CHAPTER 6

# Instructional Implications: Some Effective Teaching Methods

*In theory, there is no difference*
*between theory and practice.*
*But in practice, there is.*
Jan L. A. van de Snepscheut
quoted in [Fripp 2000]

The information in previous chapters describing what we know about the general character of learning and about the general skills we are trying to help students develop has profound implications for building an effective instructional environment. Sagredo once asked me, "OK. You've told me all this stuff about how people learn and shown me lots of references about specific student difficulties with particular bits of physics content. Now tell me the best way to teach my physics class next term."

Sorry, Sagredo. I wish it were that straightforward. First, as I pointed out in chapter 2, no single approach works for all students. Both individual differences and the particular populations in a class need to be taken into account. Second, despite the great progress in understanding physics learning that has been made in the past two decades, we're still a long way from being able to be prescriptive about teaching. All we can give are some guidelines and a framework for thinking about what might work for you. Third, the decisions teachers (or a department) make about instruction depend very strongly on the particular goals they would like to achieve with a particular course. Traditionally, these goals have been dominated by surface features rather than by deep structure—by selecting specific content matched, perhaps, to the long-term needs of the population being addressed rather than by thinking about student learning and understanding. The education research described above allows us to expand our community's discussion about what different students might learn from taking a particular physics course. This discussion has only just begun, and it is really only in the context of such a discussion that specific optimized curricula can be developed. Our goal is to transform good teaching from an art that only a few can carry out to a science that many can learn, but we've not gotten that far yet.

The traditional approach to physics at the college level involves lectures with little student interaction, end-of-chapter problem solving, and cookbook labs. Although students who are self-motivated independent learners with strong mathematical and experimental skills thrive in this environment (as they do in almost any educational environment), this category represents only a small fraction of our students. Indeed, the group seems to be shrinking, since young people today rarely have the "hands-on" mechanical experience common to physicists "of a certain age" and their teachers. The self-motivated independent learners of today are much more likely to have created their own computer games than to have built a crystal radio, rebuilt the engine of their parents' Ford, or been inspired by Euclid's *Elements*.

At present, we not only know a lot about where and why students run into difficulties, but the community of physics educators has developed many learning environments that have proven effective for achieving specific goals. With the Physics Suite, we pull together and integrate a number of these environments. In this chapter, I give brief overviews of innovative curricular materials that have been developed in conjunction with careful research, including both Suite elements and other materials that work well with Suite elements.

Before discussing specific curricula, however, I briefly discuss what I mean by a "research-based curriculum," describe the populations for which these curricula have been developed, and consider some of the specific goals that are being addressed. After this preamble, I briefly list the curricular materials of the Physics Suite and a few others that have been developed that match well with the Suite. In the next three chapters, I discuss these materials in detail.

## RESEARCH-BASED CURRICULA

Most of the curricula that have been developed over the past few years in the United States are based at least in part on a model of student thinking and learning[1] similar to the one described in chapter 2 and have evolved using the cyclic model of curriculum development that I refer to as the research-redesign wheel. In this process, shown schematically in Figure 6.1, research on student understanding illuminates the difficulties in current instruction. The results of the research can be used to design new curricula and teaching approaches that lead to modified instruction. Research and evaluation informs on the state of effectiveness of the instruction and illuminates difficulties that remain. This process begins again and cycles in a helix of continuous educational improvement.

[1] In some, the dependence on a model of thinking and learning is tacit.

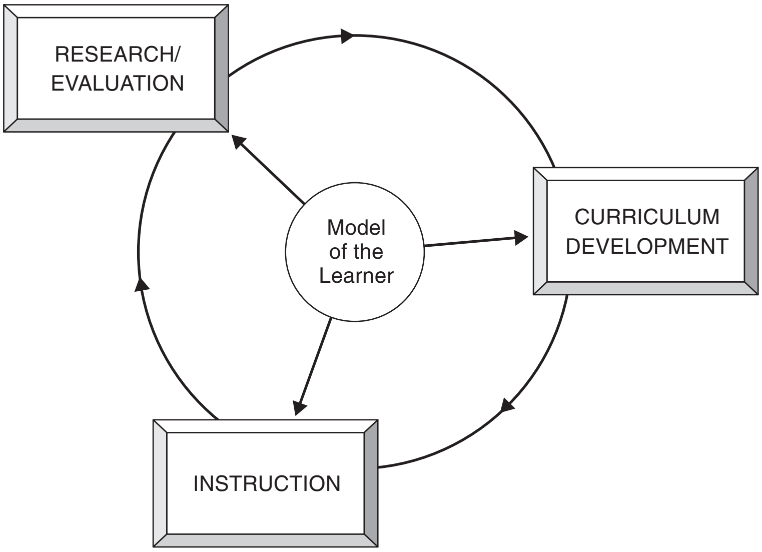


**Figure 6.1** The Research and Redesign Wheel—the role of research in curriculum reform.

Of course, to understand what one sees in a research situation, one must have a model or theory of the system under investigation in order to know what to look for and to make sense of what one sees. On the other side, the experimental observations may cause us to refine or modify our theoretical model. So to the wheel, I add an *axle*—with the model of cognition and learning serving as the point about which the wheel rotates.

The research and evaluation components in this model lead to a cumulative improvement of the curriculum that is usually absent when individual faculty members develop materials in response to local needs. In the three decades that I have been a faculty member at the University of Maryland, I have watched my colleagues, highly intelligent, dedicated to their educational tasks, and concerned about the students' lack of learning in the laboratory, modifying and redesigning the laboratories for populations of students ranging from preservice teachers to engineers and physics majors. Each faculty member changes something he or she finds ineffective and makes what he or she thinks is an improvement. But since the purpose of the change is not shared, since the value of the change is not documented, and since the culture of instruction tends to focus on the individual instructor's perception of what is good instruction, the next instructor is likely to undo whatever changes have been made and make new changes. Instead of a cumulative improvement, the curriculum undergoes a drunkard's-walk oscillation.[2] The addition of the research/evaluation component to the cycle and the input from our theoretical understandings of the student and of the learning process enable us to produce curricula that can be considerably more effective than those produced by individual faculty working alone.

[2] Perhaps one can expect a long-term improvement but only proportional to the square root of the time!

## MODELS OF THE CLASSROOM

Most physics instruction in the United States is delivered in one of two kinds of environments: the traditional, instructor-centered structure, and an active-engagement student-centered structure.

### The traditional instructor-centered environment

If the class is large (>50), there are usually three hours of class per week, with all the students meeting together. Often, there is a weekly two- or three-hour laboratory associated with the class, uncoordinated with the lecture. If there is sufficient staff (such as graduate students to serve as teaching assistants), there may be one or two hours a week of recitation—a session in which the class is divided into small groups (<30). This traditional model of introductory physics has a number of characteristics. As taught in the United States it has the following common features:

- It is content oriented.
- If there is a laboratory, it is two to three hours and "cookbook" in nature; that is, students will go through a prescribed series of steps in order to demonstrate the truth of something taught in lecture or read in the book.
- The instructor is active during the class session, while the students are passive (at least during lectures and often during recitation).
- The instructor expects the students to undergo active learning activities on their own outside of the class section, in reading, problem solving, etc., but little or no feedback or guidance is given to help the students with these activities.

For most students, the focus of the class is the lecture. The nature of this experience can be seen clearly in the structure of the classroom. A typical lecture room is illustrated in Figure 6.2. All students are turned to face the lecturer—the focus of all attention. There may be a strong tendency for the instructor to do all the talking and to discourage (or even to suppress) student questions or comments.

### The active-engagement student-centered environment

An *active-engagement* class has somewhat different characteristics.

- The course is *student centered.* What the students are actually doing in class is the focus of the course.
- Laboratories in this model are of the *guided discovery* type; that is, students are guided to observe phenomena and build for themselves the fundamental ideas via observation.
- The course may include explicit training of reasoning.
- Students are expected to be intellectually active during the class.

Active-engagement classes may occur as part of a larger class—as a recitation or laboratory combined with a traditional lecture. The smaller units have a classroom structure that

**Figure 6.2** A typical lecture classroom. Even when the lecturer is superb, the focus of the activity tends to be on the lecturer, not the students. (Here, Jim Gates presents one of his popular public lectures on string theory. Courtesy Dept. of Physics, Univ. of Maryland.)

looks something like Figure 6.3. Students' attention is focused on their work and on their interaction with the other students in their group. *Facilitators* roam the room while the students are working, checking the students' progress and asking guiding questions. There may be one or more facilitators, and they may be faculty, graduate assistants, undergraduates who have had the class previously, or volunteers looking to gain teaching experience.

I refer to such an arrangement as an *active-engagement classroom*. Of course, the structure of the room does not guarantee what will happen in that room. You can do a mindless

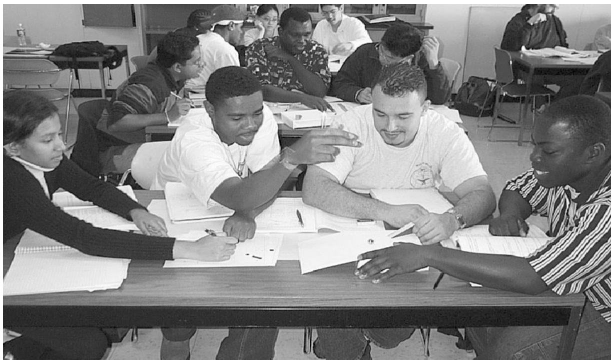

**Figure 6.3** The arrangement of an active-engagement classroom [Steinberg 2001].

cookbook lab in one of these classrooms just as easily as a highly effective discovery lab. But the structure of the room does constrain the possibilities. You can do activities in this kind of room that would be extremely difficult to carry out in a large lecture hall.

A specific type of active-engagement classroom is the *workshop* or *studio* class. In this environment, the lecture, laboratory, and recitation are combined in a single classroom. In workshop classes, most of the class time is taken up by periods in which the students are actively engaged in exploring the physics using some laboratory equipment, often involving computers in order to allow efficient high-quality data collection and to provide computer modeling tools. Only a small fraction of the period may be spent with a teacher lecturing to the students. One example of a workshop classroom is the interesting layout developed for Workshop Physics by Priscilla Laws and her collaborators at Dickinson College (see Figure 6.4). Students work two per computer station at tables with two stations. The tables are shaped so that neighboring pairs can easily collaborate. The room is set up so that there is a group interaction space in the center where demonstrations can be carried out and where the teacher can stand and easily view what is on every computer screen. This feature has the great advantage of helping the instructor identify students who might be in trouble or not on task. There is a table with a screen and blackboard at one end so that the instructor can model problem solving, do derivations, or display simulations or videos. The materials developed for Workshop Physics are a part of the Physics Suite and are discussed in detail in chapter 9.

**Figure 6.4** A typical workshop or studio classroom layout (Courtesy Kerry Browne, Dickinson College).

Other arrangements for workshop-style classes have been developed at RPI for Studio Physics and at North Carolina State for the SCALE-UP project. The SCALE-UP project is discussed as a case study for the adoption and adaptation of Suite materials in chapter 10.

There is evidence that active-engagement characteristics alone do not suffice to produce significant gains in student learning [Cummings 1999]. The presentation of traditional materials in an active-engagement learning environment does not necessarily result in better concept learning than a traditional environment. What seems to be necessary is that *specific attention is paid to the knowledge and beliefs students bring into the class from their experience and previous instruction.*

## THE POPULATION CONSIDERED: CALCULUS-BASED PHYSICS

As of this writing, the process of research-based curriculum development is farthest along for the introductory calculus-based ("university") physics course and the course taken by preservice elementary school teachers. The Physics Suite primarily addresses the former group (though Physics by Inquiry and Explorations in Physics specifically address the latter).

### Characteristics of calculus-based physics students

Calculus-based (university) and algebra-based (college) physics courses are usually the largest service courses presently offered by physics departments.[3] At present, most of the curricular materials that have been developed have been created with the calculus-based physics class in mind. The students in this class have a number of characteristics that distinguish them from other students.

- They are mostly mathematically relatively sophisticated.
- Almost all have studied physics in high school and done well in it.
- Almost all think physics is important for their careers.
- They mostly consider themselves scientists or engineers.

### The hidden curriculum and problem solving

When we talk about our classes, we usually specify a certain set of content. But if all our students take away from our course is content, their ability to use this content may be limited. They may have developed a vocabulary, learned to recognize that they've seen a particular equation before, and may perhaps have improved their algebraic skills somewhat. This is not enough to keep students taking these courses at a time when there is great competition for places in the engineering curriculum, and it does not scratch the surface of the powerful and valuable skills and attitudes that could be delivered. I refer to the (usually tacit) gains that we hope our students will achieve as a result of taking a physics course as the *hidden curriculum.*

[3] There are some tantalizing counterexamples that illustrate possibilities for future developments. One example is Lou Bloomfield's class for nonscientists at the University of Virginia, "How Things Work," using his text of the same name [Bloomfield 2001]. As of this writing, I am unaware of any research on the results of this class on student learning or understanding.

We began to discuss the hidden curriculum in chapter 3. Here, let's try to explicate some of those elements that might be important for developing authentic problem-solving skills, based on the understanding of student learning we have developed in previous chapters.

The research on problem solving shows that experts use a good understanding of the concepts involved to decide what physics to use. Novices look for an equation. Experts classify problems by what physics principles are most relevant, such as energy vs. force analysis. Novices classify them by surface structure and superficial associations (e.g., it's an inclined plane), and they remember a particular problem they did with inclined planes [Chi 1981]. We would really like our students to learn the components of problem solving used by expert physicists:

- The ability to "find what physics will be useful" for a problem
- The skill to take apart and solve complex problems
- The ability to evaluate the result of a solution and know whether it makes sense

In order to achieve all of these goals, a student has to be able to make sense of what a problem "is about." In order to develop such a mental model, an understanding of the concepts—of the physical meaning of the terms and symbols used in physics—is essential (necessary, but not sufficient). As described in chapter 1, success in algorithmic problem solving has been shown to be poorly correlated with a good understanding of basic concepts [Mazur 1997] [McDermott 1999]. This observation fits well with the cognitive structures described in chapters 2 and 3.

## SOME ACTIVE-ENGAGEMENT STUDENT-CENTERED CURRICULA

The physical (and temporal) architecture of the classroom is only one part of what controls what happens to students; the other is the cognitive architecture, which is determined by the curricular materials and by how the instructor uses them. The curricula associated with the Physics Suite, and the additional curricula I have chosen to include, are coherent, rely on the educational principles discussed in the first half of this book, and focus on getting students "to do what needs to be done." Most of them focus on the goal of improving student conceptual understanding and their ability to use these concepts in complex problem solving.

Models of instruction have been developed that replace one or more of the elements of the traditional structure by an active-engagement activity. *Lecture-based models* modify the traditional lecturer presentation to include some explicit student interaction. *Laboratory-based models* replace the traditional laboratory by a discovery-type laboratory. *Recitation-based models* replace the recitation in which an instructor models problem solving for an hour by a structure in which the students learn reasoning or problem solving in groups guided by worksheets. They may also carry out qualitative guided-discovery experiments. Finally, some models go beyond the traditional structure by creating an environment that combines elements of lecture, laboratory, and recitation in a single class, usually dominated by guided-discovery laboratories. I refer to these as *workshop models.*

Following are the models that I discuss in the next few chapters. The specific materials that have explicitly been coordinated as part of the Physics Suite are marked in bold.

**Lecture-based models (chapter 7)**
- Traditional lecture
- Peer Instruction/ConcepTests
- **Interactive Lecture Demonstrations**
- Just-in Time Teaching

**Recitation-based models (chapter 8)**
- Traditional recitation
- **Tutorials in Introductory Physics**
- **ABP Tutorials**
- Cooperative Problem Solving

**Laboratory-based models (chapter 8)**
- Traditional laboratory
- **RealTime Physics**[4]

**Workshop models (chapter 9)**
- **Physics by Inquiry**
- **Workshop Physics**
- **Explorations in Physics** (not discussed in this volume)

In the next three chapters, the discussion of each model begins with a boxed summary; each summary describes briefly the following elements:

- The ***environment*** in which the method is carried out (lecture, lab, recitation, or workshop)
- The ***staff*** required to implement the method
- The ***populations*** for which the method has been developed and tested and those to whom it might be appropriately extended
- Whether ***computers*** are required to implement the method and how many
- Other ***specialized equipment*** that might be required
- The ***time investment*** needed to prepare and implement the method
- The ***materials and support*** that are available

Within the description of the method itself, I discuss the method briefly, consider some explicit example, and, if there is data on the method's effectiveness, I present some sample data. If I have had personal experience with the method, I discuss it.

[4] *Tools for Scientific Thinking*, a somewhat lower level set of laboratory materials similar in spirit to *RealTime Physics,* are also a part of the Physics Suite but are not discussed in this volume.