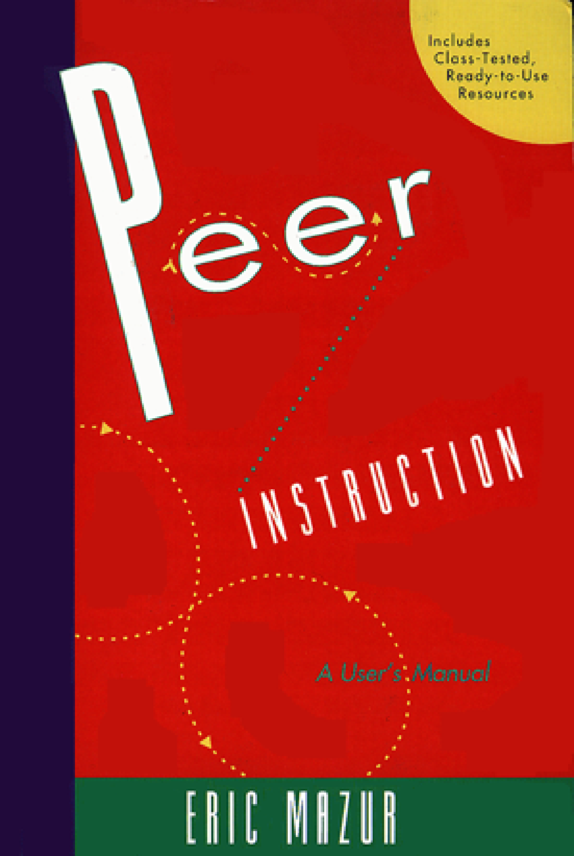

Includes
Class-Tested,
Ready-to-Use
Resources

Peer INSTRUCTION

A User's Manual

ERIC MAZUR

ei PRENTICE HALL SERIES IN EDUCATIONAL INNOVATION

Eric Mazur is Gordon McKay Professor of Applied Physics and Professor of Physics at Harvard University. He has taught introductory physics at Harvard since 1984. In addition to leading a research program in optical physics, Mazur maintains an active interest in educational innovation.

In 1991, Eric Mazur developed Peer Instruction, a simple yet effective method for teaching science. His approach involves students in the teaching process, making physics significantly more accessible to them. His technique has been highly successful and numerous instructors are already using Mazur's approach in their classes.

Many instructors have pointed out the benefits of teaching by questioning over the more traditional approach of teaching by telling. Here, at last, is a book that not only explains how to teach by questioning but also provides all the necessary tools to implement this new approach with a minimum of effort.

Praise for *Peer Instruction: A User's Manual*:

"I found this approach to be entirely different from anything I have seen. It is highly provocative and the author's style is very engaging."
Mark W. Holtz
Texas Tech University

"I am familiar with Mazur's efforts and am a great fan of using some form of Peer Instruction which Mazur has developed. At Rensselaer, we are using this technique. The Peer Instruction manual is wonderful in that it describes the process in a way which I think will encourage others to adopt the technique."
Leo J. Schowalter
Rensselaer Polytechnic Institute

"I am very impressed with the material and think people will recognize that Mazur is on to something and will want to adopt his ideas."
Joseph Priest
Miami University

"I have been using Mazur's Peer Instruction methods. The ConcepTests and ensuing discussions have certainly improved the atmosphere in the classroom, and both students and I appreciate the instant feedback and chance to confront misconceptions."
Joel R. Primack
University of California, Santa Cruz

"I like the idea of Peer Instruction. Physics is not a 'spectator sport.' It is something that must be 'learned' rather than 'taught.'"
Claude Penchina
University of Massachusetts, Amherst

"If you get to solve it for yourself, you are doing the thinking. There is an 'aha!' kind of sensation: 'I've figured it out!' — it's not that someone just told it to me, I actually figured it out. And because I can figure it out now, that means I can figure it out on the exam, I can figure it out for the rest of my life."
Francine Wiest
biology major

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PREFACE

I love teaching. What attracted me to science was not only the excitement of doing science, the beauty of discovering new truths, but also the satisfaction of transferring this excitement and curiosity to others.

I have taught undergraduates at Harvard since joining the faculty in 1984. Initially I thought—as many other people do—that what is taught is learned, but over time I realized that nothing could be further from the truth. Analysis of my students' understanding of Newtonian mechanics made it clear: They were not all learning what I wanted them to learn. I could have blamed the students for this had I not always been bothered by the frustration that introductory science courses stir up in some students. What is it about science that can lead to such frustration? I decided to change my teaching style and discovered that I could do much better in helping my students learn physics. That is what this manual is about.

I have developed an interactive teaching style that helps students better understand introductory physics. The technique, named *Peer Instruction*, actively involves the students in the teaching process. It is simple and—as many others have demonstrated—it can easily be adapted to fit individual lecture styles. It makes physics not only more accessible for students but also easier to teach.

This manual contains a step-by-step guide on how to plan *Peer Instruction* lectures using your existing lecture materials. In addition, it includes a complete set of class-tested and ready-to-use material to implement the method in a one-year introductory physics course:

- Two diagnostic tests to evaluate your students' understanding of mechanics.
- Student questionnaire handouts to assess students' expectations for the course and to point out misconceptions.

- 44 Reading Quizzes, organized by subject and designed to be given at the beginning of each class to motivate the students to read assigned material before class.
- 243 *ConcepTests*, multiple-choice questions for use in lecture to engage the students and to assess their understanding.
- 109 Conceptual Examination Questions, organized by major topic and designed to reinforce the basic philosophy of the method of *Peer Instruction.*

The enclosed diskettes contain these same materials reformatted as necessary so that they can be easily reproduced as overhead transparencies or handouts. (See the Appendix on Disk Instructions for more details.) The resources are a work in progress, and will continue to evolve. To complement the material in this book, a continually updated set of additional resources is available on the world-wide web at "http://galileo.harvard.edu". This server will act as an interactive forum for instructors who are implementing *Peer Instruction* in their courses. Your participation will be much appreciated by all users. I also welcome your comments, suggestions, or corrections for this manual. Please feel free to send me e-mail at "mazur@physics.harvard.edu".

Many have contributed to this effort. The idea of using questions during the lecture was first suggested to me by Dudley Herschbach in the Chemistry Department at Harvard University. Debra Alpert, who joined me as a postdoctoral associate in 1991, has assisted me with much of the research here and played an active role in the development of the resource material. I am grateful to Anne Hoover who distributed hundreds of copies of an early version of this manual, allowing many people to introduce the method at their own institutions. I thank them all. I would also like to thank my colleagues Michael Aziz, William Paul, and Robert M. Westervelt at Harvard for their willingness to experiment along with me and for their contributions to the resource material. All of us owe much to the students in Physics 11 at Harvard, who were an integral part of the early experiments and who taught us how to teach them. I would also like to thank Albert Altman for his unfailing enthusiasm and the energy with which he implemented the method at the University of Massachusetts at Lowell and Charles Misner for the excellent suggestion to include resource material with the manual. Special thanks go to David Hestenes, Ibrahim Halloun, Eugene Mosca, Richard Hake, the late Malcolm Wells and Gregg Swackhamer for developing the *Force Concept Inventory* and the *Mechanics Baseline Test* as well as for their permission to include these in the book.

I am enormously grateful to the following reviewers of the manuscript for *Peer Instruction: A User's Manual* and their many insightful and pragmatic comments: Albert Altman, University of Massachusetts, Lowell; Arnold Arons, University of Washington; Bruce B. Birkett II, University of California, Berkeley; Paul Draper, University of Texas at Arlington; Robert J. Endorf, University of Cincinnati; Thomas Furtak, Colorado School of Mines; Ian R. Gatland, Georgia Institute of Technology; J. David Gavenda, University of Texas at Austin; Kenneth A. Hardy, Florida International University; Greg Hassold, GMI Engineering and Management Institute; Peter Heller, Brandeis University; Laurent Hodges, Iowa State University; Mark W. Holtz, Texas Tech University; Zafir A. Ismail, Daemen College; Arthur Z. Kovacs, Rochester Institute of Technology; Dale D. Long, Virginia Polytechnic Institute; John D. McCullen, University of Arizona; James McGuire, Tulane University; Charles W. Misner, University of Maryland, College Park; George W. Parker, North Carolina State University; Claude Penchina, University of Massachusetts, Amherst; Joseph Priest, Miami University; Joel R. Primack, University of California, Santa Cruz; Lawrence B. Rees, Brigham Young University; Carl A. Rotter, West Virginia University; Leonard Scarfone, University of Vermont; Leo J. Schowalter, Rensselaer Polytechnic Institute; H. L. Scott, Oklahoma State University; Shahid A. Shaheen, Florida State University; Roger L. Stockbauer, Louisiana State University; William G. Sturrus, Youngstown State University; Robert S. Weidman, Michigan Technological University.

Finally I would like to thank Tim Bozik at Prentice Hall for encouraging me to publish this manual and Irene Nunes, who edited this manuscript with meticulous attention to detail and who contributed many valuable comments. I am also grateful to Alison Reeves, Alison Aquino, Carol Trueheart, Ray Mullaney, Eric Hulsizer, and Jeff Henn who all worked hard to turn the manuscript into a book.

CONCORD, MA

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PEW
SCIENCE PROGRAM
IN UNDERGRADUATE EDUCATION

1

INTRODUCTION

The introductory physics course often is one of the biggest hurdles in the academic career of a student. For a sizable number of students, the course leaves a permanent sense of frustration. I have only to tell people I am a physicist to hear grumblings about high school or college physics. This general sense of frustration with introductory physics is widespread among non-physics majors required to take physics courses. Even physics majors are frequently dissatisfied with their introductory courses, and a large fraction of students initially interested in physics end up majoring in a different field. Why does this happen, and can we do something about it? Or should we just ignore this phenomenon and concentrate on teaching the successful student who is going on to a career in science?

AN EYE OPENER

Frustration with introductory physics courses has been commented on since the days of Maxwell and has recently been widely publicized by Sheila Tobias, who asked a number of graduate students in the humanities and social sciences to audit introductory science courses and describe their impressions.[1] The result of this survey is a book that paints a bleak picture of introductory science education. One may be tempted to brush off complaints by non-physics majors as coming from students who are *a priori* not interested in physics. Most of these students, however, are not complaining about other required courses outside their major field. In science education, in Tobias' words, the next generation of science workers is expected to rise like cream to the top, and the system is unapologetically competitive, selective, and intimidating, designed to winnow out all but the top tier.

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[1] Sheila Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier,* Tucson, AZ: Research Corporation, (1990).

The way physics is taught in the 1990s is not much different from the way it was taught—to a much smaller and more specialized audience—in the 1890s, and yet the audience has vastly changed. Physics has become a building block for many other fields, and enrollment in physics courses has grown enormously, with the majority of students not majoring in physics. This shift in constituency has caused a significant change in student attitude toward the subject and made the teaching of introductory physics a considerable challenge. Although conventional methods of physics instruction have produced many successful scientists and engineers, far too many students are unmotivated by the conventional approach. What, then, is wrong with it?

I have been teaching an introductory physics course for engineering and science majors at Harvard University since 1984. Until 1990, I taught a conventional course consisting of lectures enlivened by classroom demonstrations. I was generally satisfied with my teaching—my students did well on what I considered difficult problems, and the evaluations I received from them were very positive. As far as I knew, there were not many problems in *my* class.

In 1990, however, I came across a series of articles by Halloun and Hestenes[2] that really opened my eyes. As is well known, students enter their first physics course possessing strong beliefs and intuitions about common physical phenomena. These notions are derived from personal experience and color students' interpretations of material presented in the introductory course. Halloun and Hestenes show that instruction does little to change these "commonsense" beliefs.

For example, after a couple of months of physics instruction, all students can recite Newton's third law and most of them can apply it in numerical problems. A little probing, however, quickly shows that many students do not understand the law. Halloun and Hestenes provide many examples in which students are asked to compare the forces exerted by different objects on one another. When asked, for instance, to compare the forces in a collision between a heavy truck and a light car, many students firmly believe the heavy truck exerts a larger force. When reading this, my first reaction was "Not *my* students...!" Intrigued, I decided to test my own students' conceptual understanding, as well as that of the physics majors at Harvard.

The first warning came when I gave the Halloun and Hestenes test to my class and a student asked, "Professor Mazur, how should I answer these questions? According to what you taught us, or by the way I *think* about these things?" Despite this warning, the results of the test came as a shock: The students fared hardly better on the Halloun and Hestenes test than on their midterm examination. Yet, the Halloun and Hestenes test is *simple*, whereas the material covered by the examination (rotational dynamics, moments of inertia) is of far greater difficulty or so I thought.

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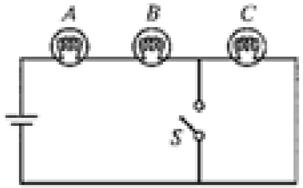
[2] Ibrahim Abou Halloun and David Hestenes, *Am. J. Phys.* 53, (1985), 1043; *ibid.* 53, (1985), 1056 ; *ibid.* 55, (1987), 455; David Hestenes, *Am. J. Phys.* 55, (1987), 440.

MEMORIZATION VERSUS UNDERSTANDING

To understand these seemingly contradictory observations, I decided to pair, on subsequent examinations, simple qualitative questions with more difficult quantitative problems on the same physical concept. An example of a set of such questions on dc circuits is shown in Figure 1.1. These questions were given as the first and last problem on a midterm examination in the spring of 1991 in a conventionally taught class (the other three problems on the examination, which were placed between these two, dealt with different subjects and are omitted here).

1. A series circuit consists of three identical light bulbs connected to a battery as shown here. When the switch *S* is closed, do the following increase, decrease, or stay the same?



(*a*) The intensities of bulbs *A* and *B*
(*b*) The intensity of bulb *C*
(*c*) The current drawn from the battery
(*d*) The voltage drop across each bulb
(*e*) The power dissipated in the circuit

5. For the circuit shown, calculate (*a*) the current in the 2-Ω resistor and (*b*) the potential difference between points *P* and *Q*.

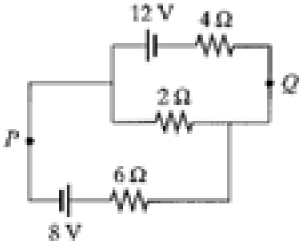


Figure 1.1 Conceptual (top) and conventional question (bottom) on the subject of dc circuits. These questions were given on a written examination in 1991.

Notice that question 1 is purely conceptual and requires only a knowledge of the fundamentals of simple circuits. Question 5 probes the students' ability to deal with the same concepts, now presented in the conventional numerical format. It requires setting up and solving two equations using Kirchhoff's laws. Most physicists would consider question 1 easy and question 5 harder. As the result in Figure 1.2 indicates, however, students in a conventionally taught class would disagree.

Analysis of the responses reveals the reason for the large peak at 2 for the conceptual question: Over 40% of the students believed that closing the switch doesn't change the current through the battery but that the current splits into two at the top junction and rejoins at the bottom! In spite of this serious misconception, many still managed to correctly solve the mathematical problem.

Figure 1.3 shows the lack of correlation between scores on the conceptual and conventional problems of Figure 1.1. Although 52% of the scores lie on the broad diagonal band, indicating that these students achieved roughly equal scores on both questions (±3 points), 39% of the students did substantially worse on the conceptual question. (Note that a number of students managed to score zero on the conceptual question and 10 on the conventional one!) Conversely, far fewer students (9%) did worse on the conventional question. This trend was confirmed on many similar pairs of problems during the remainder of the semester: Students tend to perform significantly better when solving standard textbook problems than when solving conceptual problems covering the same subject.

This simple example exposes a number of difficulties in science education. First, it is possible for students to do well on conventional problems by memorizing algorithms without understanding the underlying physics. Second, as a result of this, it is possible for a teacher, even an experienced one, to be completely misled into thinking that students have been taught effectively. Students are subject to the same misconception: They believe they have mastered the material and then are severely frustrated when they discover that their plug-and-chug recipe doesn't work in a different problem.

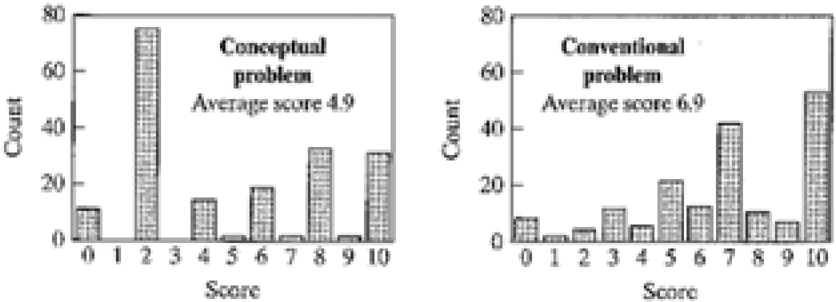


Figure 1.2 Test scores for the problems shown in Figure 1.1. For the conceptual problem, each part was worth a maximum of 2 points.

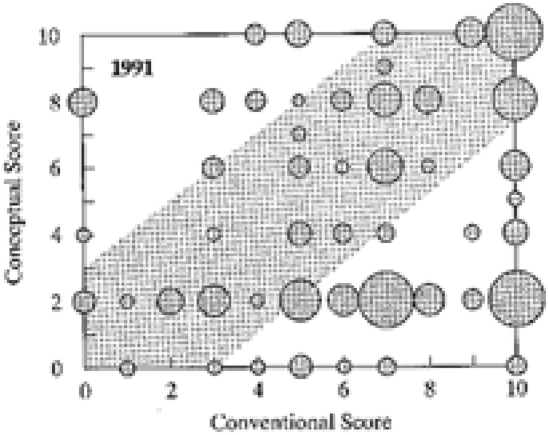


Figure 1.3 Correlation between conceptual and conventional problem scores from Figure 1.2. The radius of each datapoint is a measure of the number of students represented by that point.

Clearly, many students in my class were concentrating on learning "recipes," or "problem-solving strategies" as they are called in textbooks, without considering the underlying concepts. Plug and chug! Many pieces of the puzzle suddenly fell into place:

- The continuing requests by students that I do more and more problems and less and less lecturing—isn't this what one would expect if students are tested and graded on their problem-solving skills?
- The inexplicable blunders I had seen from apparently bright students—problem-solving strategies work on some but surely not on all problems.
- Students' frustration with physics—how boring physics must be when it is reduced to a set of mechanical recipes that do not even work all the time!