CHAPTER 7

Lecture-Based Methods

When I, sitting, heard the astronomer,
where he lectured with such applause in the lecture room,
How soon, unaccountable, I became tired and sick;
Till rising and gliding out, I wander'd off by myself,
In the mystical moist night-air, and from time to time,
Look'd up in perfect silence at the stars.
Walt Whitman

Most of the introductory physics classes in the United States rely heavily on the traditional lecture. Research has rather broadly shown (see, e.g. [Thornton 1990]) that lectures, even when given by good lecturers, have limited success in helping students make sense of the physics they are learning. Good lectures can certainly help motivate students, though, as I discuss in chapter 3, lecturers often don't know how to help students convert that motivation to solid learning.

Even in a traditional class with a large number of students, there are some things you can do to get your students more engaged during a lecture. Unfortunately, some of the "obvious" things that both Sagredo and I have tried to do in lecture—such as asking rhetorical questions, asking them to think about something I've said, telling them to make a prediction before a demonstration (but not making those predictions public), having them work out something in their notebooks, or even doing lots of demonstrations—don't seem to have much effect. Something more structured seems to be required—something that involves having them give explicit responses that are collected and paid attention to.

In this chapter, I discuss my experience in traditional lectures and provide some detailed tips that in my experience can help improve that environment. Then I describe three models that involve more structured interactions with the students and that have been shown to produce dramatic improvements in student learning: Peer Instruction, Interactive Lecture Demonstrations, and Just-in-Time Teaching.

THE TRADITIONAL LECTURE

> **Environment:** Lecture.
> **Staff:** One lecturer (*N* = 20–600).
> **Population:** Introductory algebra- or calculus-based physics students.
> **Computers:** None required.
> **Other Equipment:** Traditional demonstration equipment.
> **Time Investment:** 10–20 hours planning time per semester, 1–2 hours preparation time per lecture.

Traditional lectures offer opportunities to inspire and motivate students, but one shouldn't make the mistake of assuming that students immediately understand and learn whatever the professor says and puts on the board. I consider myself a good "learner-from-lectures," having had years of experience with them. I regularly attended my lectures in university and grad school, took excellent notes, and studied from them. As a researcher, first in nuclear physics and now in physics education, I attend dozens of seminars and conference lectures every year. I enjoy them and feel that I learn from them.

But occasionally, I've been brought up short and have been reminded what the experience is like for a student. I still vividly recall a colloquium given some years ago at the University of Maryland by Nobel Laureate C. N. (Frank) Yang on the subject of magnetic monopoles. This was a subject I had looked at briefly while in graduate school, had some interest in, but hadn't pursued at a professional level. I had all the prerequisites (though some were rusty) and was familiar with the issues. Yang gave a beautiful lecture—clear, concise, and to the point. I listened with great pleasure, feeling that I finally understood what the issues about magnetic monopoles were and how they were resolved. Leaving the lecture, I ran into one of my friends and colleagues walking toward me. "Oh, Sagredo," I said. "You just missed the greatest talk!"

"What did you learn?" he asked.

I stopped, thought, and tried to bring back what I had just heard and seen in the lecture. All I could recall was the emotional sense of clarity and understanding—but none of the specifics. I was left with the only possible response, "Frank Yang really understands monopoles."

Once I had my grad assistants (ones not associated with the course) stationed waiting at the top of my lecture hall after lecture, grabbing students leaving at the end of the class and asking them "What did he talk about today?" Of the students willing to stop and chat, almost none could recall anything about the lecture other than the general topic.

This could in principle be an acceptable situation. If I had taken good lecture notes in Yang's lecture, I could have gone back to look at them and spent the time weaving the new information into my existing schemas. (I thought I had "listened for understanding" instead.) Unfortunately, many of my students do not take good lecture notes. Of those who do, many do not know how to use them as a study aid. Of those who know how to use their notes, many are highly pressed for time by other classes, social activities, or jobs, and can't devote the time required for the task. The assumption that "most students use lectures to create good lecture notes which they then study from" can be a very bad assumption indeed.

A more interactive approach to the traditional lecture

An alternative approach is to use the lecture in a more interactive way. Even within the framework of the traditional lecture, there are many tricks the instructor may use to increase the student's intellectual engagement in the class.[1] Some are fairly obvious and are taught in classes for new faculty, probed in end-of-the-semester student questionnaires, and watched for by peer evaluators. They include:

- Speak clearly and at an appropriate pace.
- Write on the board using good handwriting and good layout.
- Give students sufficient time to copy anything you expect them to copy.

Lecturers are often not aware of defects along these lines, focusing on the content rather than on what they are saying about the content. Problems with these issues can be helped by videotaping and reviewing your lectures or by having a sympathetic colleague sit in the back and watch your presentation.

Some of the things you can do to keep the students interested and attentive are the following:

- Set the context.
- Chunk the material.
- Facilitate note-taking.
- Develop a good speaking technique.
- Ask authentic questions.
- In discussions, value process as well as right answers.
- Get students to vote on a choice of answers.
- Make it personal.

Set the context

I once heard Sagredo deliver a lecture to a graduate class of physics students on a subject I thought I needed to learn more about. The lecture was enlightening—and I learned what I needed to know—but he presented it in a way I found disturbing. He began with 45 minutes of technical development without any discussion of his motivation or why this development was going to be interesting or useful. In the last 5 minutes, he wrapped everything together in an elegant package, applying all the technical details to the case of interest. When I asked him why he approached the lecture in this way, he said, "I didn't want to give away the punch line." Sagredo, I think stand-up comedy is the wrong metaphor for a physics

[1] Many of these and more are discussed in Donald Bligh's useful book, *What's the Use of Lectures?* [Bligh 1998].

lecture. Although our students seem to be accustomed to trying to take in random, unmotivated mathematical results, I don't think that is the best way to engage their attention and interest.

Since everyone's thinking and learning is naturally associative, we can expect to get the best results by tying new material to something the student already knows.[2] I try to begin my lectures by setting a context, letting the students know beforehand what the point of the lecture is and where we are going. Before every lecture, I write an outline of what we will be doing on the upper-left corner of the board so that students can have some idea of what we are going to be talking about.

Chunk the material

Another thing I try to do when lecturing in a large hall with many students is to keep in mind the difficulty produced by the limits to working memory. You cannot expect your students to keep a large number of difficult ideas in mind for a long time and bring them together at the end as you tie everything up into a neat package.

I try to chunk my lectures into coherent pieces that begin at the upper left and that can be completed on the available board space. Once I've finished the chunk, I don't just continue, but I stop, walk to the back of the class, wait until the students finish their note-taking, and go over the entire argument again so that the students have a context and can see the entire presentation at once. Summarizing after the chunk is complete helps students find a way to integrate the new material with their existing knowledge structures.

Facilitate note-taking

Tricks to speed things up, such as using pre-prepared transparencies, are usually counterproductive, especially if you are expecting students to take notes. Copying something from the board usually takes more time than it does to write it on the board, since the copyist also has to read and interpret what's been written. Forcing yourself to write it on the board at least gives you some idea of what the students are going through. Even if you do not expect the students to copy from a display, you are likely to severely underestimate the time it takes the students to read and make sense of the material you put up since you are very familiar with it and they are not.

Handing out previously prepared lecture notes may in principle help a bit, but since the instructor (rather than the student) is preparing the notes, the instructor gains the associated processing benefits, not the student. A more plausible approach[3] is to provide students with a set of "skeleton" notes—with just the main points sketched out but with spaces in which the students are supposed to fill-in what happens in class. This could be useful in helping students to create a well-organized set of notes and might help them in following the lecture. I have adapted this idea by creating PowerPoint presentations for each lecture that have a similar "skeleton" structure. The students can choose to print these out as handouts. I do derivations and problem solutions on the board so they don't go by too quickly—but the figures and diagrams can be more neatly prepared on the computer.

[2] Recall the example with the strings of numbers in chapter 2.

[3] I learned this trick from Robert Brown at Case-Western Reserve University.

Develop a good speaking technique

Getting students in a large class to engage the material is most easily accomplished by having them engage in carefully designed individual and group activities. The research-based curricular materials discussed below give some examples of how this can be done. Even without the use of prearranged materials, you can improve your students' engagement somewhat in these ways:

- *Talk to the students*—Face the students when you speak. If you have to write something on the board, do not "talk to the board" with your back to the students. Write and then turn to the class to describe or explain it.
- *Use appropriate tones of voice*—Learn to project your voice. Test your classroom with a friend, seeing if you can be heard adequately from all parts of the room. If you can't, use a microphone. Be careful! It's natural to project in a loud voice during the test and to forget to do it when you get involved in what you are saying in lecture. One trick that seems effective is, after announcing that something is important, drop your voice a bit to present the important information. The class will quiet significantly to hear what you are saying.
- *Step out of the frame*—In a lecture hall, walk up the aisles and speak from the middle or the back of the class. This requires the students to turn around. Changing their orientation restores their attention (at least momentarily—and it allows you to stand next to and stare down a student who is reading a newspaper). This also breaks the imaginary "pane of glass" the students put up between you and them and helps to change you from a "talking head on a TV screen" (to whom they feel no need to be polite or considerate) to a human being (to whom they do).
- *Make eye contact*—When you look a student in the eye during your lecture, for that student, you change the character of the activity from a TV- or movie-like experience into one more like a conversation, even if it's only for a moment, and even if you are doing most of (or all of) the talking. But be careful not to fixate on one particular student. That can be intimidating for that student. Switch your gaze from student to student every few seconds.

Ask authentic questions

An excellent way to get students involved is to ask questions to which they respond by really thinking about and answering them. This can be very effective, but it is harder than it sounds. Most faculty questions are rhetorical—that is, they are not meant to be answered by the students—in practice, if not in intent. Faculty tend to be as nervous about "dead air" as a TV news anchor. Two or three seconds of silence can seem like an eternity while you are waiting for students to answer a question you've posed. The easiest solution is to answer it yourself. But students know that faculty do this, so they wait you out. To get them to realize that you really do want them to answer and that the question is not just a part of the lecture, you have to outwait them—at least until they get in the habit of answering. This can be quite painful until you get used to it. The idea is to wait until they get uncomfortable with the silence, and this can easily take 20 to 30 seconds or longer. Sometimes you may have to reiterate your question or call on a specific student at random to show you really want a response.

You also have to build your students' confidence that answering questions is not going to be a painful experience. Students are most reluctant to look foolish in front of their instructor (and in front of their peers), so it is often quite difficult to elicit responses to questions. Being negative or putting down a student's question or answer can in one sentence establish a lack of trust between the instructor and the class that can last for the rest of the term. The result can be a class in which the instructor does all the talking, severely reducing the students' involvement and attention. I feel strongly enough about this principle that I set it off as

> *Redish's seventh teaching commandment:* Never, ever put down a student's comment in class or embarrass a student in front of classmates.

This isn't always easy, even for a supportive and compassionate lecturer. I remember one occasion some years ago in which I was lecturing to a class of about 20 sophomore physics majors on the Bohr model. As I proceeded to put down a blizzard of equations (laid out most clearly and coherently, I was certain), one student stopped me and asked: "Professor Redish, how did you get from line 3 to line 4?" I looked at the equations carefully and mentally reminded myself that the student asking the question was mathematically quite sophisticated and was taking our math course in complex variables that semester. After a pause during which I suppressed a number of put-downs and nasty remarks, I responded: "You multiply both sides in line 3 by a factor of two," before proceeding without further comment. Thinking about the situation later, I realized that I had been going too fast, using too many equations without sufficient explanation, and not giving the students enough time to follow the argument.

In discussions, value process as well as right answers

Another important step in being able to build a class that responds and participates in discussion is to change the class's idea that you are looking for the "right answer." If that's all you ever ask for, only the few brightest and most aggressive students will answer your questions. This will only reconfirm the attitude that most students have that science in general and physics in particular is a collection of facts to be memorized rather than a process of reasoning—and that only a few really bright people can do it. (See chapter 3.)

Even if the first student answering your question gives the correct answer, one way to begin to break this epistemological misconception is to ask for other possible answers, emphasizing creativity and explaining that the students are not required to believe the answers they give. I'll give an example of my experience with this technique in the section under Interactive Lecture Demonstrations.

Get students to vote on a choice of answers

Even if only a small number of students are willing to respond to an instructor's question, there are still ways of engaging a larger fraction of students in a lecture. One of the easiest and most effective is voting. This is easy to implement. Set out some options and ask the class to raise their hands in support of the different options. In some classes, only a few students will respond. If the voting process is to work to keep them engaged, this has to be overcome. In such a case, I often walk up the aisle and point to someone who hasn't voted and ask them to explain their difficulty and why they were unable to make a decision.

Another idea is to give each student a set of five "flash cards" at the beginning of the term.[4] These should be large (the size of a notebook page) and have one of the letters "A" through "E" on one side, and other options ("true," "false," "yes," "no," and "maybe" or "?") on the back. It may help to make them different colors. The students are instructed to bring their flashcards to every lecture. (If you really want them to do this, you have to use them at least once in every lecture, preferably more often than that.) When you present your choices, you label them with the letters or other options, and the students hold up the answer they choose. You can easily see the distribution of answers. If the flashcards are not colored, it's important to report back to the students an approximate distribution of the voting. If you use colored cards, they will be able to see each other's cards. The sense of not being alone in their opinions is an important part of increasing their comfort with taking a stand that might turn out to be wrong. There are electronic versions of this system available in which each student gets a remote-control device on which they can click their answers. These answers are beamed to a collector and displayed on a computer projection screen.

Make it personal

Finally, perhaps the most important component of delivering effective lectures (and classes in general) is to show the students that you are on their side.

> *Redish's eighth teaching commandment*: Convince your students that you care about their learning and believe that they all can learn what you have to teach.

This can make a tremendous difference in a class's attitude, no matter what environment you are using. One way to demonstrate this caring is to learn as many of the students' names as you can. Even if you only learn the names of the students who ask questions in class, it will give the rest of the students the impression that you know all (or most) of them. I take photographs in recitation section and copy them. (This also helps my teaching assistants learn the students' names.) I then bring them with me to class and spend three to five minutes before class matching names to faces. After class, I check any students who have come up to ask questions. It turns out to be relatively easy to learn the names of 50 to 100 students without much effort. Not only do the students get more personally engaged in the class, but so do I.

Demonstrations

An important component of a traditional introductory physics lecture is the lecture demonstration. Sagredo suggested to me that perhaps he should just do more demonstrations "especially since they don't seem to follow the math very well. After all, seeing is believing." I wish it were that easy, Sagredo. As physicists, we are particularly enamored of a good demonstration. After all, if they are properly set up, a demonstration makes clear what the physics is—doesn't it?

[4] I learned this idea from Tom Moore. See [Moore 1998] and [Meltzer 1996].

Unfortunately, demonstrations are not always as effective as we expect them to be, for two reasons coming from our cognitive model:

- Students may not see demonstrations as important.
- Students may not see in a demonstration what we expect them to see.

Sagredo sat in on some of my lectures in the large calculus-based class for engineers to help me evaluate my presentation and to consider ideas that might be adaptable to his own class. At one point in one of the lectures, I did a demonstration. The equipment had been prepared by our superb lecture demonstration facility and was large and visible throughout the hall. Furthermore, it worked smoothly. A few students asked questions at the end. Overall, I was pleased and felt it went well.

Sagredo came up to me after class. "You will never guess what happened in your demonstration!" he said. "Fully half the class simply stopped paying attention when you brought out the equipment! Only the group in the front few rows and a few scattered around were really trying to follow. Lots of students pulled out their newspapers or started talking discretely to friends!"

Since I had been concentrating on the equipment—and on the students in the first few rows—I hadn't noticed this. It's plausible, though. As discussed in chapter 3, students' expectations about the nature of learning and their goals for the class play a big role in filtering what they will pay attention to in class. At the time, it was not my habit to ask exam questions about demonstrations, so they were reasonably certain they wouldn't be asked about it.

My next step, then, was to change how I did my demonstrations. I began to do them less frequently but to spend more time on each one. I tried to engage more of the class and assured them that there would be an exam question on one of our demonstrations. In this environment, I learned something even more striking—but not surprising given our cognitive model.

Physics education researchers learned many years ago that students often think that circular motion tends to persist after the forces producing it are removed [McCloskey 1983]. In order to attempt to deal with the common naïve conception, I did the demonstration shown in Figure 7.1. A circular ring about 0.5 m in diameter with a piece cut out of it (about

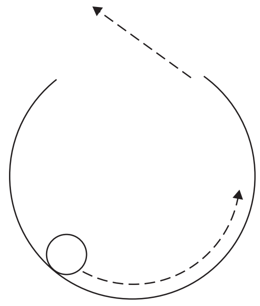

Figure 7.1 Lecture demonstration on circular motion (after [Arons 1990]). A partial circular ring lies flat on a table, and a billiard ball is rolled around the ring.

60° worth) was laid flat on the table. The point of the demonstration was to show that a billiard ball rolled around the ring would continue on in a straight line when it reached the end of the ring.

I did the demonstration in the following series of steps in order to engage more of the students' attentions in what was happening.

1. I briefly reviewed the physics—circular motion and Newton's second law.
2. I showed the apparatus and showed what I was going to do. I rolled the ball along the ring but stopped it before it got to the edge.
3. I asked students what they expected would happen. Some expected the correct straight line, but most expected it would continue to curve a bit. I called for discussion, and a number of students defended one answer or another.
4. I put the answers on the board and asked for a show of hands. It was split, with a substantial number of students supporting each answer. (No one thought it would continue on in the circle when there wasn't any ring holding it in.)
5. I then showed the demonstration, letting the ball roll on beyond the edge of the ring.

Then, by a lucky chance, instead of saying: "There. You see it goes in a straight line," I asked them what ***they*** saw. To my absolute amazement, nearly half the students claimed that the ball had followed the curved path they expected! The other half argued that it looked to them like a straight line. Lots of mini-arguments broke out among the students. Somewhat nonplussed, I looked around and found a meter stick. "Let's see if we can decide this by looking a bit more carefully. I'll align the meter stick along what a straight path would be—tangent to the point where it will leave the circle—and about an inch away. If it's going straight, it will stay the same distance from the ruler. If it curves, it will get farther away from the ruler as it goes." Now, when I did it, the path was obviously straight since it remained parallel to the ruler. It was only at this point that I got the gasp I had expected from half the class.

Now that I know "what they need," I could do the demo in the future using the ruler right away. But I feel that would be a mistake. The predictions and discussions, the taking a stand and defending their point of view, the surprise at having mis-seen what was happening—all of these contribute to the students' engagement in and attention to the activity. Although I have no hard comparative data (it would make a nice experiment), I expect the demo we did was much better remembered than if I had simply "done it right." On the midsemester exam, I gave the relevant question from the Force Concept Inventory, and more than 80% of the students gave the correct response. This is much better than the typical results from traditional instruction.

PEER INSTRUCTION/CONCEPTESTS

Environment: Lecture.

Staff: One lecturer trained in the approach ($N = 30–300$).

Population: Introductory algebra- or calculus-based physics students (though some ConcepTest questions are appropriate for less sophisticated populations).

Computers: None required, but one associated with a response system permits live-time display of quiz results.

Other Equipment: Some kind of student-response system. This can be as low tech as cards for the students to hold up or as high tech as a computer-based system with individual wireless remote-response devices for each student.

Time Investment: Low to moderate.

Available Materials: Text with ConcepTest questions [Mazur 1997]; http://galileo.harvard.edu

Eric Mazur describes his method for increasing students' engagement in his lectures in his book *Peer Instruction* [Mazur 1997]. His method includes three parts:

1. A web-based reading assignment at the beginning of the class (see the section on JiTT below)
2. ConcepTests during the lecture
3. Conceptual exam questions

During the lecture he stops after a five- to seven-minute segment to present a challenging multiple-choice question about the material just covered (a *ConcepTest*). This question is concept oriented, and the distractors are based on the most common student difficulties as shown by research. Students answer the questions at their seats by either holding up a colored card showing their answer or by using a device that collects and displays the collective response on a projection screen, such as *ClassTalk*™ or the *Personal Response System*™.

Mazur then instructs the students to discuss the problem with their neighbor for two minutes. At the end of this period, the students answer the question again. Usually the discussion has produced a substantial improvement. If not, Mazur presents additional material. A sample of one of Mazur's questions is given at the top of Figure 7.2. The ConcepTest discussion takes another five to seven minutes, breaking the lecture up into 10- to 15-minute chunks.

The response of Mazur's students in a Harvard algebra-based class to this question is shown in the lower half of Figure 7.2. Note that about 50% of the students start with a correct answer before discussion and about 70% have the right answer after discussion. What's more, the fraction of students who have the right answer and are confident about it increases from 12% to 47%. This is a rather substantial learning gain for two minutes of discussion time.

Mazur suggests that a question used in this way should be adjusted so that the initial percentage correct is between 35 and 70%. Less than this, and there will be too few students with the correct answer to help the others. More than that, and either you haven't found the right distractors or enough students know the answer that the discussion isn't worth the class time.

Imagine holding two bricks under water. Brick A is just beneath the surface of the water, while B is at a greater depth. The force needed to hold brick B in place is

(a) larger than
(b) the same as
(c) smaller than

the force required to hold brick A in place.

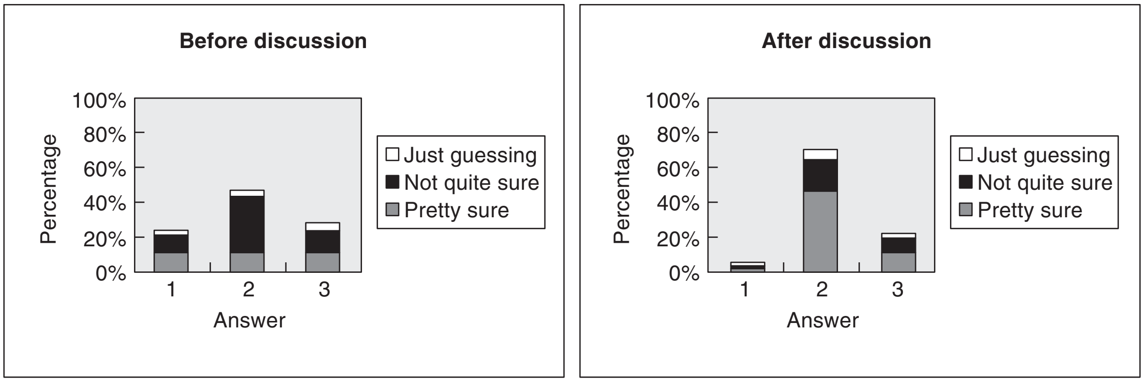

Figure 7.2 A ConcepTest question with the results before and after discussion (from [Mazur 1997]).

For all the ConcepTest questions in a given semester, Mazur found that the fraction of correct answers invariably increased after the two-minute discussions. A plot of this result is shown in Figure 7.3.

Finally, sensitive to the principle that students only focus on things that you test, Mazur includes conceptual questions on every exam. His book contains reading quizzes, ConcepTests, and conceptual exam questions for most topics in the traditional introductory physics course.

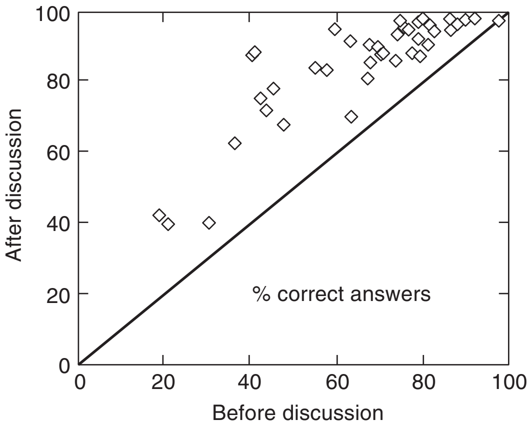

Figure 7.3 The fraction of correct answer before and after peer discussion (from [Mazur 1997]).

INTERACTIVE LECTURE DEMONSTRATIONS (ILDS)

Environment: Lecture.

Staff: One lecturer trained in the approach (N = 30–300).

Population: Introductory algebra- or calculus-based physics students (though some ILDs are appropriate for less sophisticated populations).

Computers: One required for the lecturer.

Other Equipment: LCD or other appropriately large-screen display. Some kind of computer-assisted data acquisition device. Specific standard lecture-demonstration equipment is required for each ILD.

Time Investment: Low.

Available Materials: Worksheets for about 25 ILDs [Sokoloff 2001].

An approach that has proven both effective and efficient is a series of interactive lecture demonstrations (ILDs) by Sokoloff and Thornton [Sokoloff 1997] [Sokoloff 2001]. These demonstrations focus on fundamental conceptual issues and take up a few lecture periods (perhaps four to six) during a semester. Most use computer-assisted data acquisition to quickly collect and display high-quality data.

In order to get the students actively engaged, each student is given two copies of a worksheet to fill out during the ILD—one for predictions (which they hand in at the end) and one for results (which they keep). Giving a few points for doing the ILD and handing in the prediction sheet (which should ***not*** be graded) is a valuable way to both increase attendance and get some feedback on where your students are.[5]

Each ILD sequence goes through a series of demonstrations illustrating simple fundamental principles. For example, in the kinematics demonstrations, demonstrations are carried out for situations involving both constant velocity and constant acceleration. The cases with acceleration use a fan cart to provide an approximately constant acceleration. (See Figure 7.4.) The demonstrations address a number of specific naïve conceptions, including confusion about signs and confusion between a function and its derivative. A fan is used to provide an acceleration rather than gravity so as not to bring in the additional confusion caused by going to two dimensions. The specific demonstrations are:

1. Cart moving away from motion detector at constant velocity
2. Cart moving toward the motion detector at a constant velocity
3. Cart moving away from the motion detector and speeding up at a steady rate
4. Cart moving away from the motion detector and slowing down at a steady rate (fan opposes push)

[5]Sokoloff reports that even though students are told that the prediction sheets will not be graded and that they should leave their original predictions to be handed in, some students correct their prediction sheet to show the correct answer instead of their prediction.

5. Cart moving toward the motion detector and slowing down at a steady rate (fan opposes push)
6. Cart moving toward the motion detector and slowing down, then reversing direction and speeding up

In each case, the demonstrator goes through the following steps:

- Describe the demonstration to be carried out, performing it without collecting data.
- Ask the students to make and write down individual predictions on their prediction sheets ($\Delta t \sim$ one minute).
- Have the students discuss the results with their neighbors and indicate their consensus prediction on their prediction sheets ($\Delta t \sim$ two to three minutes).
- Hold a class discussion, putting the various predictions on the board.
- Perform the demonstration, collecting data and having the students copy the results on their results sheet.
- Hold a brief class discussion reflecting on why the answer obtained makes sense and the other answers have problems.

I have carried out some of these ILDs in my algebra-based physics classes. The first time I did them, I was tempted to leave out some of the demonstrations, finding them repetitious. After all, once they got demo 4, isn't demo 5 obvious? When I did this, some students came

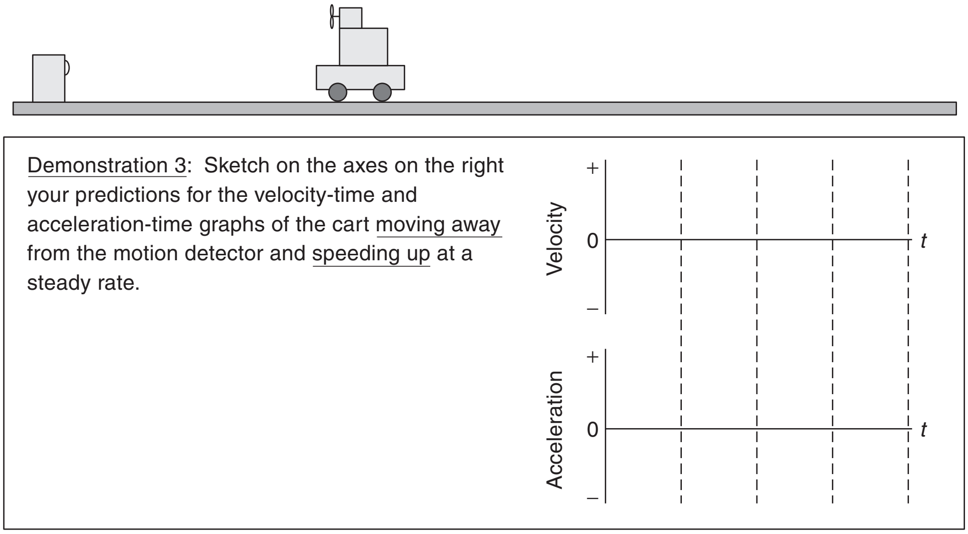

Figure 7.4 The apparatus and worksheet entry for a kinematics ILD.

up after class asking for the results. When I asked them for their predictions, they had the wrong answers, having found it difficult (not at all obvious) to make the translation from the other cases.

One place where I have found ILDs to be extremely valuable is in the class discussion step. This offers a tremendous opportunity to change the character of the class and your interaction with the students in a fundamental way. As I described in some detail in chapter 3, many of our students have the epistemological misconception that science in general, and physics in particular, is about the amassing of a set of "true facts." They think that learning scientific reasoning and sense making are a waste of time. Given this predilection, most students are reluctant to answer a question in class if they are not convinced they have the correct answer.

In discussing the predictions for the ILDs, I encourage the class to "be creative" and to find not just what they think might be the correct answer (probably the one given by the A student in the front row who answered first!), but to come up with other answers that might be considered plausible by other people (such as a roommate who is not taking the class). This frees the students from the burden of being personally associated with the answer they are giving and allows them to actually express what they might really believe. (I sometimes find it necessary to give some plausible but wrong answers myself in order to get the ball rolling.) I then ask students to try to defend each other's answers. This changes the character of the discussion from one that is looking for the right answer to one that is trying to create and evaluate a range of possible answers. The focus changes from "listing facts" to building process skills.

The results of this were quite dramatic in my class. Many more students became willing to answer (and ask) questions, and I was able to elicit responses from many more of my students than ever before. (In a class of 165 students, about 40 to 50 students were willing to participate in subsequent discussions.)

The evaluations of student conceptual improvement with ILDs were done by Thornton and Sokoloff in mechanics using the FMCE. The results they reported were spectacular, with students in classes at Tufts and Oregon improving to 70% to 90% from a starting point of less than 20%. Of course, this result is at the primary institution, and the demonstrations were performed by the developers or by colleagues they themselves have trained.

Secondary users have reported some difficulties with their implementation. One colleague of mine reported implementing ILDs and obtaining no improvement on the FCI over traditional demonstrations [Johnston 2001].[6] In my own experience with the technique, I find it not as easy to implement effectively as it appears on the surface. With traditional demonstrations, students often either sit back and expect to be entertained or tune out altogether. With ILDs, it is essential to get the students out of that mode and into a mode where they are actively engaging the issues intellectually. This is not easy, especially with a class that is accustomed to passive lecturing and instructor-oriented demonstrations. A full analysis of ILD implementation is currently under way [Wittmann 2001].

[6]In this case, the lecturer is highly dynamic and entertaining. My hypothesis is that he maintained a demonstration/listening mode in his students rather than managing to get them engaged and thinking about the problems.

JUST-IN-TIME TEACHING (JiTT)

Environment: Lecture.
Staff: One lecturer trained in the approach (N = 30–300).
Population: Introductory algebra- or calculus-based physics students.
Computers: One required for the lecturer. Students require access to the web.
Other Equipment: None.
Time Investment: Moderate to high.
Available Materials: Text with questions [Novak 1999]; website http://www.jitt.org.

The Just-in-Time Teaching or JiTT approach was developed by Gregor Novak and Andy Gavrin at Indiana University–Purdue University Indianapolis (IUPUI) and Evelyn Patterson at the U.S. Air Force Academy. The group has collaborated with Wolfgang Christian at Davidson College to create simulations that can be used over the web.

The JiTT approach is described in the group's book, *Just-in-Time Teaching: Blending Active Learning with Web Technology* [Novak 1999]. The method is a synergistic curriculum model that combines modified lectures, group-discussion problem solving, and web technology. These modifications are reasonably self-standing and can be adopted by themselves or in combination with other new methods that are described in the next two chapters.

The JiTT approach has as its goals for student learning a number of the items addressed in chapters 2 and 3:

- Improve conceptual understanding.
- Improve problem-solving skills.
- Develop critical thinking abilities.
- Build teamwork and communication skills.
- Learn to connect classroom learning with real-world experience.

To achieve these goals, JiTT focuses on two critical cognitive principles, one from each side of the teaching/learning gap:

- Students learn more effectively if they are intellectually engaged.
- Instructors teach more effectively if they understand what their students think and know.

These principles are implemented by using web technology to change students' expectations as to their role in the learning process and to create a feedback loop between student and instructor. This feedback is implemented by assigning web homework "WarmUp" assignments before each class. The components of the process are as follows.

1. Before each lecture, specific, carefully chosen *WarmUp* questions are assigned and made available on the web. The questions concern a topic that has not yet been con-

sidered in class and that will be addressed in the lecture and class discussions and activities. (The detailed character of these questions is discussed below.)

2. Students are expected to do the reading and consider the questions carefully, providing their best answers. They are graded for effort, not correctness. The student responses are due a few hours before class.
3. The instructor looks at the student responses before lecture, estimates the frequency of different responses, and selects certain responses to put on transparencies (or display electronically) to include as part of the in-class discussion and activities.
4. The class discussion and activities are built around the WarmUp questions and student responses.
5. At the end of a topic, a tricky question known as a *puzzle* is put on the web for students to answer.

The authors report that for the students, thinking about the questions beforehand, seeing their own responses as a part of class discussion, and discovering that they can solve tricky questions using what they have learned raises the level of student engagement substantially. For the instructor, the explicit display of student difficulties provides much more feedback than is typically available. This feedback can keep the instructor from assuming too much about what the students know and can help direct the class discussion to where it will do the most good.

A successful implementation of JiTT relies on:

1. *A mechanism for delivering questions over the web and for collecting and displaying student answers in a convenient form.* You can use a number of web environments such as WebAssign™, CAPA, and Beyond Question, or course management systems such as BlackBoard or WebCT.
2. *A set of carefully designed warm-up questions and puzzles that get to the heart of the physics issues.* The JiTT book includes examples of 29 threefold WarmUp assignments and 23 puzzles on the topics of mechanics, thermodynamics, E&M, and optics. Many additional JiTT materials developed by adopters and adapters are accessible via the JiTT website.
3. *An instructor with sufficient knowledge of student difficulties and with strong skills for leading a classroom discussion.* This is something that cannot be easily provided and is the reason I have rated this method as requiring a “moderate to high” time investment.

Sagredo, although I told you at the beginning of chapter 6 that I could not provide you any “best method” for teaching a particular physics topic, this approach allows you to learn about specific student difficulties and to make use of what you have learned.

Running a discussion in a large lecture in such a way that many students are involved, that the appropriate physics is covered, and that the students get to resolve their difficulties requires substantial skill. The JiTT book includes discussions of various specific examples that show the kinds of techniques that can be effective.

Since the entire structure of the class relies on the student responses to the WarmUp questions and puzzles, the choice of these questions becomes critical. The JiTT book recommends that the WarmUp questions share the following characteristics:

- They are motivated by a clear set of learning objectives.
- They introduce the students to the technical terms.
- They connect to students' personal real-world experience.
- They confront common naïve misconceptions.
- They are extendible.

The WarmUp assignments typically include three parts: an essay question, an estimation question, and a multiple-choice question. An example is shown in Figure 7.5. Note the interesting fact that some problems are stated ambiguously. Often we try to write questions in which all the assumptions are absolutely clear. Here, for example, it is left unstated whether the carousel is a large mechanical object in a theme park that is driven by a motor or a small unpowered rotating disk in a children's playground. Furthermore, even when you have envisioned the situation, the first part of the essay question has no unique answer. It depends on how you do it. This offers a good opportunity for starting a discussion.

The second part is a true estimation question as discussed in chapter 4. Not enough information is given (How fast are the planes going when they take to the air?), and information from personal experience must be provided (How long does it take the Earth to make one rotation?). This is also challenging since the intermediate variable required (the speed of the Earth's rotation) has to be connected to the personal data by a calculation.

Essay: Suppose you are standing on the edge of a spinning carousel. You step off, at right angles to the edge. Does this have an effect on the rotational speed of the carousel?

Now consider it the other way. You are standing on the ground next to a spinning carousel and you step onto the platform. Does this have an effect on the rotational speed of the carousel? How is this case different from the previous case?

Estimation: The mass of the Earth is about 6×10^{24} kg, and its radius is about 6×10^6 m. Suppose you built a runway along the equator and you lined up a million 10,000 lb airplanes and had them all take off simultaneously. Estimate the effect that would have on the rotational speed of the Earth.

Multiple Choice: An athlete spinning freely in midair cannot change his

(a) angular momentum.
(b) moment of inertia.
(c) rotational kinetic energy.
(d) All of the above conclusions are valid.

Figure 7.5 A JiTT WarmUp assignment. These are distributed on the web and answered by students before they are discussed in class.

> Hold a basketball in one hand, chest high. Hold a baseball in the other hand about two inches above the basketball. Drop them simultaneously onto a hard floor. The basketball will rebound and collide with the baseball above it. How fast will the baseball rebound? Assume that the basketball is three to four times heavier than the baseball.
>
> The result will surprise you. Don't do this in the house!

Figure 7.6 A JiTT puzzle.

The multiple-choice question is not at all straightforward, though I would have offered it as a multiple-choice multiple-response question (see chapter 4), allowing the students to pick as many of the answers as they desired. A natural error here is to choose both (a) and (c), since both conservation of angular momentum and energy have been discussed. This choice is not available in the form presented. The discussion of this WarmUp cluster can be tied in class to the classic demonstration of the student with dumb-bells on the rotating chair.

A typical puzzle is given in Figure 7.6. Novak and colleagues report that most students attempting this problem get bogged down in the algebra. They then spend a full hour discussing this problem, using it as an opportunity to thoroughly review everything that had been covered to that point and to discuss and build problem-solving skills.

This example nicely illustrates the difference between JiTT questions and traditional homework problems. The goal of a JiTT question is not to evaluate students' problem-solving skills. In that case, you would hope that you had presented a question that most students can answer. In constructing JiTT questions, you want a question that is not so difficult that most students are unwilling to spend any time thinking about it, but that is hard enough that many students will not be able to complete it successfully. The primary goal of the questions is an engaged and effective lecture discussion.

The JiTT group also includes in their approach web homework of a more standard type and problems based on simulations. The book contains a brief introduction to creating simulations in the Physlet environment[7] and a set of problems and questions that can be assigned in conjunction with existing simulations.

The JiTT approach can be used in a variety of lecture-based classes and can readily be combined with other techniques in recitation and laboratory.

[7] *Physlets* is a set of programming tools using Java and JavaScript that allows the creation of simple simulations that can be delivered on the web [Christian 2001].