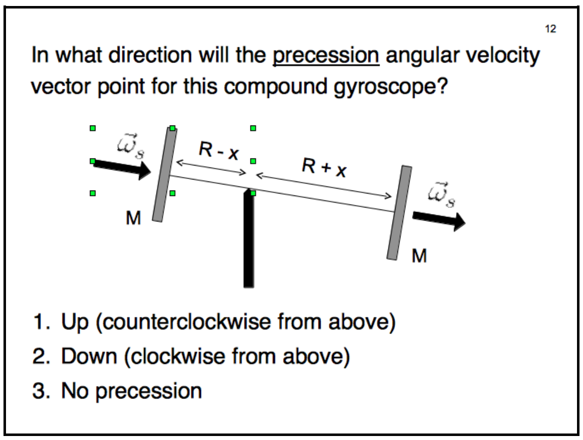


Figure 3: Concept module on gyroscopic motion, testing the students' understanding of net torque and angular momentum in precessional motion. This sequence proved to be challenging for the students, with the upper right panel polling 94% incorrectly.

A second example, a three-question module aimed at testing the the students' understanding of gyroscopic precession (Figure 3), illustrates the use of greater class facilitation. In the first question, students were asked to determine the precession direction (if any) of a compound gyroscope made up of two identical masses each spinning at the same rate in opposite directions and equally balanced on a pivot point. The first poll was quite evenly split, with votes of 49%, 19% and 32% for counterclockwise, clockwise, and no precession, respectively. The students were again asked to discuss their answers with their neighbors, but this only served to polarize the results even further: a second poll yielded 53% for counterclockwise precession and 42% for no precession (clockwise precession was all but ruled out). After advocates led a discussion with strong opinions on both sides, it was clear that the students were entrenched, so I provided the solution (no precession) and pointed out the key concepts of the problem: that the total spin vector and hence total angular momentum vector of the gyroscope is zero, so that there is no net force and no net torque acting on it. The follow-on question added a slight variation with the gyroscope set slightly off-center of the pivot. In this case the response was nearly unanimous with 94% voting for counterclockwise precession. Unfortunately, this was incorrect, and with few advocates to argue against it I again had to reveal the answer and explain how net torque in the absence of net angular momentum would simply tip the gyroscope over. The third question switched the direction of rotation of one of the wheels so that both criteria for precession were satisfied, and 95% answered correctly.

This example illustrates how, on occasion, one must lead students through a particularly challenging impasse to their conceptual knowledge. More importantly, this question revealed a conceptual problem that might have otherwise been missed. Fortunately, the extreme nature of the voting results left a profound imprint on the students' understanding of precessional motion, and later tests revealed a high level of retention.

Figure 4 shows a subset of the concept questions that required multiple polling, illustrating the fairly broad range of trends encountered. Students on alternate occasions converged to correct responses after peer discussion (high rates of incorrect to correct responses), retained incorrect conceptual views (high rates of incorrect to incorrect responses) and even changed their correct responses to incorrect ones after peer discussion (high rates of correct to incorrect responses). However, of the eleven concept questions re-polled, ten showed a net gain in correct responses in the second poll, including two cases where the incorrect answer was initially more popular. Indeed, on average students overcame a majority in favor of an incorrect answer on the first poll to a majority in favor of the correct answer on the second poll. In no case was an initially popular correct answer overturned. These statistics demonstrate how students' peer discussions are reasonably effective in guiding their conceptual learning.

Mechanics Baseline Test Results

Positive conversion rates in multi-polled concept questions is only a measure of short-term conceptual gain; long-term concept retention must be assessed through other methods, in the case the MBT results. Comparison of scores between the beginning and end of the term show only a modest rises, however. Of 73 students who took both exams, the average score changed from 19.3 to 20.5 (median scores changed from 20 to 21). In addition, the majority of the students (55%) scored better on the second exam, while 15% scored the same and 30% scored worse. The small increase in the average score corresponds to a normalized gain statistic ($\langle g \rangle$; Crouch & Mazur 2001) of only 0.17, comparable to the gains realized in traditional lectures and much below the $\langle g \rangle = 0.48$ noted for peer-instruction courses by Crouch & Mazur (2001; see also Hake 1998; note that these studies predominantly use FCI as a baseline instead of MBT). These results seem to suggest that the interactive elements introduced in 8.012 resulted in little improvement in the student's conceptual learning.

However, it is essential to take into account the very high MBT scores the 8.012 students started with. The MBT has only 26 questions, so average percentages rose from 74% to 78% (median scores 77% to 81%) over the semester, while the fraction of the class scoring ~90% or better (no more than 3 questions wrong) rose from 23% to 34%. The MBT scores at both the beginning and end of the semester are in fact comparable to end-of-semester scores for students in calculus-based, peer instruction courses examined in the Crouch & Mazur study (71-79%), and substantially higher than the end-of-semester scores for calculus-based traditional instruction and algebra-based peer-instruction courses (66-68%). It is questionable, then, whether the MBT provides a sufficiently challenging benchmark for measuring the conceptual gain of a typical 8.012 student.

Lecture Attendance/PRS Participation

In addition to assessing the impact of the concept questions on student learning, it is useful to examine whether the technology employed was optimal for fostering student participation. This was gauged by examining the number of students who participated in concept questions

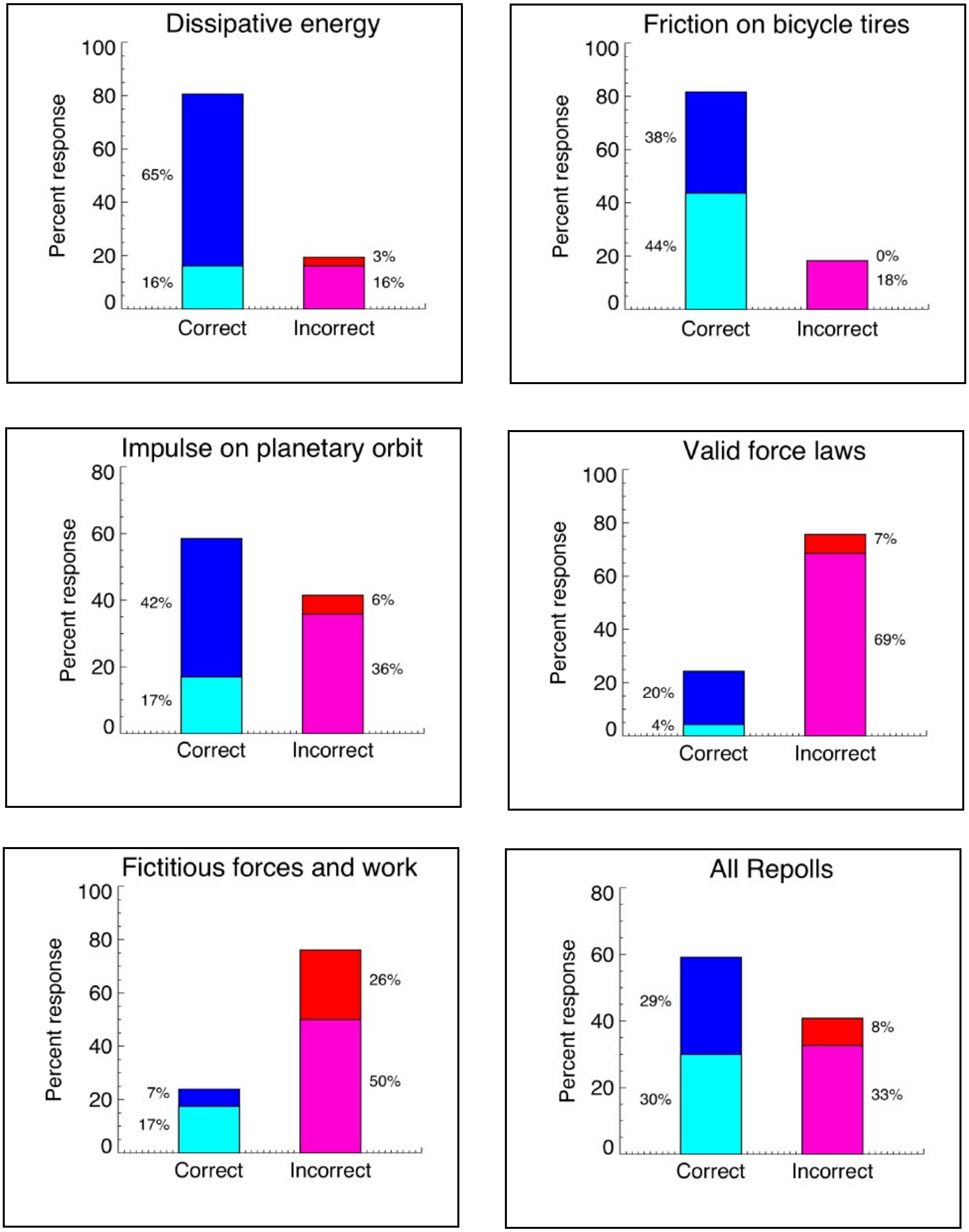


Figure 4: Conversion rates for five re-polled concept questions, and an average for all eleven re-polled questions (bottom right). Light blue indicates correct to correct conversions, dark blue incorrect to correct, pink incorrect to incorrect, and red correct to incorrect.

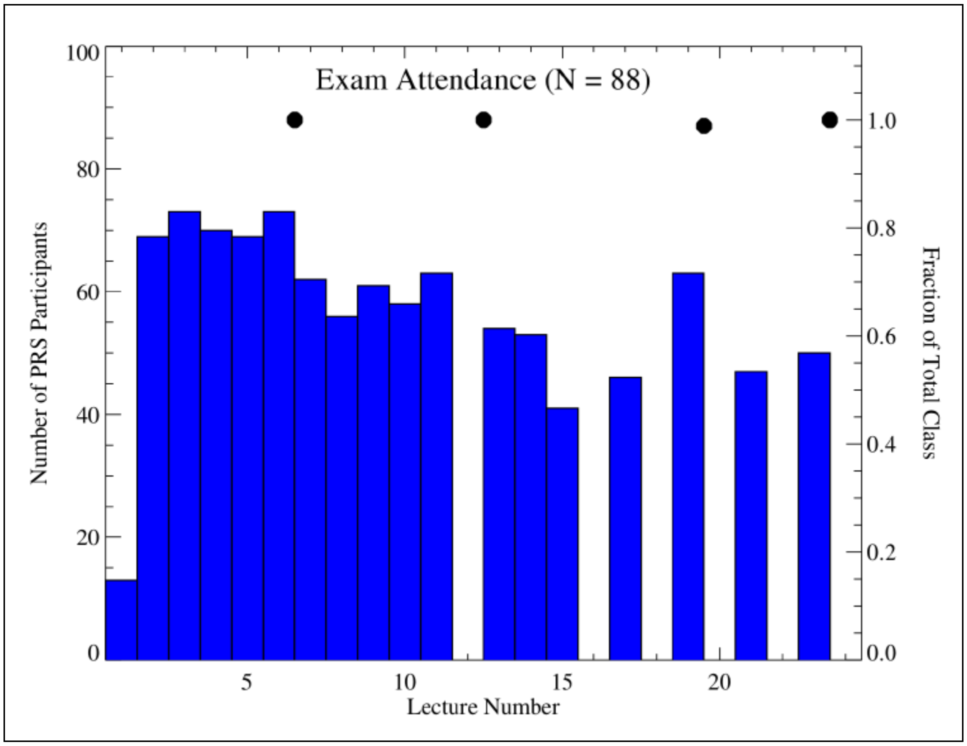


Figure 5: Number of participating students (left axis) and fraction of total class (right axis) responding to concept questions in lecture as gauged by PRS responses. The total class size, based on exam attendance, is 88 students. There were no concept questions given in Lectures 12, 16, 18, 20 and 22.

with their PRS in each lecture, as shown in Figure 5. Students were largely engaged at the beginning of the semester, with roughly 80% of the class participating by the second lecture. However, participation dropped through the semester after the first quiz, reaching a nadir of only 41 students (47% participation) by Lecture 15, an even steeper drop than that reported in Draper & Brown (2004). Participation remained at roughly 50-60% level in the second half of the semester (with only one notable spike prior to the third in-class quiz). The class size was also visibly reduced in this period, consistent with prior semesters; comments below also indicate that a few students lost their PRSs over the course of the semester. The decreased use of concept questions in this period may have also been an contributing factor in participation decline. Regardless, it is clear that even with the grading incentive, nearly half of the students failed to bring their PRS to lecture or attend at all in the second half of the semester.

Does participation in the concept questions correlate with other proficiency metrics, such as performance on exams? Figure 6 examines this possibility, by comparing average exam scores to the number of lectures in which a student's PRS response was recorded. We find a very weak *inverse* correlation (Pearson rank coefficient r = -0.10) between these, with the best performing students spanning a wide range of participation and the worst performing students participating in roughly half of the lectures. However, when we compare improvement in exam performance—for example the difference between the third and first exam scores—to PRS participation, a slightly more significant positive correlation is seen (r = 0.17). Specifically, the students with the largest improvement in exam scores were also those

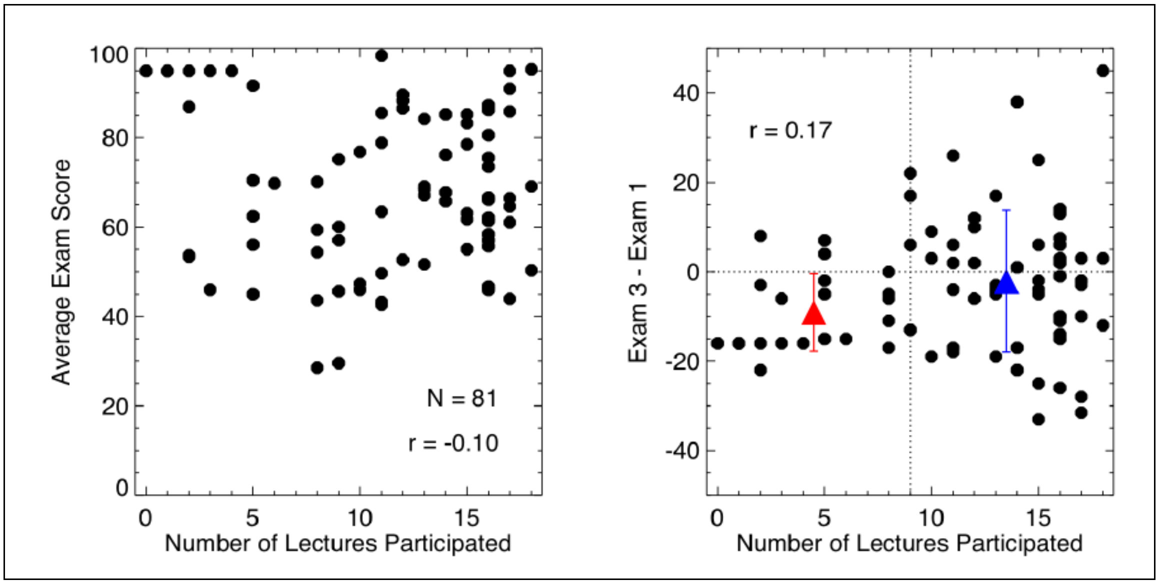


Figure 6: Comparison of the number of lectures in which PRS participation was recorded with average exam score between the three quizzes and final exam (left panel) and improvement in scores between exams 1 and 3 (right panel). The comparison is made for 81 students who took all four exams. The Pearson rank coefficients in both cases are labeled. In the right panel, the means and root mean squares of score improvements for infrequent (< 9 responses; red) and frequent (≥ 10 responses; blue) participants are also indicated.

that participated the most in the PRS questions. Of course, students with the largest drops in scores were also heavy PRS participants, and the mean change in exam score was essentially identical between frequent (-2±16%) and infrequent participants (-9%±9%). Hence, while there is a suggestion of exam performance tracking with participation in in-class concept discussions, the correlation is weak.

Qualitative Feedback from the Students

Finally, it is useful to assess what the students perceived about their learning with the concept modules. Students were specifically informed early in the semester that the concept questions and PRS cards were part of an experiment to increase interactive learning in 8.012, and they were asked to give their honest opinions about the implementation in the (anonymous) end-of-term evaluations. The following is a subset of 36 responses received that referred specifically to the "clickers":

- *I liked the concept tests, but I'm not sure it makes sense to grade them, especially since some (good) ones involve a trick.*
- *I feel that the clicker questions did assist in raising that understanding and were very helpful.*

- *Clicker questions helped grasp concepts*
- *Clickers: They helped with concept-ingraining and, frankly, were fun (unless I forgot mine in my dorm, but that's a diff. story). Maybe give a bit more time to answer.*
- *The clicker was interesting for stimulating question but DO NOT GO OVER FULLY to 8.01-style TEAL lecture*
- *Clicker questions were a good indication of how well I was understanding concepts.*
- *You can keep using the clickers, but DON'T grade w/them.*
- *I enjoyed lectures, but we spent too much time at the beginning of the semester with the clickers. Having us think about the question, argue it, defend it in front of the class, etc simply too more time than it was worth. Having the questions is fine, but we don't' have the time in class to think through things the way we do homework—that's what psets are for.*
- *The clicker is annoying. It shouldn't force me to go to class.*
- *I learned a great deal and can now apply concepts much better than I thought I could.*
- *I hated the clickers. They are expensive, easy to forget, and annoying in general.*
- *The clicker thing that was introduced this year is actually a very good idea and should be continued.*
- *The clicker thing/concept was awful. We weren't given enough time to think through the problem/work it out and I ended up just guessing randomly before polling was closed.*
- *While the clicker questions were sometimes helpful, they were mostly trick questions, which was slightly frustrating.*
- *Clicker questions in class were useful for ignited additional discussion on concepts, and self-testing if we "really" got it.*
- *The clickers were rather useful but were definitely not worth the money paid for them. If they could be supplied…*
- *The clicker questions were okay in general, but sometimes the long-winded debates and incessant repolling got annoying.*
- *The clicker questions too way to long. There were many lectures where fully 1/3 of the lecture time was spent voting and discussing and revoting and debating and revoting… all on the same question. By the end I didn't really feel as though I'd learned much that could not have been learned in 5 mins. Time spent in regular lecture was much more helpful.*
- *The clickers weren't that great. They didn't hinder learning, but for something that costs that much, they didn't really do anything.*
- *Clickers were useful as a test of understanding but the class discussion associated with them was not.*

Overall, positive responses to the concept questions and PRS cards outweighed negative responses three to one, with many students reporting that the questions specifically helped them grasp difficult concepts. Common criticisms include distaste at having a portion of their grade linked to their participation in the concept polls (and presence in lecture), a perception that some questions were “tricky” or poorly worded, dissatisfaction with the peer discussion, and the expense of the RF cards and tendency to forget to bring them to class. Many of these concerns suggest specific ways of improving peer instruction for 8.012 (see Summary Comments below), but the overall positive response indicates that the students generally welcomed the focus on concepts and interactive discussions in lecture.

Adoptability

The last objective of this program was to make the interactive elements easily adaptable and adoptable for future 8.012 instructors. To this end, the questions are included with this submission in both PDF and Powerpoint formats, with notes provided in the latter to aid in explaining relevant concepts. The questions are also rated according to polling as easy (initial polling >75% correct), ideal (initial polling <75% correct) and challenging (multiple polling <60% correct), and questions associated with a demonstration are indicated. These materials have been made available to the Fall 2009 8.012 instructor, Martin Zwierlein. I will also be posting these material and additional analysis results on my webpage, http://web.mit.edu/~ajb/www/8012.

Summary Comments

Based on the statistical results, student feedback and personal experience in class, it is clear that concept questions are an invaluable and easily adoptable addition to the traditional lecture format. One to two questions per lecture allows for rapid assessment of the students' understanding of key concepts and facilitates peer instruction and learning. However, it is also clear from the analysis of conversion rates that concept questions alone are not sufficient for conceptual learning. The rare occasions when peer discussion fails to correct, and even obfuscates, basic physical concepts indicates that focused lecture and recitation periods are still required. Such problems occur especially when concept questions are obscure, misleading or simply incorrect, and these can exasperate students already challenged by a difficult topic. That said, the frequency with which the students converged on correct ideas during the peer discussions, their retention of concepts that they themselves “discovered”, and the ability to recognize gross misconceptions among large groups of students make concept questions an effective tool in the lecture environment.

The PRS technology employed for this investigation satisfied its objectives, was readily and broadly adopted by the students, and provided quantitative data for assessment. However, the low PRS participation rates in the second half of the semester and student concerns over cost and misplacement of the RF transmitters suggests that an alternative to “clickers” should be explored. Many programs are now incorporating colored flash cards for voting (e.g., Meltzer & Manivannan 1996) that are cheap to print and distribute, easy to store in notebooks or textbooks, and trivial to replace. Paper flash cards still provide the ability for anonymous voting (e.g., by holding the card close to the body) and immediate instructor feedback, although they do not (in their current implementation) provide real-time feedback for the students nor attendance and other quantitative data for evaluation.

Finally, while the short-term metrics for concept learning—conversion rates in re-polling—

suggest that this study was successful in improving students' understanding of classical physics concepts, the long-term metrics—correlation between exam to PRS participation and the MBT exam—are ambiguous. In the case of the MBT exam, this is likely due to the high level of proficiency with which the 8.012 students began the semester, making large improvements unlikely. The lack of comparable statistics from prior semesters of instruction also prevents an assessment as to whether the concept questions specifically improved learning for 8.012 students over traditional lecture formats. The insensitivity of the MBT for this population, the more advanced of the two Physics baseline assessment tools currently employed, suggests that an even more advanced test may be needed. Perhaps the questions developed as part of this program may seed this effort.

The author thanks the MIT Classes of 1951, 1955, 1972 and 1999 for the opportunity they have provided to experiment with interactive teaching methods for the 8.012 course. He also acknowledges John Belcher, Markos Hankin, Dianne Henderson, Phillip Long, Sanjoy Mahajan, Kelley Mahoney, Andy Neely, David Pritchard and Matt Strafuss for their assistance in the proposal, preparation and execution of this project. Finally, thanks go out to the Fall 2008 8.012 students for their participation and feedback.

References

Crouch, C. H. 1998, Optical Photonics News, **9**, 37

Crouch, C. H., & Mazur, E. 2001, American Journal of Physics, **69**, 970

Dori, Y. J., & Belcher, J. W. 2005, Journal of Learning Science, **14**, 243

Draper, S. W., & Brown, M. I. 2004, Journal of Computer Assisted Learning, **20**, 81

Hake, R. R. 1998, American Journal of Physics, **66**, 64

Hestenes, D., & Wells, M. 1992, The Physics Teacher, **30**, 159-166

Hestenes, D., Wells, M., & Swackhammer, G. 1992, The Physics Teacher, **30**, 141

Halloun, I., Hake, R. R., Mosca, E., & Hestenes, D. 1995 Revised Force Concepts Inventory, http://modeling.la.asu.edu/R&E/FCI-RV95%20withInstr.pdf

Kleppner, D., & Kolenkow 1973, *An Introduction to Mechanics* (out of print)

Lyman, F. T. 1981 In A. Anderson (Ed.), *Mainstreaming Digest.* (pp. 109-113). University of Maryland Press, College Park

Mayer, R. E. 1996, Educational Psychology Review, **8**, 357

Mazur, E. 1997, *Peer Instruction: a User's Manual*. Prentice-Hall, NJ.

Meltzer, D. E. & Manivannan, K. 1996, The Physics Teacher **34**, 72

Novak, G., Patterson, E., Gavrin, A., & Christian, W. 1999, *Just-in-Time Teaching: Blending Active Learning and Web Technology.* Prentice-Hall, NJ.

Reay, N.W., Bao, L., Li, P., & Baugh, G. 2005, American Journal of Physics, **73**, 554

Wood, D., Wood, H. & Middleton, D. 1978, International Journal of Behavioral Development, **1**, 131

VanLehn, K. 2003, Cognition and Instruction, **21,** 209