CHAPTER 8

# Recitation and Laboratory-Based Methods

*The most serious criticism which can be urged*
*against modern laboratory work in Physics is that*
*it often degenerates into a servile following of directions,*
*and thus loses all save a purely manipulative value.*
*Important as is dexterity in the handling and adjustment of apparatus,*
*it can not be too strongly emphasized*
*that it is grasp of principles, not skill in manipulation*
*which should be the primary object of General Physics courses.*
Robert A. Millikan [Millikan 1903]

The recitation and the laboratory are two elements of the traditional structure that seem ready made for active engagement. The architectural environment can be arranged to be conducive to group work, focus on the task, and interaction. (See Figure 6.3.) Unfortunately, not much is usually done with the cognitive environment to take advantage of this opportunity. Recitations are set up with the room's movable chairs lined up as if in a large lecture hall (see Figure 10.3)—and the recitation leader does 95% of the talking. Students in laboratories may sit at tables in two groups of two, but if the lab is set up in "cookbook" style so that students can get through it quickly and without much thought, there may be little conversation and almost no effort at sense-making.

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In this chapter I discuss five environments, three for recitation and two for lab.

- The traditional recitation
- *Tutorials*—Materials developed by the University of Washington Physics Education Group (UWPEG) to replace recitations by guided group concept building
- *ABP Tutorials*—Materials in the frame of those developed by the UWPEG but making use of computer-assisted data acquisition and analysis (CADAA) and video technology

- *Cooperative Problem Solving* (CPS)—An environment developed at the University of Minnesota to provide guidance for students to learn complex problem-solving skills in a group-learning environment[1]
- The traditional lab
- *RealTime Physics*—A concept-building laboratory making extensive use of CADAA

Both sets of Tutorial materials and RealTime Physics are part of the Physics Suite. The CPS materials match well with and are easily integrated with other Suite elements.

## THE TRADITIONAL RECITATION

> **Environment:** Recitation.
> **Staff:** One instructor or assistant per class for a class of 20 to 30 students.
> **Population:** Introductory physics students.
> **Computers:** None.
> **Other Equipment:** None.
> **Time Investment:** Low.

The traditional recitation has an instructor (at the large research universities this is often a graduate student) leading a one-hour class for 20 to 30 students. These sections are often tied to the homework: students ask questions about the assigned problems, and the teaching assistant (TA) models the solution on the blackboard. If the students don't ask questions about any particular problems, the TA might choose problems of his or her own and model those. A brief quiz (10 to 15 minutes) may be given to make sure students attend. At Maryland, this regime has been standard practice for decades. Sometimes, due to time pressures and a limited number of TAs, homework grading is dropped, and the quiz is one of the homework problems chosen at random—to guarantee that the students have to do them all, even though they aren't collected. The recitation becomes a noninteractive lecture in which the students are almost entirely passive.

When I first taught the calculus-based physics class about a dozen years ago, I asked Sagredo for his advice. "Problem solving is really important," he responded, "so be sure your TAs give a quiz to bring the students into the recitation on a regular basis." I was intrigued by the assumption implicit in this statement: that the activity was important for student learning but that without a compulsion, students would not recognize this fact.

I decided to test this for myself. I told my students that in recitation, the TAs would be going over problems of the type that would appear on the exams. They would not be required to come, but it would help them do better on the exams. The result was the disaster that Sagredo had predicted. Attendance at the recitations dropped precipitously. When, about

[1]The CPS project has also developed a laboratory curriculum that articulates with the problem-solving recitations, putting each laboratory exercise into the context of a problem. These laboratories are not discussed in detail here. For more information, see [Heller 1996] and the group's website at http://www.physics.umn.edu/groups/physed.

halfway into the semester, I asked one of my TAs how his attendance was, he remarked: "It was great last week. I actually had eight students show up [out of a class of 30]." Now and then I stood outside one of these recitation rooms to listen to what was going on. It seemed that there were two or three students in the group who were on top of things, had tried to do the homework and had real questions, and were following closely. Then, there were another three or four students who didn't say a word but were writing down everything that was said. My assumption is that they were "pattern matchers"—students who did not assume that it was necessary to understand or make sense of the physics and felt they could get by with memorizing a bunch of problems and then replaying them on the exam. This impression was reinforced by my interaction with these students during office hours.

The next time I taught the class I decided that since the students didn't see recitations as valuable to their learning, perhaps they were right. I eliminated the recitation in favor of a group-learning concept-building activity, *Tutorials* [Tutorials 1998].[2] I told them that in Tutorial we would be working through basic concepts. They would not be required to come, but it would help them do better on the exams. Interestingly enough, despite the similarity of the instructions, the attendance results were dramatically different. The TAs reported almost full classes (80% to 95%) at every session.[3] I don't fully understand the psychology behind this, but my first guess is that the social character of the Tutorial classes changed the way they thought about the class. Since they were interacting with their peers, the activity was no longer individual and they had some responsibility for being there to interact. Put another way, Tutorials are like laboratories and one did not cut a lab if one could help it, in part because it caused a serious problem for your lab partner. The traditional recitations are more like lectures, and nobody really cared if you missed lecture.

## A more interactive approach to the traditional recitation

Even if you don't want to (or have the resources to) implement a research-based recitation replacement such as Tutorials, in a small class of 20 to 30 you can use many techniques to increase the students' engagement with the material. The small-class environment provides lots of opportunities for this engagement. Some methods include:

- *Ask authentic questions*—Questions that are relevant to what the students are learning and that you expect them to answer are much more engaging than rhetorical questions or questions that interest only one student.
- *Lead a discussion*—Don't answer student questions yourself, but see if you can get a discussion going to answer the questions. Help them along now and then if needed.
- *Have them work on problems together*—Problems that are not assigned for homework but that rely on an understanding of fundamental concepts can be effective and engaging. (Problems that only rely on straightforward algebraic manipulations are not.) Having one student from each group put their solution on the board and then having a class

[2] I use the word "Tutorials" with a capital T to distinguish the specific University of Washington style of lessons from a more traditional "tutorial" in which a student is tutored—perhaps led through a lesson step by step. "Capital T" Tutorials are a more complex activity.

[3] Early morning (8 A.M.) sessions are sometimes an exception.

discussion can be very valuable. Some of the context-based reasoning problems discussed in chapter 4 can be effective here.

- *Do fewer problems and go into them more deeply*—If you do many problems quickly, it encourages the students' view that they need to pattern match rather than understand. Going through a problem of medium difficulty with enough discussion that student confusions are revealed may take 20 to 30 minutes.

These approaches sound easier than they are. Each one succeeds better the more you understand about where the students actually are—what knowledge they bring to the class, both correct and incorrect, and what resources they have to build a correct knowledge structure. The critical element is communication.

> *Redish's ninth teaching commandment:* Listen to your students whenever possible. Give them the opportunity to explain what they think and pay close attention to what they say.

## Helping your teaching assistants give better recitations

For instructors in charge of a group of TAs, I have some additional words of advice.

- *Make sure that your TAs understand the physics*—Faculty have a tendency to assume that graduate students are well versed in introductory physics. But remember: they may be novice TAs and have last studied introductory physics four or five years ago. Little of what they have done since then (Lagrangians, quantum physics, Jackson problems) will help them with the often subtle conceptual issues in an introductory class.
- *Make sure that you and your TAs are on the same page*—If you are trying to stress conceptual issues and promote understanding, make sure that your TAs know what you are trying to do and understand it. If you want them to use a particular method to solve a class of problems, be sure the TAs know that you are pushing it.
- *Worry about grading and administrative details*—One of the easiest ways to get in trouble with your students is to have different TAs grading them in different ways. A TA who grades homework casually, giving points for effort, can produce a pattern of scores much higher than one who slashes points for trivial math errors. This can cause difficulty in assigning grades fairly and can lead to significant student anger and resentment.

These guidelines are based on my experience. One should be able to create an effective and engaging learning environment in a class of 20 to 30 students, even without adopting a special curriculum. However, careful research has yet to be done to see what elements are critical in producing effective learning in this situation.

Studies in other environments suggest that even when the instructor is sensitive to research-determined difficulties that students have with the material, research-based instructional materials may make a big difference in the effectiveness of the instruction.[4] In the next two sections I describe three elements that can transform recitations into more effective learning environments.

[4] See [Cummings 1999].

## TUTORIALS IN INTRODUCTORY PHYSICS

**Environment:** Recitation.

**Staff:** One trained facilitator per 15 students.

**Population:** Introductory physics students. (All are appropriate for calculus-based physics classes; some are also appropriate for algebra-based classes.)

**Computers:** Very limited use.

**Other Equipment:** Butcher paper or whiteboards and markers for each group of three to four students. Occasional small bits of laboratory equipment for each group (e.g., batteries, wires, and bulbs).

**Time Investment:** Moderate to substantial (one to two hour weekly training of staff required).

**Available Materials:** A manual of tutorial worksheets and homework.

Perhaps the most carefully researched curriculum innovation for introductory calculus-based physics is *Tutorials in Introductory Physics*, developed by Lillian C. McDermott, Peter Shaffer, and the University of Washington Physics Education Group (UWPEG). Numerous Ph.D. dissertations by students in this group have extensively investigated student difficulties with particular topics in calculus-based physics and have designed group-learning lessons using the research-and-redevelopment wheel. (See Figure 6.1.) References to this extensive body of work can be found in the Resource Letter included in the Appendix of this volume. The published materials cover a wide range of topics from kinematics to physical optics [Tutorials 1998]. Additional materials are continually being developed and refined.

In *Tutorials*, the traditional recitation is replaced by a group-learning activity with carefully designed research-based worksheets. These worksheets emphasize concept building and qualitative reasoning. They make use of cognitive conflict and bridging, and use trained facilitators to assist in helping students resolve their own confusions. The method can be implemented to help improve student understanding of fundamental physics concepts in a cost-effective manner within the traditional lecture structure [Shaffer 1992] [McDermott 1994].

Students in Tutorials work in groups of three to four with a wandering facilitator for every 12 to 15 students. These facilitators check the students' progress and ask leading questions in a semi-Socratic dialog[5] to help them work through difficulties in their own thinking. (See Figure 8.5.) The structure of the classroom (Figure 6.3) reflects the different focus in behavior expected in a Tutorial as compared to a lecture. In this, and in other inquiry-based classes, the student's focus is on the work (on the table) and on the interaction with the other students in their group.

[5]See Bob Morse's lovely little article "The Classic Method of Mrs. Socrates" to learn more about the difference between a "Socratic" and a "semi-Socratic" dialog [Morse 1994].

## The structure of Tutorials

Tutorials have the following components:

1. A 10-minute ungraded "pre-test" is given once a week (typically in lecture). This test asks qualitative conceptual questions about the subject to be covered in Tutorial the following week and gets the students thinking about some (usually counterintuitive) issues.
2. The teaching assistants and faculty involved participate in a one- to two-hour weekly training session. In this session, the TAs do the pre-test themselves and go over the students' pre-tests (but don't grade them). They discuss where the students have trouble and do the Tutorial in student mode, nailing down the (often subtle) physics ideas covered.
3. Students attend a one-hour (50-minute) session. Students work in groups of three or four and answer questions on a worksheet that walks them through building qualitative reasoning on a fundamental concept.
4. Students have a brief qualitative homework assignment in which they explain their reasoning. This helps them bring back and extend the ideas covered in the Tutorial. It is part of their weekly homework, which in most cases also includes problems assigned from the text.
5. A question emphasizing material from Tutorials is asked on each examination. (See Redish's sixth teaching commandment!)

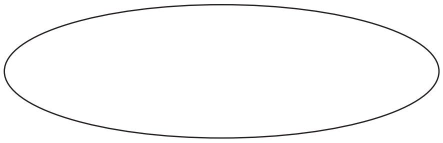
## Tutorials often focus on important but subtle points

At the University of Washington, tutorial worksheets are developed over a period of many years using the research-redevelopment cycle. The UWPEG has a highly favorable situation for curriculum development at the University of Washington—a large research group of graduate students and postdocs, continued support for research and development over many years, and an educational environment in which every term of the calculus-based physics course is taught using Tutorials four times a year. As a result, the UW Tutorials are highly refined and very carefully thought out and tested. Although one might think one sees some obvious "fixes," I recommend that they not be changed lightly.

When we first introduced Tutorials at the University of Maryland, Sagredo was lecturing one of the sections in which we were testing tutorials. He suggested that the vector acceleration activity shown in Figure 8.1 be replaced by motion on a circle. "After all," he commented, "circular motion is much simpler than elliptical motion, so they should understand it better."

Sagredo's comment misses the point of the activity. Reif and Allen have demonstrated [Reif 1992] that students often don't internalize the concept of vector acceleration well at all. They try to memorize formulas that will allow them to solve problems without struggling to make sense of the fundamental concepts. In the case of acceleration, the students needed to learn to think of vector acceleration through a process—looking at velocity vectors at nearby times and seeing how they changed. The activity in the UW tutorial is carefully designed to

*Acceleration vectors for constant speed*



Suppose that the object in part I is moving around the track at **uniform speed**.

- Draw vectors to represent the velocity at two points on the track that are relatively close together. (Draw your vectors LARGE.)
- Label the two points C and D.
- On a *separate* part of your paper, copy the velocity vectors $v_C$ and $v_D$.
- From these vectors, determine the *change in velocity vector*, $\Delta v$.

i. How does the angle formed by the head of $v_C$ and the tail of $\Delta v$ compare to 90°? ("Compare" in this case means "is it less than, greater than, or equal to 90°?")

As point D is chosen to lie closer and closer to point C, what happens to the above angle? Explain how you can tell.

What happens to the magnitude of $\Delta v$ as point D is chosen to lie closer and closer to point C?

ii. How would you find the acceleration at point C?

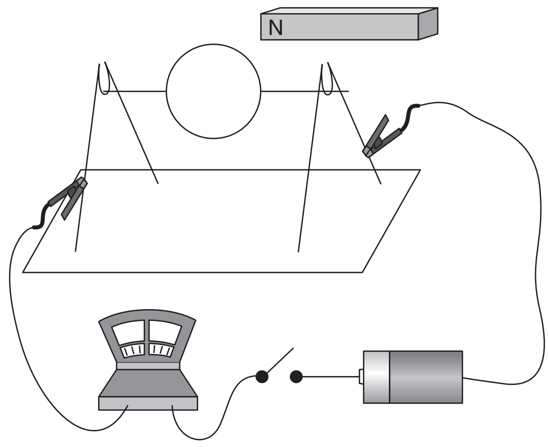
**Figure 8.1** A sample activity from a University of Washington Tutorial [Tutorials 1998].

be sufficiently general (***not*** a circle, ***not*** an ellipse) so that the students can't pattern match to something in the book, but sufficiently specific (moving at a constant speed but with changing direction, later with changing speed) to force them to focus on the process of constructing the acceleration. Following Sagredo's well-meaning advice would have completely undermined the carefully designed learning activity.

## Should you post solutions to Tutorial pre-tests and homework?

The UW Tutorials often rely on the cognitive conflict method discussed in chapter 2. In this approach, situations are presented that cue common student difficulties revealed by research. The facilitators then help those students who show the predicted difficulties work through their ideas themselves. McDermott refers to this process as *elicit/confront/resolve* [McDermott 1991]. The pre-tests often raise questions that appear to be straightforward and many (if not most) of the students miss. Note that the pre-tests should ***not*** be gone over in class, nor should the results be posted. The point of the pre-tests is to get the students thinking about the issues. They then confront these issues for themselves during the tutorial session. Giving them the answers short-circuits the learning activity.

Sagredo was worried about this and after a few weeks of Tutorials, asked his students in lecture whether they wouldn't like to have the answers to the pre-tests posted. The result was




Examine the leads to the wire coil so that you understand which portion of the wire has been stripped of the insulating enamel coating.

- For what orientations of the coil will there be a current through it due to the battery?
- Check your answer by closing the switch and observing the deflection of the ammeter as you rotate the coil manually through one complete revolution.
- Hold one pole of the magnet close to the coil. Close the switch. If the coil does not begin to spin, adjust the location of the magnet or gently rotate the coil to start it spinning.

Use the ideas that we have developed in class to explain the motion of the wire coil. (The questions on the following page may serve as a guide to help you develop an understanding of the operation of the motor.)

**Figure 8.2** An activity from a UW Tutorial involving simple equipment [Tutorials 1998].

lukewarm. One of the students spoke up and said, "Well, we just go over the answers in Tutorial the next week so we get it there."

The answers to the Tutorial homework may be a different story. The Tutorial homework is supposed to be a reasonably straightforward extrapolation of what was done in Tutorials in order to provide reinforcement at a later time. In some of my classes, this did not appear to be a problem, especially when most groups had a chance to finish the Tutorials. In classes where the Tutorials often were not finished (e.g., in my algebra-based classes), students found the Tutorial homework more difficult. When I discovered that some of my graduate assistants had gotten the answers wrong on the Tutorial homework, I decided to provide solutions.

## What does it take to implement Tutorials?

The UW Tutorials focus on fundamental concepts and low implementation costs. Although they occasionally call for a few items of easily obtained equipment (batteries and bulbs, magnets, compasses), most are done with paper and pencil as in the example shown in Figure 8.1. Some of the activities, however, involve well-designed and exciting mini-labs. (See, for example Figure 8.2.) The largest investment required is that someone has to become an expert in the method and provide training for the facilitators and someone has to manage the operation.[6]

The tutorial and homework sheets are available for purchase by the students [Tutorials 1998]. Pre-tests, sample examination problems, and equipment lists are available with the instructor's guide.

## Tutorials produce substantially improved learning gains

Tutorials have been extensively researched and tested by the University of Washington group and by others. Many of the UWPEG's publications over the past decade have been research associated with the development of specific Tutorials.

We carried out a test of a secondary implementation of Tutorials at the University of Maryland using the FCI pre and post in the first semester of engineering physics [Redish 1997]. To see the range of variation that arose from different lecturers, Saul, Steinberg, and I gave the FCI to 16 different lecture sections involving 14 different professors. Seven of the sections used traditional recitations, and nine used Tutorials. The classes chosen to use Tutorials were selected at random. Two professors taught twice, once with Tutorials and once without.

The fraction of the possible gain,[7] *g*, attained averaged 0.20 in the lecture classes and 0.34 in the Tutorial classes. Each of the professors who taught with and without Tutorials each had better scores with Tutorials by 0.15. (One of these professors taught with Tutorials first, one with recitation first.) A histogram of the results is shown in Figure 8.3. Every lecture section that used Tutorials achieved a higher value of *g* than every section that used recitations. (A later class with an award-winning professor achieved a gain of 0.34 without Tutorials, higher than our lowest gain with Tutorials but lower than most of the Tutorial-based classes.)

## Changing recitations to Tutorials doesn't hurt problem solving

In their dissertations at Maryland, Jeff Saul and Mel Sabella studied problem solving in our tutorial/recitation comparison. In most cases, there was little or no difference observed between the two groups on traditional exam problems. On a few problems, the tutorial students did dramatically better than those in recitations. The interesting cases are those where the tutorial did not specifically cover the kind of example in the problem but appeared to help students build a functional mental model.

An example of such a problem is shown in Figure 8.4, and the results at Maryland are shown in Table 8.1 [Ambrose 1998]. The problem is trickier than it looks. Students who memorize equations tend to memorize them in the order given in the book, and the one for the position of the bright fringes is always given first. The problem, however, asks for the position of the *dark* fringe. A large fraction of the students in the recitation class simply pulled out the bright-fringe formula and got an answer off by a factor of 2.

[6]At Maryland, we found that the extra costs needed to run Tutorials for 600 students corresponded to about one-half of a teaching assistant—the person needed to organize and manage the operation.

[7]See the discussion of *g* in chapter 5 for a definition.

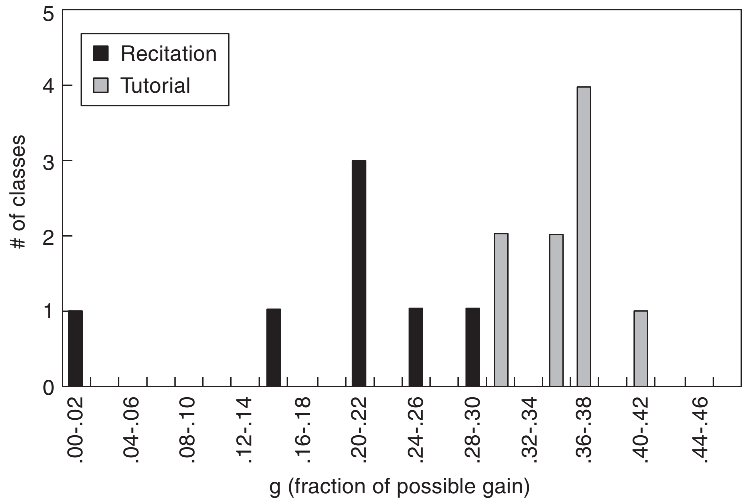



**Figure 8.3** Fraction of the possible gain attained by engineering physics students at the University of Maryland in classes taught with traditional recitations (dark) and tutorials (light).

A satisfyingly large fraction of the students in the Tutorial class actually reasoned their way to the answer using a path-length argument, showing that they could call on an underlying mental model to construct a correct result. I was particularly impressed with this result since the Tutorials we used do not explicitly consider this problem but focus on building the concept of path length and its role in interference.

## Students need to get used to Tutorials

In introducing Tutorials to a class, you should be aware of possible attitudinal difficulties. As discussed in chapter 3, students bring to their physics classes expectations about the type of knowledge they will be learning in class and what they have to do to get it. Engineering students (especially those who have taken AP physics in high school) may have a strong expectation that what they are supposed to learn in a physics class are equations and how to produce numbers. The idea of "concepts" and even the idea of "making sense" of anything in physics may be foreign to them. These students can at first be quite hostile to the idea behind Tutorials. Some of the better students think Tutorials are trivial (despite making numerous errors in their predictions). Others may be accustomed to operating in a competitive

> Light with $\lambda = 500$ nm is incident on two narrow slits separated by $d = 30\ \mu$m. An interference pattern is observed on a screen a distance $L$ away from the slits. The first dark fringe is found to be 1.5 cm from the central maximum. Find $L$.

**Figure 8.4** A problem on which Tutorial students performed significantly better than recitation students [Ambrose 1998].

**TABLE 8.1 Results on Problem Given to Recitation and Tutorial Classes**

| | Example | Recitation ($N = 165$) | Tutorial ($N = 117$) |
|---|---|---|---|
| $L = 1.8$ m (correct) | $\Delta D = d \sin \theta = \lambda/2$<br>$\sin \theta = y/L$ | 16% | 60% |
| $L = 0.9$ m | $y = m\lambda L/d$ | 40% | 9% |
| Other | $L = 5.0 \times 10^{-7}$ m | 44% | 31% |

rather than a cooperative framework and may not like "having to explain their answers to dummies." (I've gotten this comment even after a session when one of the "dummies" asked a probing question that helped that overconfident self-categorized "top student" correct a serious error in his thinking.) Once both the faculty and the student body come to accept Tutorials as a normal part of the class, Tutorials tend to be rated as one of the most valuable parts of the class.

Given that conceptual learning and qualitative reasoning may be new to many of the students in an introductory physics class, the introduction of Tutorials needs to be done carefully. I have had the most success when I have integrated the Tutorial approach fully into my lectures and tied qualitative reasoning to my problem-solving examples. Exams that contain a "Tutorial question" are a minimum necessity. Exams in which every question blends Tutorial ideas with problem solving are even more effective in helping students understand the value of concepts and qualitative thinking.

## ABP TUTORIALS

**Environment:** Recitation.

**Staff:** One trained facilitator per 15 students.

**Population:** Introductory calculus-based physics students. (Many of the tutorials are also appropriate for algebra-based classes.)

**Computers:** One for every three to four students.

**Other Equipment:** Butcher paper or whiteboards and markers for each group of three to four students. Occasional small bits of laboratory equipment for each group (e.g., batteries, wires, and bulbs). Computer-assisted data acquisition device; various programs and simulations including *Videopoint* and *EM Field*.

**Time Investment:** Moderate to substantial (one to two hours weekly training of staff required)

**Available Materials:** A set of tutorial worksheets, pre-tests, and homework. [ABP-Tutorials] These tutorials and instructions for their use are available on the web at http://www.physics.umd.edu/perg/.

Although the UWPEG Tutorials cover a wide range of topics, they strongly focus on the issue of qualitative reasoning and concept building. In addition, the UWPEG made the choice to make Tutorials as easy to implement as possible, so they rely on very little (and very inexpensive) equipment. In addition, the UWPEG Tutorials are designed so that they can be reasonably successful in helping students build fundamental concepts even if concept building is not significantly supported elsewhere in the course (lecture, laboratory, homework problems). One difficulty with such a situation is that students tend to develop independent schemas for qualitative and quantitative problem solving and to only occasionally (as discussed in the section on Tutorials) cross qualitative ideas over to help them in solving quantitative problems [Kanim 1999] [Sabella 1999].

## ABP Tutorials are mathematically and technologically oriented

The University of Maryland Physics Education Research Group (UMdPERG), as part of the Activity-Based Physics (ABP) project, developed a supplementary set of Tutorials that are based on a different set of assumptions [Steinberg 1997]:

1. We assume that conceptual learning is being integrated throughout the course—in lecture, homework, and laboratories—so that Tutorials are not the sole source of conceptual development.
2. We assume that quantitative problem solving is a significant goal of the class.
3. We assume that reasonable computer tools are available for use in Tutorials.

Given these assumptions, the structure of Tutorial lessons can be changed somewhat. They can focus more on relating conceptual and mathematical representations and on building qualitative to quantitative links. In this set of lessons, computers are used for taking data, displaying videos, and displaying simulations. For example, in Figure 8.5, a facilitator

**Figure 8.5** Interactive computer-based tutorial on Newton's law. Students are interacting with the facilitator (standing), who asks Socratic-dialog questions to focus their inquiries.

(standing) is shown talking to a group of students who are using a fan cart on a Pasco track with a sonic ranger detector to study Newton's second law.

While some of the lessons are new, others have been adapted to the Tutorial framework from *RealTime Physics* laboratories and from *Workshop Physics* activities. These include

- Discovering Newton's third law using two force probes on Pasco carts
- Exploring the concept of velocity by walking in front of a sonic ranger
- Exploring oscillatory behavior by combining a mass on a spring hanging from a force probe with a sonic ranger

New lessons include such topics as

- Tying the concepts of electric field and electrostatic potential to their mathematical representations using the software *EM Field* [Trowbridge 1995]
- Building an understanding of the functional representation of wave propagation using video clips of pulses on springs and the video analysis program *Videopoint*™ [Luetzelschwab 1997]
- Building an understanding of the oscillatory character of sound waves and the meaning of wavelength using video clips of a candle flame oscillating in front of a loudspeaker and the video analysis program *Videopoint*™ (See Figure 8.6.)

## Concept learning can be tied to the use of math

The example of sound waves gives an interesting example of how concept learning can be tied to mathematical concepts by using media effectively.

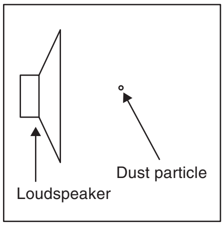

**Figure 8.6** A frame from a video used in an ABP Tutorial. A low-frequency sound wave (10 Hz) emitted by the speaker causes the candle flame to oscillate back and forth. Students use *Videopoint*™ to measure the frequency of the oscillation.

Students studying the topic of sound in the traditional way often construct a picture of a sound wave that treats the peaks of the wave (or pulse) as if it were a condensed object pushed into the medium rather than as a displacement of the medium [Wittmann 2000]. Wittmann refers to these two mental models as *the particle pulse model* (PP) and the *community consensus model* (CC). One clue that a student is using a PP model is that the student assumes that each pulse of sound that passes a floating dust particle "hits" it and pushes it along.

> Alex: *[The dust particle] would move away from the speaker, pushed by the wave, pushed by the sound wave. I mean, sound waves spread through the air, which means the air is actually moving, so the dust particle should be moving with that air which is spreading away from the speaker.*
>
> Interviewer: *Okay, so the air moves away—*
>
> A: *It should carry the dust particle with it.*
>
> I: *How does [the air] move to carry the dust particle with it?*
>
> A: *Should push it, I mean, how else is it going to move it? [sketches a typical sine curve] If you look at it, if the particle is here, and this first compression part of the wave hits it, it should move it through, and carry [the dust particle] with it.*
>
> . . .
>
> I: *So each compression wave has the effect of kicking the particle forward?*
>
> A: *Yeah.*[8]

In his thesis research, Wittmann found that most students in engineering physics used the PP model most of the time but used the CC model in some circumstances. One ABP Tutorial developed to deal with this issue uses a video of a flame in front of a loudspeaker.

A dust particle is located in front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant (low) pitch. **Which choice or combination of the choices** *a–f* (listed below) can describe the motion of the dust particle after the loudspeaker is turned on? **Circle the correct letter or letters**. Explain.




Possible responses for question 2:

a) The dust particle will move up and down.
b) The dust particle will be pushed away from the speaker.
c) The dust particle will move toward and away from the speaker.
d) The dust particle will not move at all.
e) The dust particle will move in a circular path.
f) None of these answers is correct.

**Figure 8.7** MCMR problem used to probe mental models students use in envisioning sound.

[8]Dialog quoted from [Wittmann 2001a].

**TABLE 8.2 Student Performance on Sound Wave Questions Before, After Traditional Lecture, and After Additional Modified Tutorial Instruction**

| Time during Semester MM used | Before All Instruction (%) | Post-Lecture (%) | Post-Lecture, Post-Tutorial (%) |
|---|---|---|---|
| **CC (longitudinal oscillation)** | 9 | 26 | 45 |
| **Other oscillation** | 23 | 22 | 18 |
| **PP (pushed away linearly or sinusoidally)** | 50 | 39 | 11 |
| **Other** | 7 | 12 | 6 |
| **Blank** | 11 | 2 | 21 |

(See Figure 8.6.) Using cognitive conflict methods, the lesson has students predict the flame's behavior when the speaker is turned on. Students then track how the flame moves back and forth and create a graph of the tip's oscillatory motion. Then they consider what will happen when a sound wave passes a chain of separated flames in order to build an understanding of the idea of relative phase and wavelength.

An exam question used to test the students' responses to this lesson is shown in Figure 8.7, and the results for traditional and Tutorial instruction are presented in Table 8.2. Data are matched ($N = 137$ students). The large number of blank responses in the post-all instruction category is due to the number of students who did not complete the pre-test on which the question was asked. The results show that Tutorials are a significant improvement over traditional instruction.[9]

## COOPERATIVE PROBLEM SOLVING (CPS)

**Environment:** Recitation.

**Staff:** One instructor or assistant per class trained in the approach for any number of students ($N = 20$–30); a second facilitator is helpful in larger classes.

**Population:** Introductory calculus-based physics students. (Many of the problems are also appropriate for algebra-based classes.)

**Computers:** None.

**Other Equipment:** None.

**Time Investment:** Moderate to substantial.

**Available Materials:** Manuals of problems for students and an instructor's guide. Available from the group website at http://www.physics.umn.edu/groups/physed.

[9] The development environment at Maryland does not match the ideal one at Washington, so these Tutorials have only been through two to four cycles of development compared to the eight to ten typically carried out at Washington. As a result, they are not as refined—and not as effective.

Over the past decade or so, Pat and Ken Heller at the University of Minnesota and their collaborators have developed a group-learning problem-solving environment in which students work together in recitation on problems they have not previously seen [Heller 1992]. Their work is based on the generalized studies of the Johnsons and their collaborators on the effectiveness of group learning [Johnson 1993].

## Cooperative Problem Solving relies on context-rich problems

The problems the Minnesota group have developed are *context rich*; that is, they involve realistic situations, may contain incomplete data, and may require the students to pose a part of the problem themselves. (See Figure 8.8.) The problems are intended to be too difficult for any individual student to solve but not too hard for a group of students of mixed ability to solve in about 15 to 20 minutes when working together. Groups are formed to include students of varying ability, and students may be assigned specific (and rotating) roles to play in each group.

The Minnesota group's context-rich problems have a number of general characteristics that encourage appropriate thinking. These characteristics may be difficult for a novice problem-solver to handle individually, and they facilitate discussion. They include the following:

1. It is difficult to use a formula to plug in numbers to get an answer.
2. It is difficult to find a matching solution pattern to get an answer.
3. It is difficult to solve the problem without first analyzing the problem situation.
4. It is difficult to understand what is going on in this problem without drawing a picture and designating the important quantities on that picture.
5. Physics words such as "inclined plane," "starting from rest," or "projectile motion" are avoided as much as possible.
6. Logical analysis using fundamental concepts is reinforced.

> A friend of yours, a guitarist, knows you are taking physics this semester and asks for assistance in solving a problem. Your friend explains that he keeps breaking repeatedly the low E string (640 Hz) on his Gibson "Les Paul" when he tunes up before a gig. The cost of buying new string is getting out of hand, so your friend is desperate to resolve his dilemma. Your friend tells you that the E string he is now using is made of copper and has a diameter of 0.063 inches. You do some quick calculations and, given the neck of your friend's guitar, estimate the the wave speed on the E string is 1900 ft/s. While reading about stringed instruments in the library, you discover that most musical instrument strings will break if they are subjected to a strain greater than about 2%. How do you suggest your friend solve his problem?

**Figure 8.8** Sample of a context-rich problem from the Minnesota CPS method [Heller 1999].

The problems are written so as to require careful thinking.

- The problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you."
- The problem statement includes a plausible motivation or reason for "you" to calculate something.
- The objects in the problems are real (or can be imagined)—the idealization process occurs explicitly.
- No pictures or diagrams are given with the problems. Students must visualize the situation by using their own experiences.
- The problem solution requires more than one step of logical and mathematical reasoning. There is no single equation that solves the problem.

These types of problems change the frame: students cannot simply "plug-and-chug" or pattern match. They have to think about the physics and make decisions as to what is relevant. This strongly encourages the group to try to make sense of the problem rather than simply come up with the answer.

The Minnesota group does not simply drop these harder problems on their students. They develop an explicit problem-solving strategy, and they help the students apply it when they get stuck. The broad outlines are illustrated in Figure 8.9.[10]

Although it's hard to create such problems, when you get one, the effect of the group interaction can be quite dramatic. But the whole idea of solving problems in a group may be difficult—for the TAs as much as for the students. One year I prepared some of these problems and handed one out to my TAs on transparencies each week, in order to encourage them to begin some group work instead of lecturing to the students. One TA, having had no experience with group work herself, decided not to follow my instructions. Instead of assigning the problem as group work, she presented it as a quiz at the beginning of the class. When after 10 minutes most of the students said they had no idea how to begin, she let them use their class notes. When after an additional five minutes they still were not making progress, she let them open their texts. After 20 minutes, she collected and graded the quiz. The results were awful, the average being about 20%. The students in her class complained that "the quizzes were too hard." When I questioned her about what she had done, she replied that "If they work together, you don't know who's responsible for the work." She had mistaken an activity which I had intended to serve a teaching purpose for one meant to serve as an assessment. In other sections, many groups solved the problem successfully.

## Group interactions play a critical role

Sagredo had some sympathy for my TA. "If they work together, you'll just get to see the work of the best student. The weaker students will just go along for the ride," he complained. The

[10] This strategy is an elaboration of the strategy found in Polya's famous little book, *How to Solve It* [Polya 1945]. The Minnesota group found that using Polya's strategy directly was too difficult for the algebra-based class and that some intermediate elaborations were required [Heller 1992]. Polya's strategy is: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back.

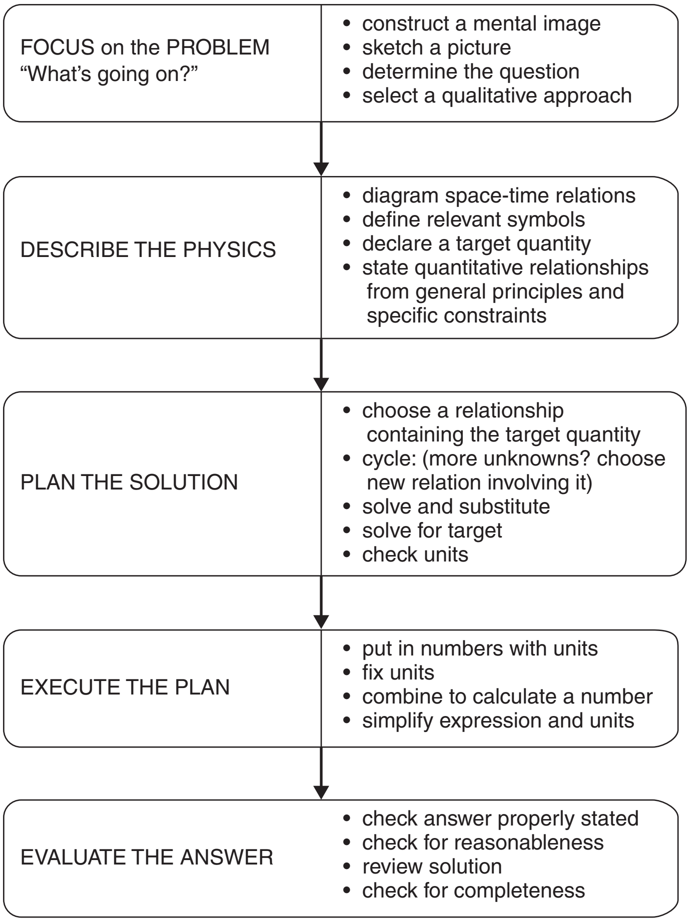



**Figure 8.9** Structure of the problem-solving method used by the Minnesota group (simplified and condensed somewhat) [Heller 1999].

Minnesota group has shown that this is not the case, and they have developed techniques to improve group interactions.

### The work of the group is better than the work of the best student in it

In order to evaluate the success of groups compared to the success of the best individual in the group, the Minnesota group compared individual and group problem-solving success [Heller 1992]. Since you can't give the same problems to the same students in different contexts and compare the results, they developed a scheme for determining problems that had approximately the same level of difficulty. They classified problem difficulty by considering six characteristics.

1. *Context:* Problems with contexts familiar to most students (through direct experience, newspapers, or TV) are less difficult than those involving unfamiliar technical contexts (such as cyclotrons or X-ray signals from pulsars).
2. *Cues:* Problems containing direct cues to particular physics (mention of force or "action and reaction") are less difficult than those for which the physics must be inferred.
3. *Match of given information:* Problems with extraneous information or information that needs to be recalled or estimated are more difficult than those where the information provided precisely matches the information needed.
4. *Explicitness:* Problems where the unknown required is specified are easier than those for which it has to be invented.
5. *Number of approaches required:* Problems that only need one set of related principles (e.g., kinematics or energy conservation) are less difficult than those requiring more than one set of such principles.
6. *Memory load:* Problems that require the solution of five equations or fewer are easier than those requiring more.

For each problem they assigned a difficulty value of 0 or 1 on each of these characteristics and found that the problem score was a good predictor of average student performance.

In order to test whether the groups were operating effectively to produce better solutions or whether they simply represented the work of the group's best student, they tested their students using both group and individual problems. Problems were matched as to level of difficulty on the scale described above. Over six exams in two terms, the groups averaged 81 ($N = 179$), while the best-in-group individual had an average of 57. These results were consistent over the different exams and classes and strongly suggest that the groups are performing better than the best individual in the group.[11] By now, the group has developed a much more detailed structure for identifying the difficulty level of a question. See the group website for details.

### Techniques for improving group interactions

The Minnesota group has studied the dynamics of group interactions in CPS and has developed a number of recommendations:

- *Assign roles:* In order to combat the tendency of students to select narrow roles during group activities and therefore limit their learning, the Minnesota group assigns roles to students in the group: manager, explainer, skeptic, and recordkeeper. These roles rotate throughout the semester.
- *Choose groups of three:* Groups of two were not as effective in providing either conceptual or procedural knowledge as groups of three or four. In groups of four, one student sometimes tended to drop out—either a timid student unsure of him/herself, or a good student tired of explaining things.

[11] Students were given unlimited time to complete the final exam. Their comparative study of incomplete problems in the midsemester (time limited) and final exams shows that time considerations do not upset this conclusion [Heller 1992].

- *Assign groups to mix ability levels:* Groups with strong, medium, and weak students performed as well as groups containing strong students only. Often, the questions asked by weaker students helped strong students identify errors in their thinking. Groups of uniformly strong students also tended to overcomplicate problems.
- *Watch out for gender problems:* Groups of two males and one female tend to be dominated by the males even when the female is the best student in the group.
- *Help groups that are too quick to come to a conclusion:* This can occur when a dominant personality railroads the group or because of a desire to quickly accept the first answer given. Some groups try to quickly resolve disagreements by voting instead of facing up to their differences and resolving them.

I have noted this last problem in Tutorials as well. In both cases, facilitators can help get them back on track, encouraging them to reconsider and resolve discrepancies. The Minnesota group suggests that group testing can help with this problem.

In Jeff Saul's dissertation, he studied four different curricular innovations including cooperative problem solving [Saul 1998]. He observed both the University of Minnesota's implementation in calculus-based physics and a secondary implementation at the Ohio State University. Pre-post testing with the FCI indicated that CPS was comparable to Tutorials in producing improvements in the student's conceptual understanding of Newtonian mechanics. (See Figure 9.4.) This is interesting since CPS focuses on quantitative rather than qualitative problem solving.

Unfortunately, Saul found no significant gains on the MPEX survey.[12] So even though students appeared to improve their conceptual knowledge (and their ability to use that knowledge), their conscious awareness of the role of concepts did not seem to improve correspondingly.

## THE TRADITIONAL LABORATORY

**Environment:** Laboratory.

**Staff:** One instructor or assistant per class trained in the approach for a class of 20 to 30 students.

**Population:** Introductory physics students.

**Computers:** If desired, one for every pair of students.

**Other Equipment:** Laboratory equipment.

**Time Investment:** Medium.

The laboratory is the single item in a traditional physics course where the student is expected to be actively engaged during the class period. Unfortunately, in many cases the laboratory has turned into a place to either "demonstrate the truth of something taught in lecture" or

[12] See the discussion of the MPEX in chapter 5.

to "produce a good result." The focus in both of these cases is on the content and not on what might be valuable for a student to learn from the activity. In the United States, "cookbook" laboratories—those in which highly explicit instructions are given and the student doesn't have to think—are common. They are unpopular with students and tend to produce little learning. Some interesting "guided-discovery labs" have been developed in the past few years that appear to be more effective.

Despite some interesting research on learning in laboratories in the early years of PER (e.g., [Reif 1979]) and a few recent studies (e.g., [Allie 1998] and [Sere 1993]), there has been little published research on what happens in university physics laboratories.

## Goals of the laboratory

One can imagine a variety of goals for a laboratory:

- *Confirmation*—To demonstrate the correctness of theoretical results presented in lecture.
- *Mechanical skills*—To help students attain dexterity in handling apparatus.
- *Device experience*—To familiarize students with measuring tools.
- *Understanding Error*—To help students learn the tools of experiment as a method to convince others of your results: statistics, error analysis, and the ideas of accuracy and precision.
- *Concept building*—To help students understand fundamental physics concepts.
- *Empiricism*—To help students understand the empirical basis of science.
- *Exposure to research*—To help students get a feel for what scientific exploration and research are like.
- *Attitudes and expectations*—To help students build their understanding of the role of independent thought and coherence in scientific thinking.

This is a powerful and daunting list. Most laboratories have at first rather limited and practical goals—to satisfy the requirements of the engineering school or to qualify for premedical certification. In implementation, most laboratories only explicitly try to achieve the first two or three goals. Sometimes understanding error is an explicit goal, but in my experience, traditional laboratories fail badly at this goal. Students go through the motions but rarely understand the point. Extensive research on this issue is badly needed.

## Often less happens in traditional labs than we might hope

In my research group's observation of traditional laboratories, one result is clear: the dialogs that take place are extremely narrow [Lippmann 2002]. Our videotapes show students spending most of the period trying to read the manual and figure out what it wants them to do. The students make little or no attempt to synthesize in order to get an overview of what the point of the lab is. Almost all of the discussion concentrates on the concrete questions of how to configure, run, and get information from the apparatus. There is little or no discussion of the purpose of the measurement, how it will be used, the physics to be extracted, or the limitations of the measurements. The students are so focused on achieving the "paper" goals of the lab—getting numbers to be able to construct lab reports—that the learning goals appear totally lost.

Of course, one might hope that they "get the numbers" in the lab and then "think about them" outside of class. This may be the case, but I suspect it is a pious hope. Students rarely have the skills to think deeply about experiments. This is where they need the help and guidance of an instructor, and they don't get it if this activity is carried out outside of class (or with instructors who can't handle the serious pedagogy needed).

## A more interactive approach to the traditional laboratory

Some of my colleagues and TAs have experimented with variations in the traditional laboratory in order to get the students more intellectually engaged. From this anecdotal evidence, I extract a few tentative guidelines. I sincerely hope that in a few years, educational research will be able to "put legs" under these speculations.

- *Make it a "class" through discussion*—Often students in lab speak only to their lab partner. There is little sharing of results or problems with other students in the class. An overall class discussion at the beginning and end of the class might increase the engagement.
- *Take away the lab manual*—Having a step-by-step procedure may guarantee that most students complete the lab but undermines important learning goals. Pat Cooney at Millersville University has had success with simply writing the task on the board and having students figure out what they have to do.
- *Start the class with a planning discussion*—Most students do not spontaneously relate the broad goals of the lab to the details of the measurements. Having them think about these issues before beginning their measurements is probably a good idea. Bob Chambers at the University of Arizona has had good results with two-week labs in which the students use the first week to plan the experiment and the second week to carry it out.
- *Occasionally ask them what they're doing and why*—Students frequently get lost in the details of an activity and can get off on the wrong track. Asking them perspective questions ("What are you doing here? What will that tell you? What could go wrong?") might help them make the connection to the purpose of the experiment.
- *Share results*—Arranging labs so that there is some time for discussion and sharing of results at the end of the lab might help identify problems and give students a better idea of the meaning of experimental uncertainty.

The laboratory is the traditional instructional environment that is, in principle, best set up for independent active-engagement learning in line with our cognitive model of learning. Much more research will need to be done in order to figure out what learning goals can be effectively accomplished in the laboratory environment and how.

## REALTIME PHYSICS

**Environment:** Laboratory.

**Staff:** One trained facilitator per 30 students.

**Population:** Introductory calculus-based physics students.

**Computers:** One for every two to four students.

**Other Equipment:** An analog-to-digital converter (ADC). Probes needed for the ADC include motion detector (sonic ranger), force probes, pressure and temperature probes, current and voltage probes, and rotary motion probe. Low-friction carts and tracks required for the mechanics experiments.

**Time Investment:** Low to moderate.

**Available Materials:** Three published manuals of laboratory worksheets for Mechanics (12 labs), Heat and Thermodynamics (6 labs), and electric circuits (8 labs) [Sokoloff 1998–2000]. Laboratories in electricity and optics are under development. An instructor's guide is available on-line to registered instructors at http://www.wiley.com/college/sokoloff-physics/.

Sokoloff, Thornton, and Laws have recently combined to develop a new series of mechanics laboratories that can be used in a traditional lecture/lab/recitation teaching environment. They make heavy use of computer-assisted data acquisition and the results of research on student difficulties.

### RTP uses cognitive conflict and technology to build concepts

The primary goal for these laboratory exercises is to help students acquire a good understanding of a set of related physics concepts [Thornton 1996]. Additional goals include providing students with experience using microcomputers for data collection, display, and analysis, and enhancing laboratory skills. The primary goal has been extensively tested by the designers and by other researchers using standardized evaluation surveys. Significant gains appear to be possible. (These results are discussed in detail at the end of this section.)

The critical tool in these laboratories is an analog-to-digital converter (ADC) connected to a computer. Many different probes can connect to these ADCs and provide the student with graphs of a wide variety of measured and inferred variables. Our senses do not provide us with direct measures of many of the quantities that are critical to an understanding of fundamental physics concepts. Our brains easily infer position and change in position, but inferring speed from visual data seems to be a learned skill (and one most people who have experience crossing streets learn effectively). Acceleration, on the other hand, seems to be quite a bit more difficult. Our brains easily infer rate of heat flow to the skin but are hard pressed to distinguish that from temperature. The computer probes allow live-time plots[13] of position, temperature, pressure, force, current, voltage, and even of such complex calculated

[13]"Live-time" in this context means that there is no noticeable time delay between the event being measured and the display of the data.

**Figure 8.10** Analog-to-digital converters from Vernier and Pasco. Either box connects to the computer's serial port. A variety of probes can be connected to the box's front (shown).

variables as velocity, acceleration, and kinetic energy. The ADCs from Pasco and Vernier are shown in Figure 8.10.

The authors combine pedagogically validated methods such as cognitive conflict, bridging, and the learning cycle (exploration/concept introduction/concept application) with the power of computer-assisted data acquisition to help students re-map their interpretation of their experience with the physical world.[14]

## RTP relies on psychological calibration of technology

When I first told Sagredo about the microcomputer use in the laboratory, he complained. "But if they don't understand how a measurement is made, they don't really understand what it means." This may be true, Sagredo. I am fairly certain that my introductory students who use the sonic ranger to measure velocity understand neither how the sounds are created and detected nor how the position data is transformed into velocity data. (They do seem to understand the idea that the sound's travel time gives a measure of distance—at least qualitatively.) On the other hand, I don't require that they know how their calculator calculates the sine function before I permit them to use it. When I have them carry out some indirect activity, such as producing a spark tape from some motion, making measurements of the positions, and then calculating and graphing the result, I may be helping them to understand how to make measurements, but the time delay between the motion itself and the production of the graph may be 15 minutes or more. This is far too long for them to buffer or rehearse their memory of the motion and make an intuitive connection.

A good example of how this works is the first RTP activity, "Introduction to Motion." This is the first lab and begins by having students use a sonic ranger motion detector (see Figure 8.11) to create position graphs of their own motions.[15] They see how the apparatus works by performing a series of constant-velocity motions and seeing what position graph appears. I refer to this process as a *psychological calibration*. They quickly get the idea and identify some interesting and relevant experimental issues, such as getting out of range of the beam of sound waves, getting too close (the motion detector only works at distances greater than about 50 cm), and seeing "bumps" produced by their individual steps. They then make predictions for a specific motion described in words, do the measurement, and reconcile any

[14] See chapter 2 and the discussion of primitives and facets.

[15] The ranger works be emitting clicks from a speaker in the ranger and measuring the time until an echo returns and is detected by a microphone in the ranger.

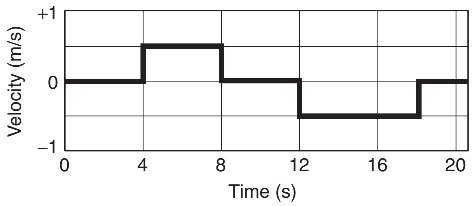
**Figure 8.11** A sonic ranger motion detector from Vernier software.

discrepancies. Finally, they carry out a variety of position graphs in order to see a broader range of possibilities.

The experiment then turns to a study of velocity graphs. Again, they begin with a psychological calibration, measuring simple constant-velocity motions, inspecting the graphs, and comparing them to the position graphs. They then undertake an interesting activity: matching a given velocity graph, the one displayed in Figure 8.12. The graph is cleverly chosen. An initial velocity of 0.5 m/s away from the detector for 4 seconds produces a displacement of

In this activity, you will try to move to match a velocity—time graph shown on the computer screen. This is often much harder than matching a position graph as you did in the previous investigation. Most people find it quite a challenge at first to move so as to match a velocity graph. In fact, some velocity graphs that can be invented cannot be matched!

1. Open the experiment file called **Velocity Match (L1A2-2)** to display the velocity—time graph shown below on the screen.




**Prediction 2-2:** Describe in words how you would move so that your velocity matched each part of this velocity-time graph.

2. **Begin graphing**, and move so as to eliminate this graph. You may try a number of times. Work as a team and plan your movements. Get the times right. Get the velocities right. Each person should take a turn. Draw in your group's best match on the axes above.

**Question 2-4:** Describe how you moved to match each part of the graph. Did this agree with your predictions?

**Question 2-5:** Is it possible for an object to move so that it produces an absolutely vertical line on a velocity—time graph? Explain.

**Question 2-6:** Did you run into the motion detector on your return trip? If so, why did this happen? How did you solve the problem? Does a velocity graph tell you where to start? Explain.

**Figure 8.12** An activity from a RealTime Physics lab. Students are making use of a sonic ranger attached to a computer to display velocity graphs in live time.

2 m. A return velocity of –0.5 m/s for 6 seconds produces a displacement of −3 m. Although I have not run these laboratories at the University of Maryland, we have adapted them for the Activity-Based Physics Tutorials. In their prediction, students describe the motion required in terms of the velocities—speeds and directions—but rarely think about distances. (I've never seen anyone do it.) As a result, they start at the minimum distance from the ranger and begin by walking backward. After having gone back 2 meters, they try to come forward 3 meters and run into the detector. In their attempt to resolve the difficulty (sometimes a carefully placed question from the facilitator is needed), they effectively explore the relation between a velocity graph and the resulting displacements. They are then asked to predict position graphs given a velocity graph.

The RealTime Physics laboratory continues with an exploration of average velocity and with fitting the graph with a straight line using computer tools that are provided. Specific questions try to ensure that the students actually think about the result the computer is giving and do not simply take it as a given. Finally, the lab ends with a measurement of the velocity of a cart on a track in preparation for the second experiment, which is concerned with acceleration.

The above example illustrates many of the features common in RTP labs. They often include:

1. Psychological calibration of the measuring apparatus
2. Qualitative kinesthetic experiments (using one's own body as the object measured)
3. Predictions
4. Cognitive conflict
5. Representation translation
6. Quantitative measurement
7. Modeling data mathematically

## RTP labs are effective in building concepts

The psychological calibration, live-time graphs, and kinesthetic experiments appear to have a powerful effect on intuition building. In my experience, students who have done these experiments are much more inclined to make physical sense of velocity and acceleration than students who have done more traditional experiments. Thornton and Sokoloff report data at their home institutions on subsets of the FMCE[16] with RTP laboratories [Thornton 1996]. At Tufts, Thornton tried the RTP laboratories with an off-semester calculus-based class of about 100 students. He reports that off-semester students tend to be less well prepared than those who begin physics immediately in the fall. The results are shown in Table 8.3. The gains were excellent. (The two rows report a cluster of questions probing Newton's first and second laws in a natural language [*n*] environment[17] and in a graphical [*g*] environment—the velocity graph questions.)

These results are compelling. The fractional gains achieved by the students with RTP are exceptional: greater than 0.8. Sagredo is skeptical. He points out that there is no direct

[16] See the discussion of the FMCE in chapter 5. The FMCE is on the Resource CD associated with this volume.

[17] These are the questions on the FMCE involving the sled. See the FMCE on the Resource CD.

**TABLE 8.3 Pre- and Post-Results for Results on the FMCE's Sled [*n*] and Velocity Graph Questions [*g*] in Different Environments.**

| | Tufts RTP (pre) | Tufts RTP (post) | ⟨g⟩ | Oregon NOLAB (pre) | Oregon NOLAB (post) | ⟨g⟩ | Oregon RTP (pre) | Oregon RTP (post) | ⟨g⟩ |
|---|---|---|---|---|---|---|---|---|---|
| **NI&II [n]** | 34% | 92% | 0.81 | 16% | 22% | 0.07 | 17% | 82% | 0.78 |
| **NI&II [g]** | 21% | 94% | 0.92 | 9% | 15% | 0.07 | 8% | 83% | 0.82 |

"head-to-head" comparison with a traditional laboratory and that the instruction was carried out at the primary institution. Moreover, the test used was developed by the researchers who developed the instruction. Sagredo is concerned that the extra hours of instruction the students had in laboratory (compared to those with no laboratory) might have made a big difference and that the instructors might have "taught to the test."

On the first issue, Sagredo, I'm not so concerned. It's my sense that traditional laboratories contribute little or nothing to conceptual learning. In fact, instructors in traditional courses making their best effort rarely produce fractional gains better than 0.2 to 0.35. Gains of 0.8 or 0.9 suggest that the method is highly effective.

The second item is of more concern. Of course, in a sense we *always* "teach to the test." As discussed in chapter 5, if the test is a good one, it measures what we want the students to learn. The problem occurs when instructors, knowing the wording of the questions to be used in an evaluation, focus—perhaps inadvertently—on cues that can lead students to recognize the physics that needs to be accessed for a particular question.

To deal with this issue, we have to see how well the instructional method "travels." The RTP/ILD dissemination project (supported by FIPSE) sponsored the implementation of RTP

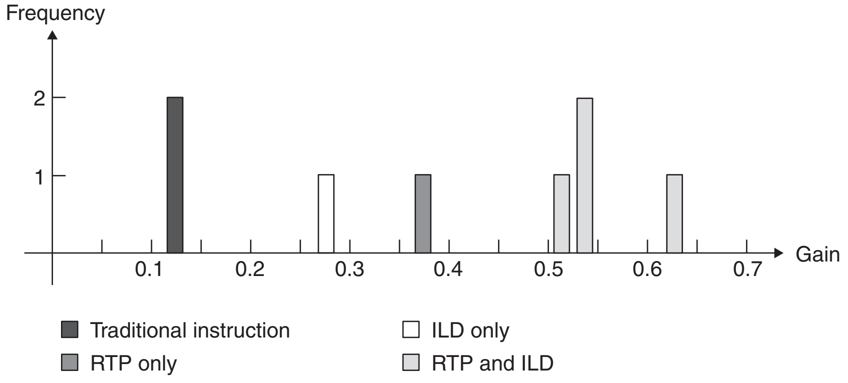



**Figure 8.13** Fractional gains on the FMCE in five different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 1000$) [Wittmann 2001].

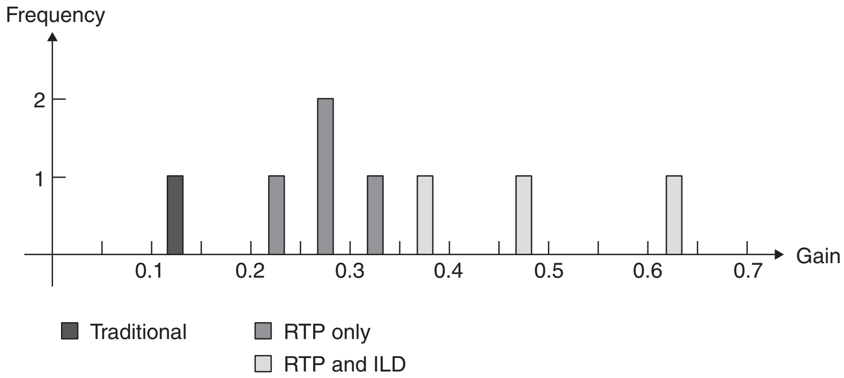



**Figure 8.14** Fractional gains on the ECCE at four different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 797$) [Wittmann 2001].

laboratories and Interactive Lecture Demonstrations (ILDs—see chapter 7) at a number of different colleges and universities. Preliminary results using the FMCE as a pre- and post-test show that the RTP Mechanics lab alone produces substantial improvement compared to schools using traditional laboratories [Wittmann 2001]. When the RTP Mechanics laboratories are supported by the use of ILDs in lecture, the results tend to be even better. These results are displayed in Figure 8.13.

I infer that the RTP laboratories can have a significant effect on student understanding of basic concepts and on their ability to use a variety of representations in thinking about these concepts. They tend to spend less time on error analysis than traditional labs, but since it is my sense that students in traditional labs typically "go through the motions" of error analysis but gain little real understanding ([Allie 1998] [Sere 1993]), this may be a case of giving up two birds in the bush in order to get one in the hand.

A preliminary version of the RTP Electricity labs was available for the FIPSE dissemination project. A preliminary analysis of the first-year implementation of these labs at secondary institutions using the Electric Circuits Concept Evaluation (ECCE)[18] pre and post shows strong gains with RTP over traditional and even stronger gains when RTP Electricity labs are supported by the use of ILDs in lecture (see Figure 8.14).

[18] The ECCE is on the Resource CD associated with this volume.