CHAPTER 8

Peer Instruction:

Making Science Engaging

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Science is a creative process where the synthesis of new ideas requires discussion and debate. However, the traditional model for teaching assumes that all information presented to students is automatically learned. As a result, most students leave their introductory science courses frustrated and without a solid conceptual understanding. At the same time, instructors feel that students have not lived up to their expectations, yet they cannot identify the problem. Peer Instruction (PI) is an interactive approach that was designed to improve the learning process. This approach provides students with greater opportunity for synthesizing the concepts while instructors get timely feedback that can help focus the instruction on the points that are the most difficult for the students. PI is flexible and easy to use on its own or in conjunction with other teaching methods. This chapter discusses the motivation for using PI and the mechanics of implementing it in the classroom.

Why Use PI?

Science instructors are often faced with the problem that students leave their courses without a good grasp of the concepts, in some cases even in spite of having obtained good grades in the course (Crouch and Mazur 2001). The primary goal of PI (Mazur 1997) is to improve students' conceptual understanding of the course material.

The basic premises of PI are that students need an opportunity to discuss the concepts with one another and that instructors need timely feedback on what the students do and do not understand. Students are given time in class to explore their understanding of the material by participating in a genuine scientific discussion. At the same time, instructors can gain valuable feedback by listening in on these conversations. Even more important for the instructor, feedback is received from all of the students in response to the administration of a conceptual test (see the section on ConcepTests later in this chapter). A full description of the PI method is presented in a later section.

New teaching methods can be daunting to implement, but the modular nature of PI allows for as much or as little implementation as an instructor is comfortable with. PI is not a rejection of the lecture format, but a supplement that can help engage students who have a range of learning styles. The research shows that PI is an effective method for improving student learning.

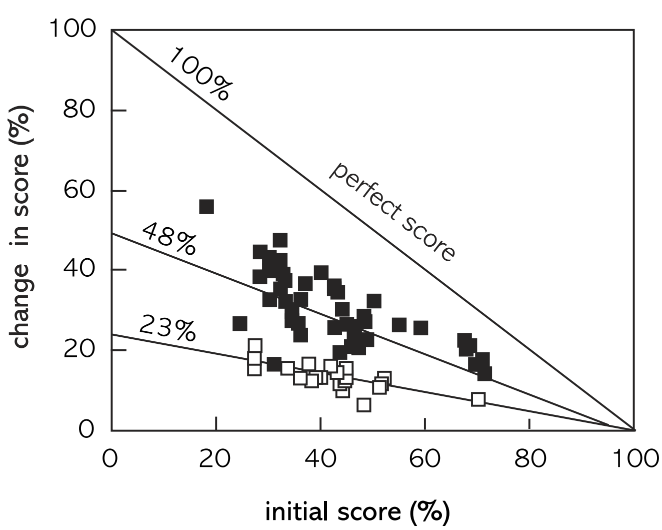
The Achievements of PI

Research has shown that students in courses using interactive engagement techniques, including PI, achieve a much greater gain in conceptual understanding than students in traditional lecture courses while also improving their ability to solve quantitative problems (Crouch and Mazur 2001; Hake 1998).

To assess students' conceptual understanding of Newtonian mechanics, Hestenes, Wells, and Swackhammer (1992) developed the Force Concept Inventory (FCI), which was revised by Halloun, Hake, Mosca, and Hestenes in 1995 (Mazur 1997). Many instructors use the FCI as a measure of the effectiveness of an instructional method by giving the test before and after their course. The gain in the students' scores then provides a measure of the gain in their conceptual understanding of Newtonian mechanics. Figure 8.1 shows the average gain on the FCI for tradi-

Figure 8.1

The Impact of Interactive Engagement on Force Concept Inventory (FCI) Score



Each square represents the average gain in score vs. the average initial score for all of the students in a class. The open squares show the gain in FCI score in lecture-based courses (average gain out of maximum possible = 23%); the filled squares show the gain for active engagement courses (average gain out of maximum possible = 48%). The "perfect score" line shows the gain required to take students to a score of 100%.

tional lecture courses and interactive engagement courses as a function of the initial score. Each point represents the average for all of the students in a particular class. In traditional lectures, students, on average, only realize 23% of the maximum possible gain at the end of the course, whereas in interactive engagement courses they realize 48% of the possible gain (Hake 1998). For PI specifically, students realize 49–74% of the possible gain (Crouch and Mazur 2001).

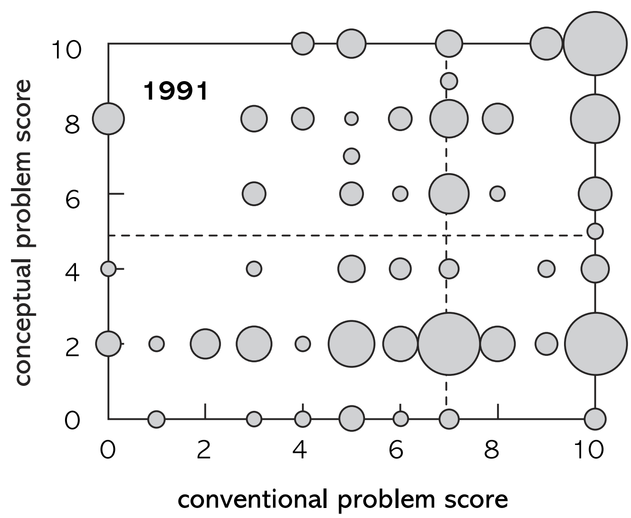
Time spent on developing conceptual understanding does not jeopardize students' quantitative problem solving. The top panel in Figure 8.2 shows the relationship between student scores on a single conceptual and conventional (quantitative) problem on the same subject in a traditional lecture course. Note that the size of the points is proportional to the number of students who got that score. The bottom panel is the same plot for students in a PI course. The dashed lines show the average scores on the conceptual and conventional problems. Only a small fraction of students in the traditional lecture course got the conceptual question correct. In fact, there are many students who got perfect scores on the conventional problem but only got 0–2 on the conceptual problem; these students have learned how to "plug and chug" without understanding the meaning of what they are doing. The scores on the conceptual problem for students in the PI course were greatly improved, while the difference in the scores on the conventional problem was small.

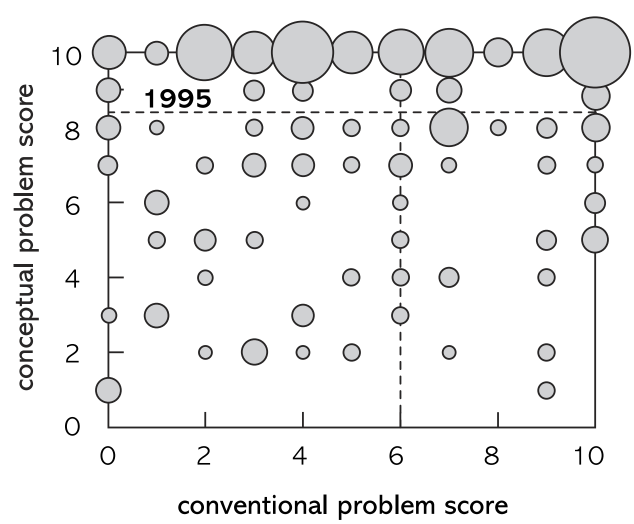
The Mechanics Baseline Test (MBT; Hestenes and Wells 1992) provides a quantitative measure of students' problem-solving ability. Like the FCI, the MBT is a standardized test that is often given to measure the effectiveness of an instructional method in a mechanics course. Figure 8.3 shows the MBT results for a study of problem solving in a traditional lecture course (1990) and in PI courses (1991–1997) for the full test and for the quantitative questions (Crouch and Mazur 2001). Despite the conceptual nature of the PI courses, the average MBT scores on the full test and specifically on the quantitative questions are higher than for the traditional course.

Figure 8.2

The Relationship Between Student Answers to a Conceptual and Conventional Problem on the Same Topic

The top panel is for students in a traditional lecture course; the bottom panel is for students in a Peer Instruction (PI) course. The size of the dots is proportional to the number of students with a given score. The dashed lines show the average scores. The students in the PI course show a large increase in their scores on the conceptual problem and only a small change on the conventional problem.





A gender gap exists in the FCI scores when students enter physics courses. In a study of Introductory Physics students at Harvard between 1990 and 1997, the average FCI pretest score was 72 ± 1.7% for men and 61 ± 0.9% for women (Lorenzo, Crouch, and Mazur 2006). Both male and female students gain a much better conceptual understanding in courses taught using PI; however, the gain for female students is much greater than for their male peers. The posttest gender gap (the difference between male and female scores) is reduced by only 9% in traditional lecture courses, but by 74% in courses using PI. Most notably, at the end of PI courses there is no statistically significant gender gap in the FCI scores.

The research shows that PI is an important technique for improving both conceptual and problem-solving skills in science courses. In addition, the method provides a way to close the achievement gap between male and female students while improving the achievement of all students.

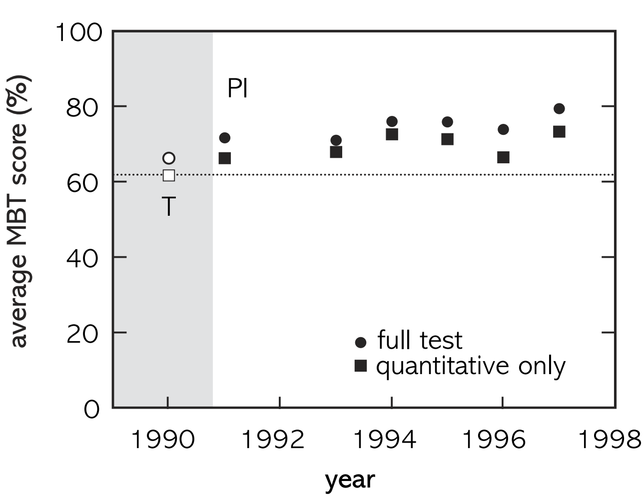
The PI Method

The basic components of PI are (1) preclass reading assignments, (2) mini-lectures, (3) ConcepTests, and (4) discussion. When these components are added to a course, one must also consider how problem solving is to be incorporated and how exams are to be structured. Other elements can also be combined with PI, including traditional lecture and other interactive engagement techniques, but we do not discuss those here.

Figure 8.3

The Average Scores on the Mechanics Baseline Test (MBT) for an Introductory Physics Course Taught With Traditional Lecture (T; 1990) and With Peer Instruction (PI; 1991–1997)

The circles are for the full test, and the squares are for the quantitative questions. Reprinted with permission from C. H. Crouch and E. Mazur, "Peer Instruction: Ten Years of Experience and Results," *American Journal of Physics* 69: 970–977, 2001. Copyright 2001, American Association of Physics Teachers.



Preclass Reading Assignments

Preclass reading assignments are designed to motivate students and to engage them in the reading. The assignments consist of a text to be read along with several challenging conceptual questions, graded purely on effort. In addition, the students are always asked, "What did you find most confusing? If nothing, what did you find most interesting?" The students submit their answers to the reading questions electronically long enough before class that the instructor has time to review the answers (see the "Implementing PI" section later in this chapter for a discussion of adopting preclass reading with and without computer technology). The conceptual questions are designed to probe students' understanding of the material, not their ability to search for the appropriate answer in the text. Based on the knowledge gleaned from a review of their answers (not necessarily a thorough reading of all responses), the instructor can select the appropriate content to be discussed in detail in class.

Mini-Lectures

Each PI class consists of several mini-lectures that focus on key topics where students have difficulties or misconceptions. These difficulties or misconceptions can be identified from previous teaching experience, student answers to the preclass reading, or the literature. Each mini-lecture is only about 10 minutes, so it must be concise and focused on a single subject. This is in contrast to standard lectures, which last for an entire class and tend to have the breadth and detail more comparable to the material covered in the textbook.

ConcepTests

The mini-lectures are interspersed with ConcepTests—short conceptual questions designed to probe student understanding of one of the concepts discussed. The ConcepTests, such as the sample shown in Figure 8.4, are based on misconceptions or student difficulties (see sidebar, "Writing and Vetting ConcepTests").

The ConcepTest is administered according to the following sequence:

1. Question posed (1 minute)
2. Students given time to think (1 minute)
3. Students record individual answers
4. Students convince their neighbors (optional, based on results of 3; 1–2 minutes)
5. Students record revised answers
6. Feedback to instructor: Tally of answers
7. Explanation of correct answer (2+ minutes)

As indicated in this sequence, the students are given time to formulate their answer (step 2) and then record it (step 3). Once they have committed to an answer, the students then discuss their answers with each other (step 4), as long as enough students have the correct answer (see "Discussion" section for details). After this discussion the students record their (possibly revised) answer again (step 5). This process forces students to think through and talk through the arguments being developed, providing them and the instructor with an assessment of their understanding of the concept.

Figure 8.4

A Sample ConcepTest From a Newtonian Mechanics Course

A ball is thrown downward (not dropped) from the top of a tower. After being released, its downward acceleration is:

1. greater than g
2. exactly g
3. smaller than g
4. not covered in the reading assignment

Writing and Vetting ConcepTests

- Use questions based on student difficulties, mistakes, and misconceptions.
- Focus on a single concept.
- Ask questions that cannot be solved by relying on equations.
- Make sure questions and answers are clear and concise.
- Use only questions that are manageable in their level of difficulty.
- Keep track of questions that produce good discussion and improvement in understanding.
- Make use of existing question databases (e.g., *www.deas.harvard.edu/galileo* and *www.flaguide.org/tools/tools_technique.php*).

Discussion

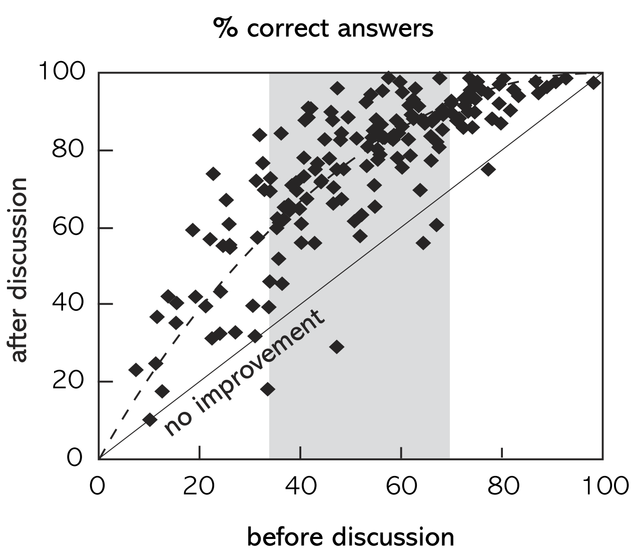
Whether to have students discuss their answers after a ConcepTest depends on what fraction of students get the correct answer. Figure 8.5 shows the percentage of correct ConcepTest answers after discussion as a function of the percentage of correct answers before discussion. Each data point corresponds to a single ConcepTest. The dashed line shows the trend defined by these points. The aim of having students discuss their answers to a ConcepTest is to improve their understanding of the concept. The farther above the "no improvement" line the points are in Figure 8.5, the larger the fraction of students who moved from the incorrect answer before discussion to the correct answer after discussion. If the percentage of correct answers before discussion is too low (< 35%), then most of the students in the class have not understood the concept; in this case, slowing down, lecturing in more detail on the same subject, and then reassessing with another ConcepTest is more effective than a student discussion. If the percentage of correct answers before discussion is high (> 70%), then most students have understood the concept and one can proceed without discussion. The shaded region on Figure 8.5 highlights the prediscussion ConcepTest scores for which the largest fraction of students move to the correct answer after discussion. It is in this region that students derive the maximum benefit from discussing their answers with their peers.

Figure 8.6 shows the percentage of students who moved from the incorrect answer to the correct answer after discussion versus the percentage of students who got the correct answer both times. This figure shows that the fraction of students who are convinced to change their minds from the incorrect to the correct answer after discussion is larger when the initial percentage of students who understand the concept is larger.

Figure 8.5

Effect of Discussion on ConcepTest Scores

The plot shows ConcepTest score averages for the entire class before (*x*-axis) and after (*y*-axis) discussion. The solid line indicates where points would fall if discussion did not improve student scores. The shaded region shows where 35%–70% of students get the correct answer before discussion. This is the region in which discussion among the students produces the largest increase in correct answers.



Problem Solving

Quantitative problem solving is an important aspect of many science courses and is entirely compatible with PI. As discussed in the earlier section on the achievements of PI, the improvement in conceptual understanding from PI does lead to better problem solving (Crouch and Mazur 2001).

Problem solving requires logical reasoning as well as mathematical skills. The problem with the way conventional problems are presented in a standard introductory textbook is that most textbooks test mathematical instead of analytical thinking skills. By adding conceptual questions to the curriculum, students are led to develop their logical reasoning skills as well as their mathematical skills, both of which help them become better problem solvers. The development of mathematical skills to complement the logical reasoning developed with PI requires time and practice. Time can be devoted during a mini-lecture or, more effectively, as part of small-group problem-solving sessions as discussed in the section on implementation of PI later in this chapter. Quantitative homework assignments also provide an opportunity for students to practice this skill.

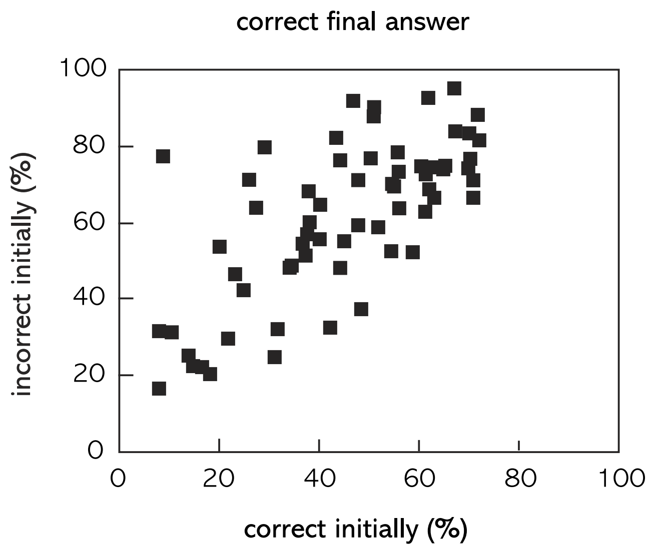
Exams

One of the best ways to help students accept a new teaching method is to make the exams reflect the philosophy of the course. If only conceptual questions are addressed in class and in homework, then exams should contain only conceptual questions. Alternatively, if the students have been exposed to a mix of conceptual and mathematical questions, then the exams should reflect that balance. Students should not be faced with something completely new in a high-stakes, high-pressure situation. Adding conceptual questions on exams also reinforces that such questions are important and makes it more likely that the students will recognize the value of the ConcepTests.

Figure 8.6

Effect of the Percentage of Students Who Initially Get a ConcepTest Correct on the Postdiscussion Response of Students Who Initially Got It Incorrect

The plot shows the fraction of students who are convinced to change their minds from the incorrect to the correct answer after discussion vs. the percentage of students who got the correct answer both times.



Implementing PI

PI is designed to be flexible and easy to implement—one could ask a single ConcepTest, implement all of the components of PI, or do something in between. The modular nature of PI allows for experimentation with the method without total disruption of a previously established course design. In addition, PI can easily be combined with other classroom methods such as tutorials (e.g., Adams et al. 2003; McDermott, Schaffer, and the University of Washington Physics Education Group 2002), group work (see, e.g., *http://groups.physics.umn.edu/physed/Research/CGPS/GreenBook.html*), other active engagement techniques (see, e.g., *www.calstatela.edu/dept/chem/chem2/Active/index.htm*), or standard lecture.

To convert a traditional lecture to a PI format, one must select the concepts in the lecture that are the most difficult for the students. The preclass reading assignments, prior knowledge of students' difficulties and misconceptions, and the literature can help guide this selection. The goal is to avoid spending significant amounts of class time on the material the students can obtain on their own. Mini-lectures (from one to six, depending on the overall class format and length) and the ConcepTests for each mini-lecture can then be based on the most difficult concepts of the material to be covered. Which and how many of the ConcepTests are administered can be based on the student scores on the ConcepTests and the misconceptions/difficulties that come to light in their discussions (see sidebar, p. 81).

In a PI course most of the quantitative problem solving is done outside class. Small-group sessions are an effective means of improving students' problem-solving skills. Quantitative problem solving can be incorporated as part of the homework and small-group sessions.

Technology is useful but not necessary for the implementation of PI. For the preclass reading assignments, technology is especially beneficial because it allows the instructor to view student answers to the reading questions before class (Novak et al. 1999). If computer access is limited, reading quizzes can be administered at the beginning of class to motivate students to do the reading ahead of time. The Interactive Learning Toolkit (for more information see *http://deas.harvard.edu/ilt*) can be used for the administration of preclass reading assignments and other pieces of a PI course (Blackboard [*www.blackboard.com*] and other online resources can also be used for this purpose). Unlike the preclass reading assignments, ConcepTests can easily be administered in multiple high- and low-tech ways. The most common examples are flashcards, personal response systems (PRS), and handheld computers.

- *Flashcards:* Each student is given a set of six or more cards labeled with letters or numbers (and sometimes color coded as well) to signal the answer to a question. Flashcards are an easy, low-tech way to gather student answers, but there is no permanent record of the answers provided by the students.
- *PRS:* Many institutions are now investing in radio or infrared devices that allow students to "click in" their answer, providing the instructor with an instantaneous histogram and a permanent record of the student responses. The disadvantage of this method is cost, but systems are getting cheaper and more commonly available. For more information on PRS, see *www.vanderbilt.edu/cft/resources/teaching_resources/technology/crs.htm*.
- *Handheld computers:* Many students come to class with a variety of communication or computing devices—cellular phones, palmtops, and laptops. Technology is now being developed so that these devices can all be used to provide responses to ConcepTests (for more information on this developing technology, see *http://mazur-www.deas.harvard.edu/lt3*).

While the improvisation required to use ConcepTests in the classroom may seem daunting at first, they often make teaching easier for the instructor and learning easier for the student. Students are given the opportunity to take a break from listening in order to think about and discuss the material being presented. The instructor is given a chance to listen to how students explain the material to one another. Students sometimes provide a completely different perspective on the material—one that is often more convincing to their peers because the students understand why the concepts are difficult. Putting ideas into words helps the students develop their understanding. At the same time, PI provides feedback to the instructor that is often lacking in the conventional classroom.

Summary

Research has shown that students often leave introductory science courses with little gain in understanding of the scientific concepts. Interactive engagement in the classroom using PI can increase students' understanding and can shrink the achievement gap between men and women. The method is easy to implement either within an existing course structure or as a redesign of a course. PI provides a dynamic environment in which instructors get feedback from students and students become active participants in the learning process. More information on PI, including an interactive DVD tutorial, is available at *www.teachingdvd.com*.

Recommendations

When deciding to implement a new teaching method in your course, there are issues to consider in terms of how you, your colleagues, and your students are going to respond to the changes. Here are a few suggestions to help make this change with PI:

1. *Convince yourself (and your colleagues) that changing the format of your course makes sense.* To this end, administering a benchmark test like the Force Concept Inventory (Hestenes, Wells, and Swackhammer 1992), the Mechanics Baseline Test (Hestenes and Wells 1992), the Astronomy Diagnostic Test (Zeilik et al. 1997), and the California Chemistry Diagnostic Test (Russell 1994) can provide useful data. Ideally you should administer the test both at the beginning and end of the semester—first during your conventional course and then when you are using PI. These data will provide a clear picture of what the changes to the course have accomplished.
2. *Motivate the students.* Students resist change, so explaining what you are doing, why you are making these changes, and how they will benefit is probably the most important thing you can do to make the change in your course succeed.
3. *Change the exams to reflect the change in the course format.* Students focus much, if not most, of their attention on exams, and their feelings about the course often reflect whether they felt that the exam adequately reflects the class activities. If most of the class time is spent on concepts, then giving exams that include conceptual questions is necessary for students to appreciate the time spent on conceptual material.
4. *Maintain adequate opportunities for problem solving.* For any course where problem solving is still an important part of the curriculum, there must be time devoted to developing this skill. Opportunities for students to sharpen their problem-solving skills include homework assignments and problem-solving sessions.

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