3

Just-in-Time Teaching and Peer Instruction

Eric Mazur and Jessica Watkins

Peer Instruction (PI) is an interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material (Crouch, Watkins, Fagen, & Mazur, 2007; Crouch & Mazur, 2001; Mazur, 1997). By providing opportunities for students to discuss concepts in class, PI allows students to learn from each other. However, for this method to be most effective, students need to come to class with some basic understanding of the material. Just-in-Time Teaching (JiTT) is an ideal complement to PI, as JiTT structures students' reading before class and provides feedback so the instructor can tailor the PI questions to target student difficulties.

Separately, both JiTT and PI provide students with valuable feedback on their learning at different times in the process—JiTT works asynchronously out of class, and PI gives real-time feedback. Together, these methods help students and instructors monitor learning as it happens, strengthening the benefits of this feedback. As this chapter details, the combination of these methods is useful for improving student learning and skill development.

PEER INSTRUCTION AND JUST-IN-TIME TEACHING: THE BASICS

How PI Works. This book includes many descriptions of how JiTT can help successfully prepare students by structuring reading before class. In comparison, PI structures time during class around short, conceptual multiple-choice questions, known as ConcepTests, an example of which is shown in Figure 3.1. These questions are targeted to address student difficulties and promote student thinking about challenging concepts.

The ConcepTest procedure is depicted in Figure 3.2. After a brief presentation by the instructor, the focus shifts from the instructor to the student, as

A blood platelet drifts along with the flow of blood through an artery that is partially blocked by deposits.

As the platelet moves from the narrow region to the wider region, its speed

1. increases.
2. remains the same.
3. decreases.

Figure 3.1. A Sample ConcepTest

the instructor encourages the students to think about the material by posing a ConcepTest.

After 1–2 minutes of thinking, students commit to an individual answer. If an appropriate percentage of students answer the ConcepTest correctly, the instructor asks students to turn to their neighbors and discuss their answers. Students talk in pairs or small groups and are encouraged to find someone with a different answer. The teaching staff circulates throughout the room to encourage productive discussions and guide student thinking. After several minutes students answer the same ConcepTest again. The instructor then explains the correct answer and, depending on the student answers, may pose another related ConcepTest or move on to a different topic.

In science courses PI has been shown to be a useful way to engage students in classroom demonstrations, much like interactive lecture demonstra-

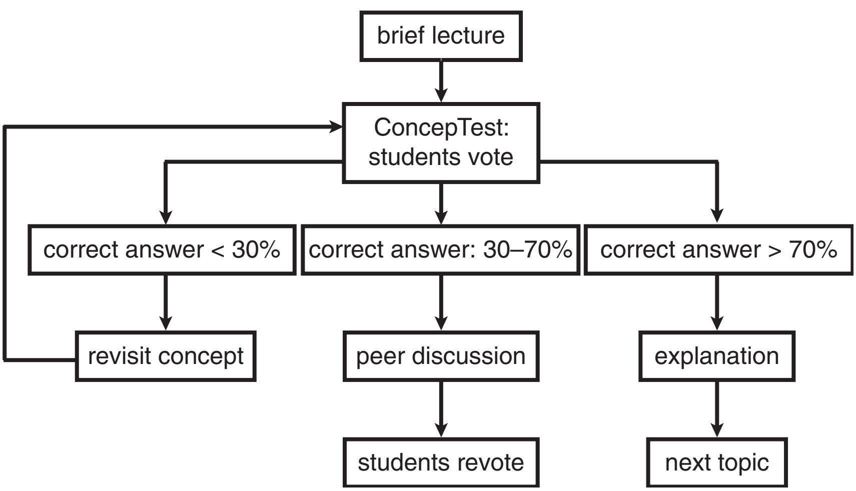


Figure 3.2. The ConcepTest-Peer Instruction Implementation Process. From Lasry et al. (2008). Reprinted with permission. © American Association of Physics Teachers.

tions (Sokoloff and Thornton, 1997). Before showing students what happens when you mix two chemicals or flip a switch on a given circuit, instructors can ask students to predict the outcomes. Research shows that asking students to predict the outcome of an experiment results in greater conceptual understanding (Crouch, Fagen, Callan, & Mazur, 2004) and instructors report increased student engagement (Mazur, 1997). In social science or humanities courses PI can be used to involve the students as participants in experiments with human responses (Draper, Cargill, & Cutts, 2002).

A variety of question-types can be used with PI, including questions about general theories and definitions, questions asking students to apply concepts in different contexts, and questions that illustrate how different ideas are related. PI is not only useful for questions with "correct" answers, but also for promoting discussion among students with questions that lack a clear-cut answer. For example, a ConcepTest may ask students to consider the relative importance of different assumptions in a scientific hypothesis or the relative value of different interpretations of a literary passage. The structure of PI provides opportunities for students to hone their skills in critical listening and developing solid arguments. Regardless of subject matter, PI enables students to create knowledge through discussion and become active participants in the discipline they are studying.

PI and JiTT. The quality of student discussion and learning in a PI classroom depends on the quality of the ConcepTests. Several databases of class-tested questions exist in physics (Mazur, 1997), chemistry (Ellis et al., 2000; Landis et al. 2001), astronomy (Green, 2002), mathematics (Hughes-Hallett et al., 2005; Terrell, 2005), geoscience (Starting Point—Teaching Entry Level Geoscience: ConcepTest Examples, 2008), philosophy (Bigelow, Butchart, & Handfield, 2007), and psychology (Canadian In-Class Question Database: Psychology, 2005). For a ConcepTest to be most effective, the question must require higher-level thinking about a concept so students aren't simply recalling something they read or using "plug-and-chug" with equations. Questions must also be at an appropriate difficulty level so students are challenged but can reason to the answer with their existing knowledge.

To choose the best ConcepTests, instructors need to gauge what concepts are causing student difficulties and what level of question is appropriate for their class. By assigning JiTT assignments before class, instructors receive important feedback on their students' knowledge and understanding of the material, enabling them to better prepare for a PI lecture. Reading student responses helps instructors learn what difficulties students have, what topics students are most apprehensive about, and what concepts students understand well. Combining

JiTT with PI makes preparation for class especially efficient, as it becomes much easier to choose effective ConcepTests. Often, reading student problems or misconceptions even leads to ideas for new questions.

JiTT is not only useful for instructor preparation; it also helps students prepare for class. As Figure 3.3 shows, students get the most benefit from peer discussion when about 30–70% of the class answers the ConcepTest correctly before discussion.

Too few correct answers may indicate that students do not have enough understanding or knowledge to engage productive discussions. Therefore, students must come to class with some knowledge and ideas about the material. Often instructors administer reading quizzes at the start of class to promote pre-class reading; however, this assignment often relies solely on student memorization of facts, definitions, or equations. JiTT also encourages students to read the material, but the questions ask for more than memorization of key words and definitions and push students to start thinking more deeply about the concepts. In addition, most JiTT exercises include a question of the type, "After completing this exercise, what concepts are still unclear to you?," which promotes reflective thinking by students and provides formative feedback on students' thinking processes for instructors.

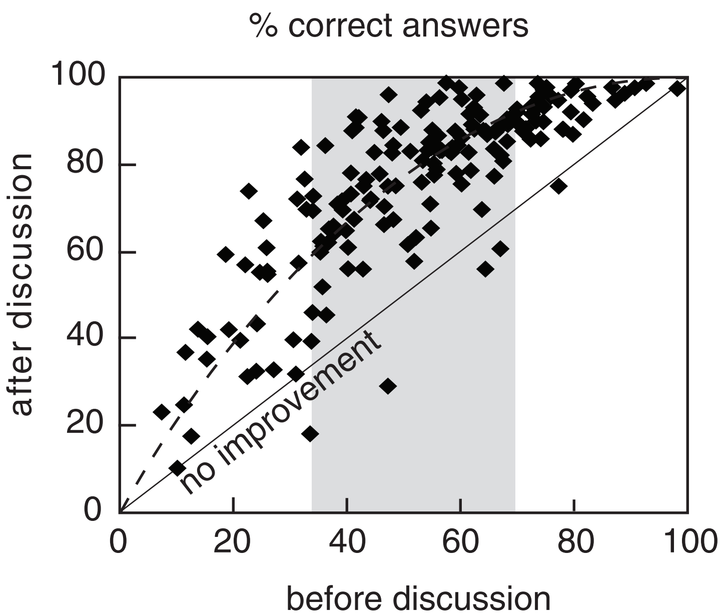


Figure 3.3. Percentage of correct answers before discussion versus after discussion. Gray area indicates optimum before-discussion percentages for the highest gain.

WHY PI PLUS JiTT WORKS

A great deal of research on cognition and learning indicates that students learn by using their existing knowledge, beliefs, and skills to create new knowledge (Bransford, Brown, & Cocking, 1999). Therefore, pedagogies in which teachers are made aware of students' incoming knowledge enhance learning. JiTT and PI provide opportunities for teachers and students to recognize background knowledge during the pre-class reading, initial vote, and discussion. The best in-class ConcepTests often take advantage of common student preconceptions or ideas about the material so students can recognize these ideas and build on them. With the constant feedback from the reading assignments and ConcepTests, the instructor can monitor student progress and help guide students to use their previously-held ideas to understand new concepts and theories. For example, in physics students may not fully understand Newton's First Law—an object in motion stays in motion unless acted on by an outside force—because of their own conflicting experiences outside the classroom sliding objects on flat surfaces involving friction. However, JiTT and PI can work together to help students first express their initial ideas and then through targeted questioning, guide them to develop more comprehensive ideas about motion that include friction. Although there are many books and papers that catalogue and describe commonly-held ideas in introductory science (e.g. Driver, Squires, Rushworth, & Wood-Robinson, 1994), JiTT is very useful in informing the instructor of these ideas before class, particularly for subjects with less research in student background knowledge. Additionally, the flexibility of a PI lecture makes it easy for instructors to spend more time on concepts that are difficult for students by giving more focused, short presentations or asking more ConcepTests. In a JiTT/PI class, instructors are paying attention to student thinking throughout the learning process.

PI provides a structured environment for students to voice their beliefs and resolve misunderstandings by talking with their peers. By working together to learn new concepts and skills in a discipline, students create a more cooperative learning environment that emphasizes learning as a community in the classroom (Hoekstra, 2008). Research suggests that this type of cooperative learning environment can help promote deeper learning, as well as greater interest and motivation (Cross, 1998). Furthermore, the strategies students use during collaboration (explaining, reasoning, and justifying arguments) can also help students develop more advanced critical thinking skills that can be used beyond the classroom (Gokhale, 1995).

Although PI can help students develop discussion skills, JiTT can help students develop skills in reading for understanding, which may be especially difficult for students when learning new, unfamiliar material. Additionally, novice learners often employ surface learning approaches that differ markedly from the deeper thinking processes of experts (Bransford et al., 1999). With JiTT, instructors can help guide students' reading by choosing questions that highlight the most important or challenging points or target deeper issues. With this guidance, students have the opportunity to become better readers as they get more directed practice with reading throughout the semester.

Research shows that experts are able to monitor and regulate their own understanding (Bransford et al., 1999). These metacognitive abilities enable experts to employ different strategies to improve their learning. PI and JiTT can help students develop better metacognitive skills, as they check their own understanding during pre-class reading and in-class questions. This is especially true when JiTT exercises include questions of the type, "What is still unclear?" These methods can help students recognize when they do not understand a concept, when they are unable to answer a JiTT question, or when they cannot give complete explanations to their peers during in-class discussion. With this formative, internal feedback, students can learn how to better assess their own understanding during the learning process. Both methods encourage students to take responsibility for their own learning, and emphasize understanding over simple task completion.

Another advantage to using JiTT in combination with PI is that both methods "personalize" the large classroom. With advances in both technology and pedagogy it is easy for instructors to connect with students and monitor their progress. JiTT and PI provide formative feedback to both students and instructors, and as we discuss later in the chapter, technology makes it even easier for instructors to respond to students individually, even in a large classroom.

Both JiTT and PI can readily be adopted for a variety of disciplines and classroom environments, and can be modified for different instructional goals. ConcepTests and JiTT questions can be tailored to individual classes and for diverse learning objectives. The modular nature of both methods means that instructors only need to use each method when and how they see fit. Reading assignments need only be given before class when necessary, and during class instructors can use as few as one question per class or as many as time allows. As such, JiTT and PI can be easily adapted to an instructor's personal style of teaching and combined with other teaching methods such as tutorials (McDermott, Schaffer, & Group, 2002), small group problem-solving (Heller, Keith, & Anderson, 1992), or lecture. It is this flexibility that makes these two methods so effective in so many classrooms.

USING JiTT AND PI: AN EXAMPLE

In this section we review a sample JiTT assignment and PI lecture to show how these two methods can be used together to help address student difficulties and deepen their understanding. Our example is from an introductory physics course at Harvard University, covering topics in electricity and magnetism, although these methods work well in a variety of disciplines.

This class met twice a week and students submitted JiTT assignments online by midnight the evening before each lecture. For this assignment students typically read a half chapter from the textbook and answered two conceptual JiTT questions and one additional question: "Please tell us briefly what *single* point of the reading you found most difficult or confusing. If you did not find any part of it difficult or confusing, please tell us what part you found most interesting." Students were graded for effort, not correctness, on these reading assignments. After the submission deadline, students could log into their accounts to see the correct answers for the first two questions as well as common questions (plus answers) from their peers. The instructor reviewed student answers before lecture, responded by email to student issues, and designed the next lecture, choosing which ConcepTests were appropriate. During the 1.5-hour-long lecture, students answered several ConcepTests, using either a wireless infrared device or their own personal wireless device, such as a cell phone, PDA, or laptop. Students' answers were recorded and students received participation credit for their responses. After lecture students could log in to review the ConcepTests as well as correct answer explanations, and the instructor could see statistics on students' answers before and after discussion.

To further illustrate how JiTT and PI complement each other, we detail one reading assignment and lecture from a one-semester course covering electricity and magnetism. We have selected a topic that was more likely to be covered in high school science courses—and therefore does not need a great deal of background knowledge—to help make this sample lecture more accessible to instructors in a variety of disciplines.

To prepare for lecture students were required to read four sections of a physics textbook covering ray optics, including topics such as transmission, reflection, absorption, refraction, dispersion, and image formation. They were then asked to answer three questions as part of their JiTT assignment:

1. Several of the figures show the paths of three so-called "principal" rays (1, 2, and 3) emitted from a light bulb and focused by a converging lens. How would you trace the path of a fourth ray emitted by the light bulb that bisects rays 1 and 2? (See Figure 3.4 for an example figure from the text.)
2. You are looking at a fish swimming in a pond. Compared to the actual depth at which the fish swims, the depth at which it appears to swim is *greater, smaller,* or *the same?*

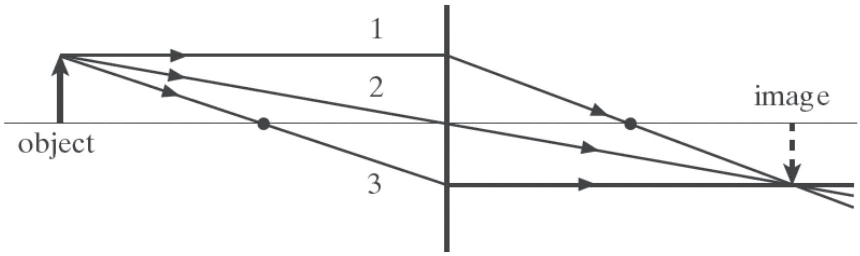


Figure 3.4. Sample Figure of Light Rays with a Converging Lens from the Text.

3. Please tell us briefly what *single* point of the reading you found most difficult or confusing. If you did not find any part of it difficult or confusing, please tell us what parts you found most interesting.

The correct answers were posted on the website for the first two questions after the assignment was due.

1. From the bulb to the lens: bisect rays 1 and 2 to find the point *P* where the ray strikes the lens. Then, draw a line from point *P* to the point where the principal rays intersect on the image of the light bulb.
2. Smaller, because at the water/air interface the light bends; the rays from the fish travel less steeply in air than in water. Therefore, the light appears to have come from a more shallow source.

Most students were able to correctly answer the first JiTT question by describing the path of a fourth ray. Students who had problems with this question often had issues with terminology or did not explicitly state how all rays would converge at the same point. Below is a sample of student JiTT responses.

- If you had a fourth ray that bisects rays 1 and 2 you would have it emerging at an angle after passing through the lens that didn't allow it to pass through the focus point. This is because it would not be paraxial and would be displaced away from the focus point.
- A fourth ray emitted by the light bulb and bisecting the angle between rays 1 and 2 should be directed through the focal point after reaching the center of the lens (so it makes a smaller angle upon reaching the center of the lens than ray 1 does, but a larger one than ray 2 makes, because ray 2 does not bend upon reaching the center of the lens).

- Well, I would probably draw it following a path that continued half way in between the other the paths followed by rays 1 and 2, but beyond that the sketch would not be very precise.

Many students answered the second JiTT question correctly, but often with sparse or incomplete explanations. Students who answered incorrectly didn't seem to grasp the concept of refraction in different mediums, especially with a flat interface. The sample student responses illustrate this point.

- The depth would be smaller due to the way the light is refracted by the water.
- The depth is the same. The water will act as a sort of lens, but because it will be a flat lens, the image size will not be changed so the fish will appear to be at the same depth.
- It obviously depends on whether the pond resembles a smooth clear lens, or a convex lens (concave doesn't really make sense here). Assuming clear/flat, the depth is the actual depth, however if the pond serves as a convex lens, no matter where the fish is it will appear as a smaller fish swimming less deep than actuality.

In addition, students wrote about their difficulties in their answer to the third JiTT reading question:

- I don't understand what a virtual image actually is. Is it literally just a trick our mind plays on us when processing visual information?
- It is difficult to conceptualize Fermat's principle in terms of the amount of time it takes light to travel. How are we supposed to know which path this is?
- I don't understand how it's possible not to see an image (as in when the object is at the focal point). Where do the light rays go? It just seems so counter-intuitive.

Students expressed difficulty or confusion on a number of different concepts. Some of these questions were best addressed by posting an answer on the website or talking about the question in class. Other student questions provided good opportunities for students to think about these concepts in class and discuss them with their neighbor.

To prepare for lecture the instructor spent a couple hours reading the student responses and reviewing the textbook and ConcepTest database to determine what additional concepts should be covered. In this particular lecture the first few ConcepTests were related to concepts about reflection, concepts that were not explicitly covered in the JiTT questions.

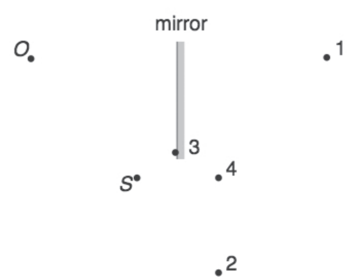
At the start of the lecture the instructor went over some basic logistics, including upcoming assignments and lab meetings. He then quickly summarized student responses to the JiTT assignment. As student problems were varied—spread out over many different concepts—the instructor went straight to ConcepTests to find out where students were in their understanding about the propagation of light.

The first ConcepTest (see Figure 3.5) asked about basic reflection and most students were able to answer this question correctly before discussion, indicating that they understood the idea of a virtual image formed with a mirror.

The instructor gave a short explanation and moved quickly to the next question without asking the students to discuss their answers or repolling. The second and third ConcepTests (see Figures 3.6 and 3.7) asked students to think about ray paths with reflection, which was aimed at helping students with more complex ray drawings later.

About 40% of students answered these ConcepTests correctly before discussion, while 60% of students were able to answer correctly after discussion. To help students better understand the ray paths that light takes when reflected, the instructor took some additional time to explain the concept and described examples in everyday life that might help struggling students understand. After encouraging students to review these ConcepTests again on

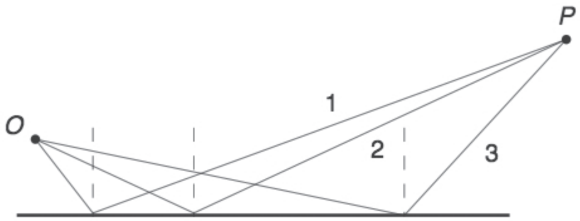
An observer O, facing a mirror, observes a light source S. Where does O perceive the mirror image of S to be located?



1. 1
2. 2
3. 3
4. 4
5. Some other location.
6. The image of S cannot be seen by O when O and S are located as shown.

Figure 3.5. First ConcepTest from Sample Lecture.

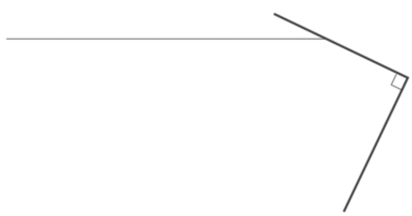
Rays of light travel from an object O to an observer at P via a reflecting surface. Which of the three paths provides the shortest path from O to P?



1. Path 1
2. Path 2
3. Path 3
4. All three are the same
5. The answer depends on the roughness of the surface

Figure 3.6. Second ConcepTest from Sample Lecture.

Light enters horizontally into the combination of two perpendicular mirrors as shown below.



After reflecting off of both mirrors the light

1. bounces back and forth many times, until it hits the corner.
2. is reflected back in a direction that depends on the original angle of incidence.
3. is reflected back and upwards.
4. is parallel and in the opposite direction to the original path.
5. is reflected back and downwards.

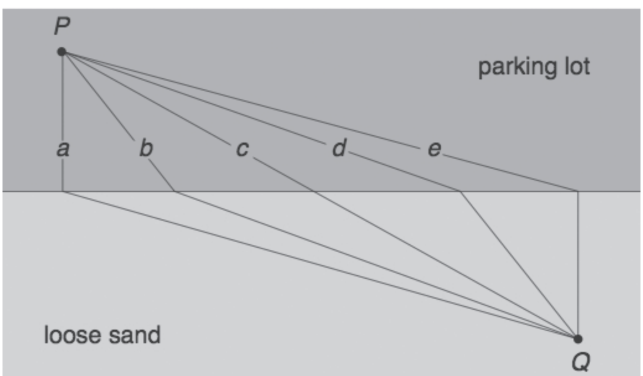
Figure 3.7. Third ConcepTest from Sample Lecture.

their own online, the instructor moved on to talk about the speed of light through different materials. Students had additional opportunities to work with ray drawings with mirrors in the next lecture and on the homework assignment.

In their answers to the third JiTT question several students expressed confusion about Fermat's principle. After a brief reintroduction to the concept and talking about how light changes speed in different materials, the instructor posed a ConcepTest that used this principle in a more relatable context to help clear up some confusion about "least time" (see Figure 3.8).

Less than half of the students answered the ConcepTest correctly initially, but after discussing the concept with their peers, more than three-quarters of the class had a correct answer. As many students demonstrated understanding of this concept, the instructor began discussing a related concept: refraction.

A group of sprinters gather at point P on a parking lot bordering a beach. They must run across the parking lot to a point Q on the beach as quickly as possible. Which path from P to Q takes the least time? You should consider the relative speeds of the sprinters on the hard surface of the parking lot and on loose sand.



1. a
2. b
3. c
4. d
5. e
6. All paths take the same amount of time.

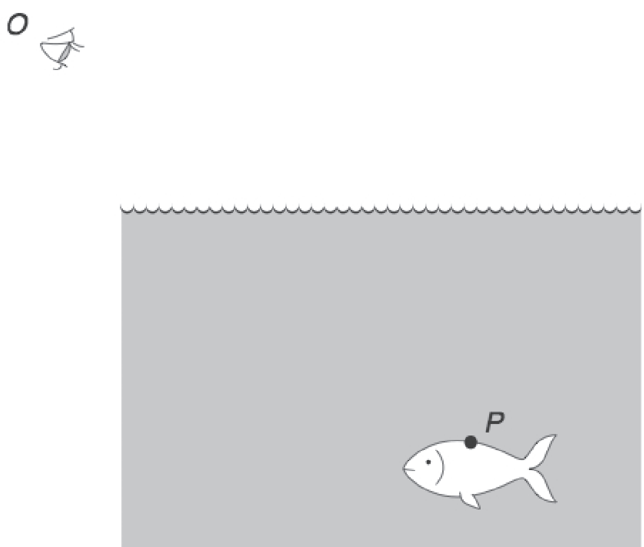
Figure 3.8. Fourth ConcepTest from Sample Lecture.

Based on the pre-class reading, the instructor could not be sure that students really understood the concept of refraction of light into different mediums, as many students did not give good explanations to the fish-in-water JiTT question. Therefore, the fifth ConcepTest asked students to think again about the perceived depth of the fish in the water (see Figure 3.9).

The instructor also posted a ConcepTest on the course website that phrases the question in a slightly different way, so the observer is directly over the fish. This question addresses a misconception a few students had on the reading assignment.

Looking at student answers to the pre-class reading, most students understood the basics about ray drawing with lenses. However, students needed to use these concepts for the problem set, so a series of ConcepTests were developed to probe student knowledge and advance their understanding. Due to time constraints, this lecture included only one of these ConcepTests (see Figure 3.10).

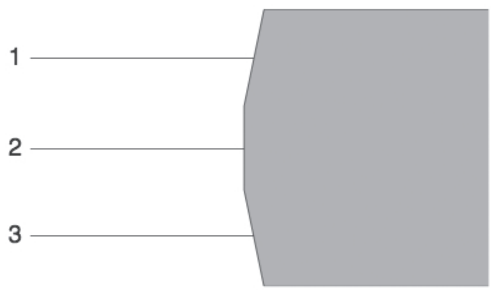
A fish swims below the surface of the water. Suppose an observer is looking at the fish from point O straight above the fish. The observer sees the fish at



1. a greater depth than it really is.
2. the same depth.
3. a smaller depth than it really is.

Figure 3.9. Fifth ConcepTest from Sample Lecture.

Three parallel rays of light travel to the faceted piece of glass shown below. After entering the glass, the three rays



1. continue parallel.
2. converge into a point.
3. diverge.
4. other.

Figure 3.10. Sixth ConcepTest from Sample Lecture.

This particular ConcepTest helped bridge the principles of refraction to lens concepts. The next reading and lecture covered this topic more extensively.

This lecture on optics used six ConcepTests to both review material in the reading and address student difficulties. With the many resources available, the instructor was able to gauge student understanding before class, target specific areas or concepts during class, and post additional information and questions online for students to review after class. The interaction of technology and pedagogy helped streamline the work for both the instructor and students, maximizing the benefit of class time and making the classroom more personalized.

RESULTS OF USING PI AND JiTT TOGETHER

Research in physics education shows that courses incorporating "activities that yield immediate feedback through discussion with peers and/or instructors" result in greater student conceptual understanding than traditional courses (Hake, 1998). Data from introductory physics courses at Harvard University confirms this finding for PI, as seen in Figures 3.11 and 3.12.

Figure 3.11 compares results from a traditional course and several PI courses using a standardized conceptual assessment of Newtonian mechanics, the Force Concept Inventory (Hestenes, Wells, & Swackhammer, 1992). As a measure of student learning, we obtained the average normalized gain

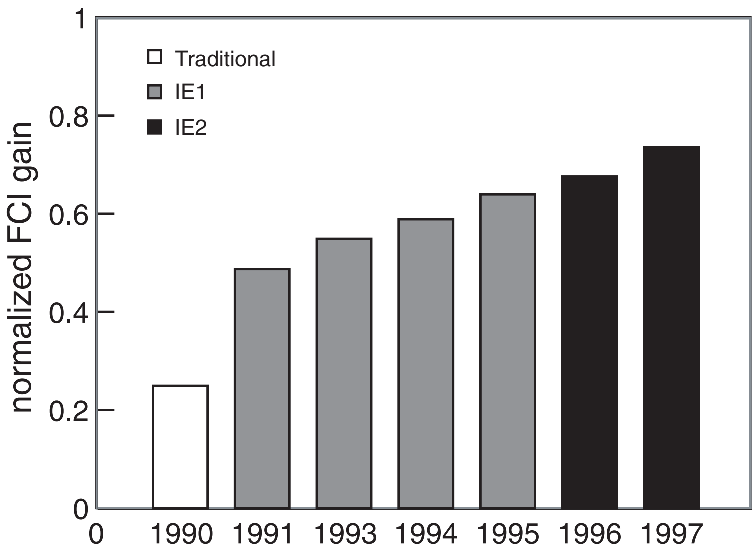


Figure 3.11. Normalized gain on the Force Concept Inventory with a traditional course (1990), IE1 courses that used PI (1991, 1993–1995), and IE2 courses that used JiTT, PI, and other interactive techniques (1996–1997). From Crouch and Mazer (2001). Reprinted with permission. © American Association of Physics Teachers.

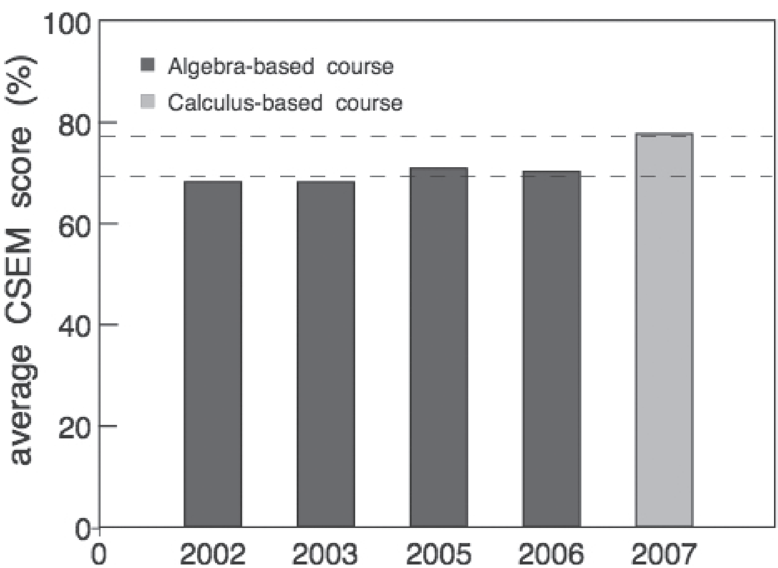


Figure 3.12. Average scores on the Conceptual Survey of Electricity and Magnetism for algebra-based and calculus-based introductory physics courses. Dotted lines represent the average scores obtained by advanced undergraduate physics majors and 2-year college professors.

(Hake, 1998) for each course, which is the gain from pretest to posttest, divided by the maximum gain possible (100% minus pretest score): $g = (post - pre)/(100 - pre)$.

As seen in Figure 3.11, PI courses (IE1) obtained greater learning gains than traditional courses. In 1996 and 1997, JiTT and tutorials were used with PI (IE2), which resulted in even higher normalized gains (Crouch & Mazur, 2001). The combination of several interactive, feedback-intensive methods, including JiTT and PI, received the highest learning gains.

Figure 3.12 shows results from introductory electricity and magnetism courses that incorporated JiTT and PI with the Conceptual Survey of Electricity and Magnetism (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001). The algebra-based non-major physics courses achieved average scores similar to those obtained from senior undergraduate physics students and the calculus-based course achieved an average score similar to those from two-year college physics professors (Maloney et al., 2001).

JiTT and PI not only improve conceptual learning gains of the entire class but can also help diminish gender gaps in student learning. As Figure 3.13 shows, females enter an introductory physics course at Harvard with a lower score on the Force Concept Inventory than males and this gap persists to the end of a traditional course.

With just the use of PI, the difference between males and females decreases, although the gap in posttest scores remains significant. With the use of PI, JiTT, and other interactive techniques, the gap in posttest scores is reduced even more, until males' and females' posttest scores are no longer statistically different in these introductory courses at Harvard (Lorenzo, Crouch, & Mazur, 2006). Although the results are less clear in other settings and populations (Pollock, Finkelstein, & Kost, 2007), the interactive, constructivist nature of these methods holds promise in reducing the gender gap and encouraging female students in science courses (Hazari, Tai, & Sadler, 2007; Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000; Lorenzo et al., 2006).

The increased overall learning gains with the use of PI occur not only at Harvard University. The results were replicated at a community college (Lasry, Mazur, & Watkins, 2008), indicating that PI is effective with varied student populations. Additionally, the positive results of PI are not limited to physics courses. Other studies have shown that PI is useful in improving learning in biology (Knight & Wood, 2005), engineering (Nicol & Boyle, 2003), psychology (Morling, McAuliffe, Cohen, & DiLorenzo, 2008), medicine (Rao & DiCarlo, 2000), philosophy (Bigelow, Butchart, & Handfield, 2006), and mathematics (Miller, Santana-Vega, & Terrell, 2006). Although these studies have focused on the use of PI alone, our results from adding JiTT to PI at Harvard

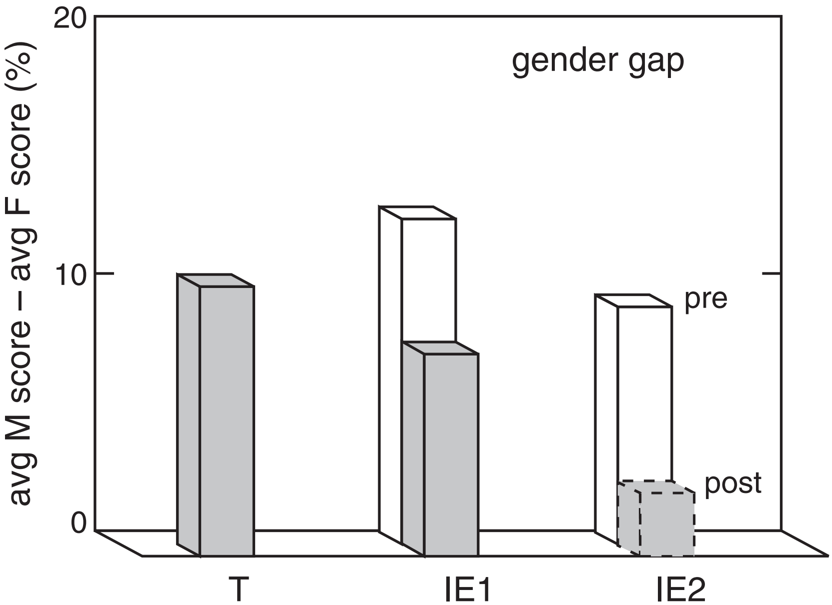


Figure 3.13. Differences in average male and average female scores on the Force Concept Inventory before and after discussion with three different pedagogies: traditional, IE1, and IE2. From Lorenzo et al. (2006). Reprinted with permission. © American Association of Physics Teachers.

suggest that students in these disciplines would similarly benefit from a combination of JiTT and PI pedagogies.

As our research has shown, combining JiTT and PI enables students to achieve greater conceptual learning gains. By exposing students to the material before class through JiTT, instructors can spend more time focusing on student understanding during class and make the classroom more centered on learning by using PI. The feedback from both methods allows instructors to adapt to their students' needs and personalize their interactions. During class, students can use their ideas developed during pre-class reading to interact with their peers and become active participants in their own learning. As a result, both instructors and students are more connected and learn more from each other, even in the largest courses.

USING PI AND JiTT WITH THE INTERACTIVE LEARNING TOOLKIT (ILT)

JiTT and PI are particularly advantageous in providing formative feedback to the instructor about students' understanding. Figure 3.14 shows a schematic

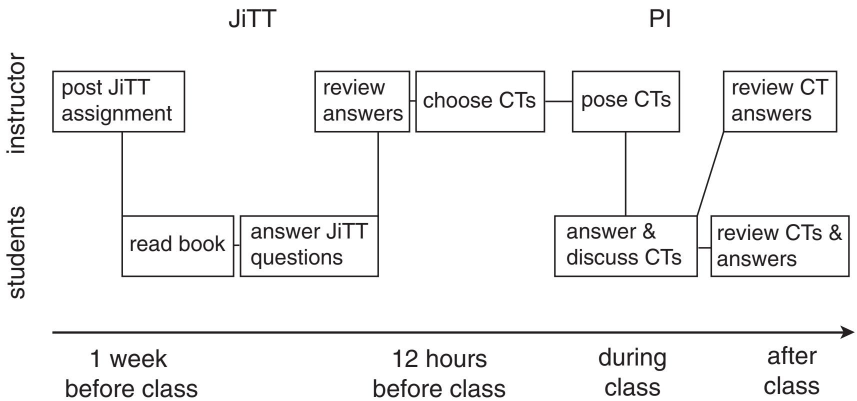


Figure 3.14. Timeline of JiTT and PI for a Given Class.

on how these methods work together, emphasizing the role of technology in providing structure and feedback throughout the learning process.

Various commercial and open-source course management systems such as Blackboard and Moodle are available to help administer JiTT to students. At Harvard University, however, we use the Interactive Learning Toolkit, (ILT, http://www.deas.harvard.edu/ilt) which helps implement both JiTT and PI, in addition to traditional course management features. The ILT includes reading and lecture modules, as well as a database of ConcepTests and a ConcepTest creation tool.

For JiTT, the reading module provides features to help create and announce reading assignments. Students complete the assignment online by a given due date. Instructors and teaching assistants are able to quickly review all student responses to a given question, revealing common weaknesses in the class's understanding (see Figure 3.15). The ILT also permits instructors to respond to questions or difficulties expressed in student responses via a labor-saving web interface, increasing students' sense of individual connection to the instructor.

With PI, use of electronic devices such as "personal response systems" (clickers) is helpful, although not necessary, for successful implementations (Lasry, 2008). Many instructors use simple hand-raising or flashcards to poll their students (Fagen, 2003). However, hand-raising allows students to see how their peers vote, which may bias their responses. Flashcards keep students' responses private from their peers and results show that flashcards work just as well as technological polling methods (i.e., handheld devices) in improving student learning (Lasry, 2008). Although it is not necessary for implementation of PI, technology can be very useful to instructors, as students can submit their answers to ConcepTests electronically, giving precise,

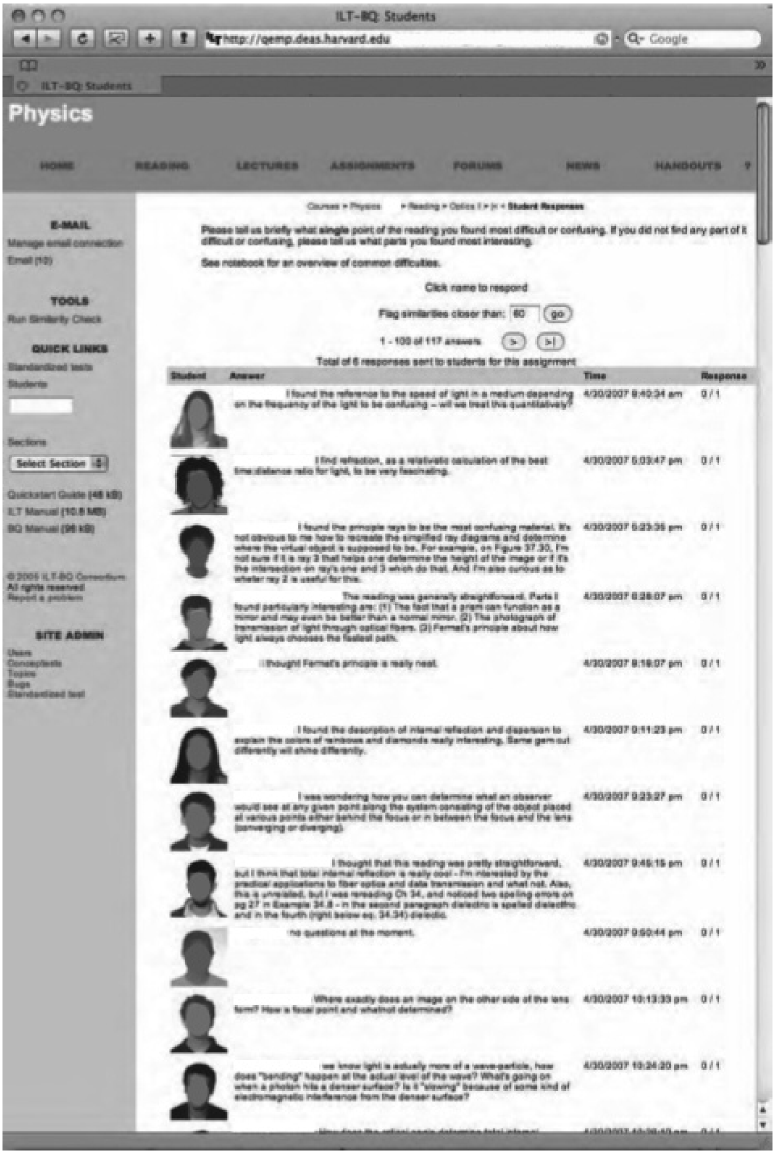


Figure 3.15. Screenshot of JiTT Reading Responses from Instructor's Viewpoint on ILT.

real-time feedback. In addition, students can use wireless handheld devices, clickers, or more recently, personal wireless devices such as cell phones, PDAs, or laptops. With these devices instructors can collect data on student performance in class and longitudinal data on individual students. Additionally, advances in technology have allowed for the creation of seating maps with students' responses, enabling instructors to focus their attention on groups of struggling students during their discussions.

In addition to helping coordinate the JiTT reading assignments, the ILT contains a searchable ConcepTest database, with over 800 physics questions, many developed at other institutions for either algebra- or calculus-based introductory physics, and some developed for non-introductory courses. Users can generate class-ready materials, such as pages for a course website or overheads for class, directly from the database. Links to separate databases of ConcepTests for astronomy and chemistry are also available. Lectures can be used to design PI classes and are linked by dates and times. With the database of ready-to-use ConcepTests the instructor can choose which conceptual questions best probe students' understanding. Additionally, the ILT provides an easy way to create additional ConcepTests in .pdf format, which can also be shared and added to the database. The instructor can easily generate a set of ConcepTests for a given lecture topic and post these for students to access after class.

If the instructor uses an electronic response system to poll students for answers to in-class ConcepTests, the lecture module of the ILT contains a feature to record student responses and statistics for each question (see Figure 3.16).

The ILT also links student answers with other aspects of the course, such as performance on pre-class reading, assignments, and exams. Additionally, we have integrated the technology of the ILT with *Beyond Question* (Junkin, 2008), which allows students to use wireless-enabled devices, such as cell phones, laptops, or PDAs to respond to in-class ConcepTests. With many students already using these devices in class, this feature alleviates the need for students to purchase an additional device and reduces the technical infrastructure needed in the classroom.

Standardized tests, including those mentioned in this article, are also available on the ILT and can be provided to students as online assignments. These tests are designed to assess students' conceptual understanding, quantitative problem-solving skills, or attitudes about undergraduate science courses, and can be taken pre- and post-course to provide information on the effectiveness of the instruction in these specific areas. The database of these tests is growing, and currently includes the Force Concept Inventory (Hestenes et al., 1992), Mechanics Baseline Test (Hestenes & Wells, 1992), Astronomy Diagnostic Test (Hufnagel et al., 2000), Conceptual Survey on Electricity and Magnetism (Maloney et al., 2001), Lawson's Test of Scientific Reasoning (Lawson, 1978), and the Maryland Physics Expectations Survey (Redish, Saul, & Steinberg, 1998). Other standardized tests can be easily added to the database. The ILT software is freely available to any interested instructor, requiring only that the instructor register at http://www.deas.harvard. edu/ilt.[1]

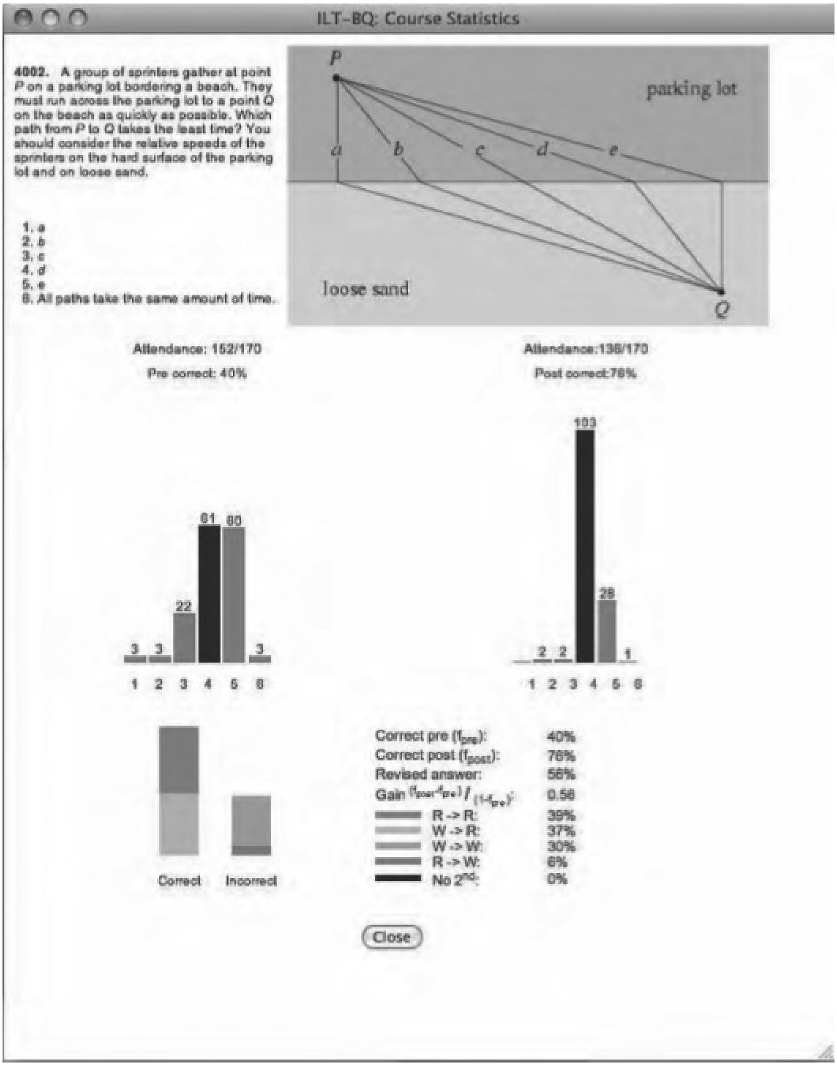


Figure 3.16. Screenshot of ConcepTest and Student Distributions of Responses, as Displayed on the ILT.

CONCLUSION

Just-in-Time Teaching and Peer Instruction work well together to advance and deepen student understanding, provide feedback to students and faculty, and help the instructor make better use of class time. By shifting students' first exposure to the material to before class, time spent in class is better used on more difficult concepts and to extend students' understanding and analysis of the concepts they already understand. Moreover, both pedagogies give formative feedback to the professor and to the students, which helps the professor tailor her/his instruction and gives students an opportunity to monitor their own learning. PI and JiTT, used together, are easy to implement in a variety of classroom settings and disciplines, and the results so far are promising for improving student learning.

Note

1. In order to preserve the security of standardized tests such as the Force Concept Inventory an instructor must also send email to galileo@deas.harvard.edu in order to gain access to these tests.

References

Bigelow, J., Butchart, S., & Handfield, T. (2006). *Evaluations of peer instruction.* Retrieved May, 2008, from http://arts.monash.edu.au/philosophy/peer-instruction/evaluations/index.php

Bigelow, J., Butchart, S., & Handfield, T. (2007). *Peer instruction question database.* Retrieved May, 2008, from http://arts.monash.edu.au/philosophy/peer-instruction/database/index.php

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school.* Washington, D.C.: National Academy of Science.

Canadian in-class question database: Psychology. (2005). Retrieved May, 2008, from http://cinqdb.physics.utoronto.ca/questions/psychology/

Cross, K. P. (1998). Why learning communities? Why now? *About Campus 3*(3), 4–11.

Crouch, C. H., Fagen, A., Callan, J. P., & Mazur, E. (2004). Classroom demonstrations: Learning tools or entertainment? *American Journal of Physics, 72*(6), 835–838.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970–977.

Crouch, C. H., Watkins, J., Fagen, A., & Mazur, E. (2007). Peer instruction: Engaging students one-on-one, all at once. In E. F. Redish & P. Cooney (Eds.), *Reviews in Physics Education Research, 1*(1). Retrieved May, 2008 from http://www.percentral.org/per_reviews/volume1.cfm

Draper, S., Cargill, J., & Cutts, Q. (2002). Electronically enhanced classroom interaction. *Australian Journal of Educational Technology, 18*(1), 13–23.

Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas.* London: Routledge.

Ellis, A. B., Cappellari, A., Lisensky, G. C., Lorenz, J. K., Meeker, K., Moore, D., Campbell, K., Billmann, J., & Rickert, K. (2000). *ConcepTests.* Retrieved May, 2008, from http://www.jce.divched.org/JCEDLib/QBank/collection/ConcepTests/

Fagen, A. (2003). *Assessing and enhancing the introductory science course in physics and biology: Peer instruction, classroom demonstrations, and genetics vocabulary.* Cambridge: Harvard University Press.

Gokhale, A. (1995). Collaborative learning enhances critical thinking. *Journal of Technology Education, 7*(1), 22–30.

Green, P. (2002). *Peer instruction for astronomy.* Upper Saddle River: Prentice Hall.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64–74.

Hazari, Z., Tai, R., & Sadler, P. (2007). Gender differences in introductory university physics performance: The influence of high school physics preparation and affective factors. *Science Education, 91*(6), 847–876.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics, 60*(7), 627–636.

Hestenes, D., & Wells, M. (1992). A mechanics baseline test. *The Physics Teacher, 30*(3), 159–166.

Hestenes, D., Wells, M., & Swackhammer, G. (1992). Force concept inventory. *The Physics Teacher, 30*(3), 141–158.

Hoekstra, A. (2008). Vibrant student voices: exploring the effects of the use of clickers in large college courses. *Learning, Media and Technology, 33*(4), 329-341.

Hufnagel, B., Slater, T. F., Deming, G., Adams, J. P., Adrian, R. L., Brick, C., & Zeilik, M. (2000). Pre-course results from the astronomy diagnostic test. *Publications of the Astronomical Society of Australia, 17*(2), 152–155

Hughes-Hallett, D., Gleason, A. M., McCallum, W. G., Flath, D. E., Lock, P. F., Tucker, T. W., Lomen, D. O., Lovelock, D., Mumford, D., Osgood, B. G., Quinney, D., Rhea, K., & Tecosky-Feldman, J. (2005). *ConcepTests.* New York: John Wiley & Sons.

Junkin, W. *Beyond Question.* Retrieved May, 2008, from http://www.erskine.edu/bq/

Knight, J. K., & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4*(4), 298–310.

Labudde, P., Herzog, W., Neuenschwander, M. P., Violi, E., & Gerber, C. (2000). Girls and physics: teaching and learning strategies tested by classroom interventions in grade 11. *International Journal of Science Education, 22*(2), 143–157.

Landis, C. R., Ellis, A. B., Lisensky, G. C., Lorenz, J. K., Meeker, K., & Wamser, C. C. (2001). *Chemistry ConcepTests: A pathway to interactive classrooms.* Upper Saddle River: Prentice Hall.

Lasry, N. (2008). Clickers or flashcards: Is there really a difference? *The Physics Teacher, 46*(4), 242–245.

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From Harvard to community colleges. *American Journal of Physics, 76*(11), 1066-69.

Lawson, A. E. (1978). The development and validation of a classroom test of formal reasoning. *Journal of Research in Science Teaching, 15*(1), 11–24.

Lorenzo, M., Crouch, C. H., & Mazur, E. (2006). Reducing the gender gap in the physics classroom. *American Journal of Physics, 74*(2), 118–122.

Maloney, D. P., O'Kuma, T. L., Hieggelke, C. J., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics, 69*(7/Supp1), S12–S23.

Mazur, E. (1997). *Peer instruction: a user's manual.* Upper Saddle River: Prentice Hall.

McDermott, L. C., Schaffer, P. S., & University of Washington Physics Education Group. (2002). *Tutorials in Introductory physics.* Upper Saddle River: Prentice Hall.

Miller, R. L., Santana-Vega, E., & Terrell, M. (2006). Can good questions and peer discussion improve calculus instruction? *Primus, 16*(3), 193–203.

Morling, B., McAuliffe, M., Cohen, L., & DiLorenzo, T. (2008). Efficacy of personal response systems ("clickers") in large introductory psychology classes. *Teaching of Psychology, 35*(1), 45–50.

Nicol, D. J., & Boyle, J. T. (2003). Peer instruction versus class-wide discussion in the large classes: A comparison of two interaction methods in the wired classroom. *Studies in Higher Education, 28*(4), 457–474.

Pollock, S. J., Finkelstein, N. D., & Kost, L. E. (2007). Reducing the gender gap in the physics classroom: How sufficient is interactive engagement? *Physical Review Special Topics - Physics Education Research, 3* (010107), 4 pages.

Rao, S., & DiCarlo, S. (2000). Peer instruction improves performance on quizzes. *Advances in Physiology Education, 24*(1), 51–55.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics, 66*(3), 212–224.

Starting point—Teaching entry level geoscience: ConcepTest examples. (2008). Retrieved May, 2008, from http://serc.carleton.edu/introgeo/interactive/ctestexm.html

Terrell, M. (2005). *GoodQuestions Project.* Retrieved May, 2008, from http://www.math.cornell.edu/~GoodQuestions/

Sokoloff, D. & Thornton, R. (1997). Using interactive learning demonstrations to create an active learning environment. *AIP Conference Proceedings, 399*, 1061–1074.