Introduction Part I: The Textbook, the Instructor's Manual, and Active Learning

Note to the Reader: *Research and curriculum development related to the introductory physics course have uncovered much information and insight regarding student learning in physics classes that faculty would find useful for improving student learning in their classes. Unfortunately many instructors are unaware of these research-based efforts to improve instruction. Rather than give a brief overview that would skimp on many of the important issues and details, this introduction is intended as a more complete reference to be read at the reader's convenience. Both parts of the introduction are written so that the first six or seven pages summarize the most important points. Each section is written to make sense if it is read independently. Despite its length and coverage, this is still only an introduction; readers who are interested in these issues are encouraged to use the references and recommended reading lists to obtain further information.*

The inclusion of Physics Education Research summaries is a new feature; comments and suggestions regarding how to make this instructor's manual more useful to physics faculty in the future are welcome and encouraged. Please send comments and suggestions to:

Physics Editor
Harcourt College Publishers
150 South Independence Mall West, Suite 1250
Philadelphia, PA 19103

Overview

For the last twenty years, many researchers have turned their scientific background and training to understanding student learning in the introductory physics course. They have begun understanding how students learn physics, the nature of their learning difficulties, and how to make instruction more effective. The findings of these physics education researchers (described in more detail in Part II of this introduction) can be summarized in the following four points.

1. Traditional lecture instruction is not working for many students in the introductory physics course.[1] Even many students who can successfully solve plug-and-chug problems demonstrate poor understanding of the underlying material or are unable to solve similar problems in new contexts.
2. Students are not "blank slates." They come to the introductory physics sequence with beliefs and attitudes based on years of experience with school and the world around them. In particular, they have their own preconceptions about how to solve physics problems, common sense beliefs about how things work, and cognitive beliefs on learning, physics, and mathematics. Many of these views are incompatible with what instructors want the students to learn, hinder the students' learning, and outlast traditional lecture instruction.[2]
3. Students' physics knowledge is often fragmented and ill defined. Their knowledge consists of a small number of facts and equations stored randomly in the mind.[3]
4. Research-based curricula can help improve students' conceptual understanding and/or problem solving techniques through active-learning activities that take into account students' initial views.[4]

This version of the textbook and the instructor's manual has incorporated several pedagogical features designed to help physics instructors incorporate some of the lessons from physics education research. The main changes in the textbook are the inclusion of suggestions for active learning activities and the incorporation of a expert-like problem solving protocol. In addition, the presentation of material in the textbook has been modified to help students understand the material better and see how what they learn applies to other disciplines.

What is Active Learning?

Active learning is a technique that recognizes some of the weaknesses inherent in the traditional lecture style of teaching. For example,

- Listeners in lecture classes typically have an attention span of twenty minutes or less.
- The lecture information passes too quickly for serious contemplation and reflection in class and very few students take the time to review their notes except for finding examples similar to the homework problems.
- Many students don't know how to listen to a lecture, take good notes, and learn by reconstructing their notes.
- Since many lectures reiterate the material in the textbook, this encourages students to not prepare for class by reading the textbook or thinking about the material before class.

While lecture is an effective way to transmit information, it is not effective for helping students learn unless the students go back and reconstruct the lecture on their own from their notes. Unfortunately many students lack the time, the motivation, or the skills to do this type of active processing. Active-learning (also called interactive engagement) methods are specifically designed to encourage and teach students to actively process the course material through activities. The basic idea is that students will learn the material better if they are thinking about, discussing, or using what they are learning. The active-learning approach is based on the constructivist philosophy that students learn best when they construct their own understanding, rather than simply receive knowledge.

Several research-based introductory physics curricula using active-learning have been shown to help students develop better conceptual understanding and / or better problem solving skills. The curricula range from approaches that make small changes to the lecture approach to some that do-away with lecture altogether. Although these curricula have different ways of implementing the active-learning philosophy, the successful implementations have some common characteristics:

- Students are actively, not passively engaged in the course material for a significant fraction of class time.
- The activities involve students interacting with their peers in small groups of 2-4. This student interaction gives students the opportunity to ask questions of their peers and in turn makes the student who answers the question think about how to explain what they know.
- During the active-learning activity, the instructor becomes more of a facilitator or coach and less of an authoritative source.
- The students take responsibility for their own learning. They are responsible for attending the class, completing all assignments, and filling in the gaps of what they don't understand. It is also the students' responsibility to make-up work that was missed or not completed in class.

It should be noted that even though recitation/discussion sections are question and answer sessions, most of them are not active-learning environments. Usually only a small fraction of students in the section are active participants while the majority of the class watches and listens passively. The same is true for many lecture courses that encourage student questions and discussions. To be an active-learning activity, all or nearly all the students should be active participants in the activity.

Using The Textbook

This version of the textbook has several features to aid instructors in teaching their classes. These include the Instructor's Notes, Puzzlers, the Quick Quizzes, the QuickLabs, and the GOAL problem-solving protocol described below:

Instructor Notes

The Instructor's annotated version of the textbook includes tips and comments by the author in blue in the margin. These annotations include brief notes on student preconceptions, call attention to particularly useful exercises and examples in the textbook, and cite related references from the physics education literature.

Puzzlers

The puzzler problems at the beginning of each chapter pose a thought-provoking question related to the material in the chapter. These questions can be used as a means to introduce and motivate the material in the chapter to come. After the material has been read and/or discussed in class, the puzzler problem may be used as the subject of a class discussion or a quiz problem.

Quick Quizzes & QuickLabs

The Quick Quizzes and QuickLabs are activities designed to help students better understand the material they read in the textbook. The Quick Quizzes are short problems designed to help students see if they understand the concepts presented in the chapter. They can also easily be used as reading quizzes. Many of the teaching methods discussed below depend on students reading the relevant sections of the text for understanding ahead of the lecture to prepare for class. Many instructors have reported success in getting students to read ahead; the trick is to make your expectation clear and to hold the students accountable for the reading. Using Quick Quizzes as reading quizzes is one way to do this. (Additional discussion on getting students to read the text can be found in the FAQ section below.)

QuickLabs are "string and sticky tape" experiments that students can perform at home. These experiments provide active learning activities that help connect physics concepts to real physical situations. To be most effective, students should write down their estimate of a measurement or prediction of what will happen with their reasoning before they perform the experiment. In cases where the students are asked to observe the experiment, students should record their observations and try to explain the result in terms of the underlying physics concepts. If what they observe is different from what they predicted, students should be encouraged to reconcile the difference.

Note that both Quick Quizzes and QuickLabs can also be used during class as cooperative group activities to promote active learning. The Quick Quizzes could be done in a style similar to the active-learning methods for lecture discussed below.

The GOAL Protocol

The physics problem-solving literature[5] shows that approaches used by introductory physics students and physicists are very different. These differences are discussed in more detail in Part II of this introduction, but the main points are summarized as follows:

> Experts work forward from the given information using their understanding of the situation and the underlying physics to analyze the situation, plan and carry out a solution, and check their solution to see if it is reasonable.
>
> Most introductory physics students solve problems by looking for an equation that contains the unknown quantity and work backward to the given information. When stuck, they look for examples that have similar surface characteristics (i.e. a ramp, a pulley, etc.) to the problem they are working on. They classify problems by these surface characteristics and the algorithmic recipes they use to solve them. In addition, novice problem solvers often fail to check their solution, and when they do check, they tend to affirm the correctness of their solution even when it is wrong.

This pattern-matching approach is one reason why even students who can solve quantitative problems often have difficulty with the underlying concepts or solving problems using the same concepts in a different context. One way to help students develop better problem-solving skills is to teach them to use an expert-like problem solving strategy. The core of the approach is to teach students to use a general heuristic strategy that can be used with any problem rather than the haphazard algorithmic approach students typically use in introductory physics courses. In an analogy with cooking, we teach the students general heuristic cooking skills so that they are not limited to just following a recipe. Heuristic expert-like problem-solving strategies like GOAL have been used with success at North Carolina State University,[6] University of Minnesota[7] and Carnegie Mellon University.[8] This textbook, the *Student Solutions Manual and Study Guide* and the instructor's manual have incorporated features to help instructors implement the GOAL problem- teaching strategy in their classes.

To use this strategy effectively, the literature strongly recommends that instructors model the GOAL problem-solving approach in-class, let students practice it in- and out-of-class, and give them feedback on their solutions. Several example solutions using the GOAL protocol are included in each chapter of the Student Solutions Manual and Study Guide and this instructor's manual. These problems should serve as examples of how the GOAL strategy can be applied to nearly any physics problem. As always when instructors are modeling how students should do something, instructors should model problem solutions the way they want their students to solve them.

The description of the GOAL protocol steps given in Chapter 2 are shown in Table 1. Although the steps described in the table are pretty much self-explanatory, there are some subtle points in the four-step protocol that should not be overlooked.

TABLE 1: GOAL PROBLEM SOLVING STEPS

Gather information: The first thing to do when approaching a problem is to understand the situation. Carefully read the problem statement, looking for key phrases like "at rest," or "freely falls." What information is given? Exactly what is the question asking? Don't forget to gather information from your own experiences and common sense. What should a reasonable answer look like? You wouldn't expect to calculate the speed of an automobile to be 5 (106 m / s. Do you know what units to expect? Are there any limiting cases you can consider? What happens when an angle approaches 0(or 90(or a mass gets huge or goes to zero? Also make sure you carefully study any drawings that accompany the problem.

Organize your approach: Once you have a really good idea of what the problem is about, you need to think about what to do next. Have you seen this type of question before? Being able to classify a problem can make it much easier to lay out a plan to solve it. You should almost always make a quick drawing of the situation. Label important events with circled letters. Indicate any known values, perhaps in a table or directly on your sketch.

Analyze the problem: Because you have already categorized the problem, it should not be too difficult to select relevant equations that apply to this type of situation. Use algebra (and calculus, if necessary) to solve for the unknown variable in terms of what is given. Substitute in the appropriate numbers, calculate the result, and round it to the proper number of significant figures.

Learn from your efforts: This is the most important part. Examine your numerical answer. Does it meet your expectations from the first step? What about the algebraic form of the result before you plugged in numbers? Does it make sense? (Try looking at the variables in it to see if the numeric and algebraic forms of the answer would change in a physically meaningful way if they were drastically increased or decreased or even became zero.) Think about how this problem compares to others you have done. How was it similar? In what critical ways did it differ? Why was this problem assigned? You should have learned something by doing it. Can you figure out what?

When solving complex problems, you may need to identify a series of subproblems and apply the GOAL process to each. For very simple problems, you probably don't need this protocol. But when you are looking at a problem and you don't know what to do next, remember what the letters in GOAL stand for and use that as a guide.

- In the gather step, many students have difficulty estimating a reasonable answer, especially for problems that involve unfamiliar quantities (how big is a farad?) Order of magnitude problems provide an excellent opportunity for students to gain experience practicing this skill.
- In the organization step, it is useful to include qualitative representations such as motion diagrams, free body diagrams, or velocity graphs to make the physics underlying the problem clearer. Once students have classified a problem according to the physics of the situation and drawn qualitative sketches, they are ready to develop a plan to solve the problem. Once students have a plan of attack, it is time for the next step. In helping students to learn the skills needed for this step, it may be helpful to give them exercises that ask for a qualitative sketch or come up with a plan that may or may not be used by another student to analyze the problem in question.

- In the analysis step, it is important to encourage students not to skip the step of solving for the unknown quantity symbolically before substituting numbers. Students generally want to plug numbers into problems as quickly as possible despite the fact that it may make the calculation more complex and it makes the problem harder to debug if they get it wrong. It also removes much of the physics from the calculation. The literature suggests that students are much more comfortable with numeric calculation than symbolic calculation; perhaps because numeric calculations require less thought and many students have not developed good mathematical thinking skills. Learning to solve problems symbolically will take time, but it will help students make better connections between the physics and the calculations. The paired problems where a symbolic problem is paired with an identical problem with numbers can be used to help students become better at symbolic calculations.
- One tool for checking solutions that is not mentioned explicitly in the GOAL process is unit checks or dimensional analysis. These are particularly useful checks on a solution that many students know about, but few of them use. As with all the steps in the GOAL protocol if you require students to use it, they will learn it. One way to give them practice is to show them incorrect solutions and ask them to use unit checks to find the mistake. This can be done either as an individual or a group activity.

Two things that help encourage students to use the GOAL protocol are worksheets with sections for each of the four steps (this can be dropped once students are used to using GOAL) and assignment of problems that would be more difficult without the GOAL approach. Although the GOAL protocol can be used with problems that students can solve more easily with a plug-and-chug approach, these problems do not encourage student use of the protocol.

The Instructor's Manual

The instructor's manual has also undergone several changes from previous editions. In addition to the problem solutions found in previous editions, this instructor's manual contains both general and topical summaries of physics education research to give instructors a working knowledge of the literature as well as detailed GOAL solutions to several problems in each chapter. The general summary can be found in Part II of this introduction. The topic summaries are structured around the major topics in the text, sometimes extending over several chapters. Note that some topics do not have summaries as not all topics are well documented in the physics education literature. Each topic summery contains an overview of the topic, a list of general learning goals, a description of student difficulties and preconceptions, suggestions for teaching and a list of problems that promote understanding of the material. Both the general and topic summaries end with a suggested reading list. (Note that the learning goals for each chapter are not meant to be specific learning objectives which may or may not match instructor's goal for the class but are intended to give new instructors an idea of what points need to be emphasized.[9])

Incorporating Active Learning in the Classroom

As discussed above, effective learning requires that students be active participants in building an understanding of the concepts and skills being taught, not just passive listeners. The challenge for instructors is to create an active-learning environment in their classrooms. In this type of environment, the textbook is viewed as the students' source of factual knowledge, new ideas, and example applications including problems. In class, emphasis is placed on practicing physics rather than presenting new material. Class time is used to discuss key concepts and principles, answer questions, clarify the more subtle issues, relate the current material to previously studied material, demonstrate connections to real-world examples, and practice problem solving in an environment where the students can receive rapid feedback from the instructor.

Part of what makes active-learning effective is based on two experiences shared by most physics instructors. The first is that you learn the material best when you consider how to explain it so that someone else can understand it. Many instructors comment on how they did not really learn a topic well until they taught it. The second is that best teaching situations are one-on-one tutoring or instructors working with one or two students in office hours. The student(s) can pose questions without fear of embarrassing themselves in front of the whole class and can interact with the instructor with immediate feedback. A key aspect of active-learning techniques is to incorporate these experiences on a larger scale by having the students work in small cooperative learning groups of two to four students each. The students are given a structured task and asked to work together as a team to resolve the situation. In building a team consensus to resolve the situation, students use their reasoning to convince their peers. This form of peer instruction makes the student who is explaining think more carefully about the material and allows the other members of the group to interact and question the first student in a non-threatening environment. Students are much less hesitant to ask questions of a classmate than the instructor. In addition to creating more student-student interaction, this type of activity can free the instructor to walk around and interact with the groups, thereby increasing and improving in-class student–faculty interactions as well.

In addition to the improved learning benefits of active-learning group activities, instructors who are reluctant to adopt this type of teaching approach should note that there are numerous employee surveys illustrating that teamwork and interpersonal skills are a top hiring criterion for scientists and engineers. Other benefits of active-learning in groups include improved information retention, academic achievement, higher-level thinking skills, attitudes, motivation to learn, communication skills, self-esteem, attendance, race/gender relations and reduced levels of anxiety. Although this seems like a huge list, there are numerous studies where these results have been carefully documented.

This section describes some methods for introducing active learning in different aspects of the introductory physics class. This is not meant to be a complete list of active-learning techniques, but rather to give examples of how active learning is being implemented in the classroom. Each method uses active-learning activities with cooperative learning groups. They range from relatively small changes in the lecture course to the complete elimination of lecture. Most physics instructors should be able to find suggestions for implementing active-learning that are suitable for their teaching style, class size, and institution. The section concludes with a discussion of Cooperative Learning groups and additional suggestions for active-learning activities.

Active Learning in Lecture

These methods make use of the main advantage of lecture, presenting material and demonstrations to large numbers of students. They are minimally invasive techniques that can supplement any textbook or lecture style. They do not depend or interfere with what is done in recitation, laboratory, or other lecture sections. (Although, for any of the active-learning methods, student learning can be enhanced if all section of the class—lecture, laboratory, and recitation—are coordinated and build on the same key points.) These active-learning methods for lecture are also particularly well suited to large classes and can be used with minimal equipment. Students work in cooperative learning groups with their nearest neighbors. The disadvantages of this approach are that it is hard for instructors to interact with students in the middle of the row and the students do not get hands-on experience with the physical examples.

Peer Instruction and Think-Pair-Share:

Peer Instruction was developed at Harvard University by Eric Mazur to help improve students' understanding of physics' concepts and their ability to reason with them.[10] His method is based on the idea that lectures can be more effective if the students' first exposure to new material comes from reading the textbook prior to class and using the lecture to build on what the students have read. This method requires instructors to change their lectures and exams. In addition, although it does not necessarily **require** instructors to change the amount of material covered, it does require some flexibility in content coverage. Describing *Peer Instruction* in his own words, Mazur says,[11]

> First I assign the students pre-class reading for each lecture period. To make sure the students carry out this important assignment, I begin each and every lecture period with a five-minute mini quiz on the material they have read. I then divide the remainder of the class into ten-to-fifteen minute long periods, each devoted to one of the main points of the reading. I might begin each period with a very brief lecture on a point I wish to get across or with a lecture demonstration. This is followed by a conceptual question, which tests students' understanding of the idea or point presented. I project these multiple-choice questions, which I call *ConcepTests*, onto a screen and give the students one minute to select an answer. Each student individually must commit to an answer—I do not allow students to speak to each other during this minute. After the students have recorded their answer, I ask them to try to convince their neighbors of their answer. The ensuing discussions are always animated. After a minute or so, I again ask students to select an answer (one can use a show of hands, flashcards, scanning forms, or a computerized voting system). The proportion of students who chose the correct answer always increases after the discussion, suggesting that students are successfully explaining their reasoning, and in the process teaching each other. If about half the students select the right answer (with the correct reasoning) before discussion, a minute or so of discussion is sufficient to dramatically improve the level of understanding of the class.

After the second polling, Mazur discusses the answers and the reasoning associated with them.

Mazur uses this method of instruction with his students at Harvard with very encouraging results. His students' attendance, attention, and involvement have all significantly improved. His students' performance on exams show improvement in both conceptual understanding and problem solving.

The critical components of the *Peer Instruction* method are the students' writing down of an answer, the group discussion where they try to convince their peers their answer is correct, the first and second polling, and the follow-up discussion of the question. The writing down of individual responses is important because this forces the student to commit to and defend a position. This gets the student actively thinking about the question and the underlying concepts. It also prevents students from just turning to their neighbor and asking, "What do you think?" The discussion with their peers where the students use their reasoning to justify their answer is a further step of engagement. The polls let the students compare their answers with their peers; this lets students know they are not alone when they make mistakes (another word about this in a moment). The follow-up discussion with explanations gives the student feedback from the instructor that explains why the correct answer is right.

Although any of the four polling methods mentioned by Mazur (a show of hands, flashcards, scanning forms, or a computerized voting system) will work, the flashcards and computerized voting methods have significant advantages. Scanning forms cannot be used to tally results in class and therefore must be paired with another method of polling. A show of hands can give immediate feedback, but students who are not sure of their answer or their reasoning may be reluctant to put their hand up in front of their peers or may switch responses to join in with the majority. Both flashcards and electronic polling produce an instantaneous tally while not allowing the students to see how their peers answer. Mazur uses electronic polling where the student responses can be saved for further analysis.

The flashcard method has been used successfully by Meltzer and Manivannan at Southeastern Louisianna University.[12] The students are given five large flashcards, labeled A to F. When the instructor polls the class the students simultaneously raise the flashcard to indicate their response. The instructor estimates a rough percentage distribution and writes the result on the board. The students cannot easily see each other's cards, so they remain fairly anonymous to one another. If the students also fill out and submit an op-scan form, the student responses can also be saved for further analysis.

A significant advantage of this approach is that the responses to the in-class questions (Mazur refers to these problems as *ConcepTest* questions) provide the instructor with constant feedback on the class' understanding of the course material. By walking around and interacting with a few of the student groups, the instructor can get a feel for the mistakes being made and how students who give the right answer explain their reasoning. By looking at the poll results, instructors can gauge whether more time is needed on a topic or whether it is time to move on. If more time is needed, the instructor can give another mini-lecture followed by a different *ConcepTest* question on the same topic.

Mazur and others have noted that an initial student response of 40-60% correct responses is optimal. Fewer correct responses means too few students know the correct answer to convince their neighbor; more correct responses means there is not enough disagreement for the student groups to generate a good discussion. Instructors who are interested in the *Peer Instruction* method are encouraged to read Mazur's book, *Peer Instruction: A User's Guide*,[13] which describe this active-learning method in more detail and contains examples of reading quiz and *ConcepTest* questions on topics from throughout the introductory physics curriculum.

The *Think-Pair-Share* method is basically a less structured version of *Peer Instruction*. The main points of this method are that the instructor poses a question to the class, the students think about the question individually and write down an answer, and then the students discuss their responses with their nearest neighbor. Once the student groups have had time to discuss their viewpoints and come to some form of closure, the instructor polls the students and asks a few of the students to explain their reasoning. It is very important that during this discussion instructors give serious consideration to all viewpoints and not put down incorrect answers or reasons. Students are already highly sensitive to taking a risk and being shown wrong in front of their peers. Students will need assurance that errors during the learning process are not penalized and can even be healthy if the goal is to overcome these errors before the exam.

One advantage of *Think-Pair-Share* is that it can be used with just about any type of question or problem, even demonstrations (see below). It can even be used with impromptu questions that come up in class. The *Think-Pair-Share* approach also works well with the GOAL process of problem solving; however, at least at first, doing an entire problem is too much at one time. Students should be asked to do only one step of the process at a time. For example, an instructor might begin be asking students to do the Gather step. Only after students have written down their response to the Gather step, discussed it with their neighbors, received feedback from the class discussion and everyone has the first step correct, should the class proceed to the second step. It may take up to twenty minutes of class time to solve problems this way, but it is a highly effective way to teach students better problem solving because each student is being guided through the process with feedback from their peers and the instructor at each stage.

Interactive Lecture Demonstrations:

David Sokoloff and Ron Thornton are pioneers in the development of researched-based introductory physics curricula using *Microcomputer-Based Laboratory* (*MBL*) activities. Their methods combine real-time data acquisition with effective pedagogy to promote conceptual change. This is discussed in more detail in the *MBL* section below. Together with Priscilla Law, they developed the *Workshop Physics* and *MBL* laboratory curricula discussed below.[14],[15],[16] These approaches have been very successful at improving student understanding of basic physics concepts and multiple-representations of these concepts. Recognizing that not all schools have the resources or structure to adopt their laboratory curricula, their most recent project involves developing *MBL* demonstrations for use in large lectures.

Although demonstrations are a popular activity in many physics classes with both instructors and students, recent studies suggest that students do not learn much physics from these demonstrations unless there is an active learning component.[17] Sokoloff and Thornton created *Interactive Lecture Demonstrations* to meet this need.[18] The steps for conducting a *Interactive Lecture Demonstration* are as follows:[19]

1. The instructor describes the demonstration and does it for the class without *MBL* measurements.
2. The students record their names and individual predictions on a Prediction Sheet, which will be collected. (Students are assured that these predictions will not be graded, although some course credit is usually awarded for participating.)
3. Students engage in small group discussions with one or two of their nearest neighbors to persuade them their prediction is correct.
4. Students record their final predictions on the prediction sheet.
5. The instructor elicits common student predictions from the whole class.
6. The instructor carries out the demonstration with *MBL* measurements with the apparatus and the computer display visible to the students.
7. The instructor calls on a few students to describe the results and discuss them in the context of the demonstration.
8. The instructor discusses analogous physical situations with different surface features, i.e. different physical situations based on the same concept(s).

Note that this procedure is very similar to Mazur's *Peer Instruction* method described above.

It is important to note two points in the above procedure where the role of the instructor is crucial. The first is in step 3. The instructor must observe the students groups carefully and decide when they have finished discussing their predictions. Second, the instructor must have a definite agenda for the discussion in steps 7 and 8 to guide the discussion towards the important points raised by the demonstrations.

Sokoloff and Thornton also describe a variation of procedure listed above where students are given two sheets to write down their predictions. One sheet is handed in before step 6. The other sheet has additional space for recording the results of the demonstration during step 7. The students keep this sheet for their notes.

Sokoloff and Thornton follow two basic guidelines for designing the short, simple experiments that make up the *ILD* sequence. First, the order and the content of the sequences are based on research of physics learning. The sequences begin with what the students know and lay the basis for further understanding. Second, the Interactive Lecture Demo's must be presented in a way so that students can see and understand the measurement being made and trust the experimental apparatus. The real-time display of data from an *MBL* experiment gives students feedback in way that builds confidence in the measuring devices and the data. Unfortunately, many traditional exciting and flashy demonstrations are too complex to provide effective learning experiences for introductory students.

Although Sokoloff and Thornton developed the *Interactive Lecture Demonstration* procedure as part of their *MBL* curriculum, this method can be used independently of the curriculum. Instructors can use similar procedures to make most demonstrations more interactive, provided they follow the two guidelines described above. Instructors who are interested in this approach are encouraged read Sokoloff and Thornton's article in *The Physics Teacher*.[20]

Active Learning in Recitation

The recitation / discussion section offers an excellent opportunity to introduce active learning into the introductory physics course. A typical recitation section of 20-24 students can easily be broken into 6-8 groups of three to four students each for group activities. This number of student groups is small enough that one or two instructors can interact more closely with each group than is possible in the lecture part of the course. This type of faculty-group interaction permits the implementation of activities where the student groups can work more on their own, but also allows instructors to interact with each group, keeping them on task and offering guidance when the groups begin to flounder. Although active-learning activities in recitation work best when they are closely tied to the lecture component of the introductory course, these recitation methods place minimal restrictions on the lecturer in terms of structure and content coverage. The two curricula described below use active-learning recitation activities to supplement and support the lecture part of the course. These activities work best if the group members can face each other while they work, one reason they are more suitable for recitation sections than lecture sections. Note that both methods are designed to use specially trained TAs, although a single faculty member with a small class could implement either approach. In addition, both methods can be used in a low-tech environment.

Tutorials in Introductory Physics:

Many different schools use the word tutorials to describe certain course activities. The *Tutorial* method described here was developed by Lillian C. McDermott and the Physics Education Group at the University of Washington (UW) to improve student understanding of fundamental physics concepts in a cost-effective manner within the traditional large lecture structure.[21] The *Tutorials* grew out of the group's research on students' common sense beliefs and their work developing the *Physics by Inquiry*[22] curriculum for pre-service and in-service K-12 teachers. These tutorials have the following components:[23]

1. A 10 minute ungraded "pretest" is given in lecture once a week. This test asks qualitative conceptual questions about the subject to be covered in tutorial the following week. Often the material covered in the pretest has already been covered in lectures and homework assignments. Students receive points for taking the pretest but not for the correctness of their responses. The pretests play two roles. One, they help focus the students' attention on issues that will be discussed in tutorial the following week. And two, the pretests give an indication of student thinking and difficulties before the tutorial.

2. The teaching assistants and faculty involved participate in a 1.5 hour training session every week. In the training session they take the pretest, go over both the student responses to the pretests, and then go over the tutorial to be used in the coming week. The emphasis of the discussion on the tutorial is on developing appropriate questions to ask the students to illuminate their thinking and lead them towards a physics point of view.
3. A one-hour *Tutorial* session replaces the traditional problem-solving recitation section. Students work together in groups of three or four and answer questions on a worksheet that guides them through building qualitative reasoning on a fundamental concept. At least two teaching assistants serve as facilitators in each tutorial section, asking leading questions in a semi-Socratic dialog[24] to help the students work through their difficulties by encouraging them to think. The students' worksheets are not collected. The students select their own group with little or no intervention by the TAs.
4. Students have a brief qualitative homework assignment in which they must explain the reasoning behind their responses. This is a part of their weekly homework that also includes problems assigned from the text. No solutions of tutorial homework are made available to the students.
5. At least one question emphasizing material from tutorials is asked on each examination.

At the University of Washington, *Tutorial* worksheets are developed over a period of many years through an iterative cycle of research/curriculum-development/instruction. The tutorials often make use of "cognitive conflict." In this approach, situations are presented which trigger the common student conceptual difficulties revealed by research. After the student difficulty is triggered, a situation is presented where the difficulty brings about a contradiction with what the students have been taught. 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. At University of Washington, the facilitators are mostly graduate and undergraduate TAs who receive no special training prior to their assignment to teach tutorials. The *Tutorial* program is administered by the Physics Education Group. Note that lecturers may choose not to be facilitators or to participate in the weekly training meeting. If so, the *Tutorials* have no adverse impact on instructor time outside of the weekly ten minute pre-test during lecture. However, the instructors are required to include at least one *Tutorial* problem written by the Physics Education Group on each exam.

The key to teaching effective *Tutorials* is in helping the students form effective groups. An effective group is one where the issues and difficulties are discussed and resolved but the group continues to progress through the *Tutorial*. Some groups will go through the tutorial too quickly and don't develop a good grasp of the Tutorial issues. For the instructors, typically the hardest part of teaching *Tutorials* is learning to listen to what the students are saying, to ask leading questions and not tell them the answers, and to know when to just listen and leave well enough alone.

At University of Washington, individual *Tutorials* are evaluated through classroom observations, tests, and course examinations as well as post-tests administered one or more quarters after the relevant course was completed.[25] McDermott's group has found that exams and interviews both show that *Tutorials* help improve student understanding of basic concepts; on some exam questions, the *Tutorial* students did as well as graduate students who were given the same qualitative problems on qualifier exams.[26] Other schools adopting tutorials have also reported gains in conceptual understanding, problem solving, and retention.[27]

Instructors interested in the tutorial method are encouraged to read the articles published by McDermott's group[28] and examine the *Tutorial* workbook, *Tutorials in Introductory Physics*.[29]

Cooperative Group Problem Solving

The *Cooperative Group Problem Solving* (*CGPS*) approach was developed by Patricia Heller and the Physics Education Group at University of Minnesota.[30] Since a primary goal of instruction in the introductory physics course is to help students build a good functional understanding of physics that they can use to solve problems in new contexts, the Minnesota group developed activities that emphasize problem solving instead of conceptual understanding. Their approach is to use cooperative group activities that work explicitly on building expert-like problem solving skills. Unlike the other teaching methods described in this section, the *CGPS* approach uses the formal cooperative learning group format described later in this section.

Although this method retains the lecture/recitation/lab format of the traditional large lecture course, in the University of minnesota *CGPS* approach all three parts of the course are modified to promote active learning and present an integrated curriculum to the students.[31] However, the recitation component of the cooperative group problem solving approach can be used separately with only minor modifications to the lecture part of the course (the laboratory component is described separately below).

The course goals were established by surveying the departments served by the introductory physics sequences. The results of the survey showed that the departments wanted their students to learn:

1. the fundamental principles of physics,
2. general quantitative and qualitative problem solving, and
3. to be able to apply the physics knowledge and skills they acquire to new situations.

The three components of the course are coordinated to cover the material coherently by a course team consisting of the lecturer and the TAs teaching the associated labs and recitations.[32] The course team meets biweekly to brief the TAs on the direction of the lectures, to give feedback to the lecturer, to decide on problems and course emphasis for the next two weeks, and to discuss student performance. In addition, all three aspects use and/or support the following strategies:

- use of a story line to determine specific content,
- modeling the construction of knowledge,
- use of multiple contexts for each concept,
- focus on the fundamental principles and concepts,
- use of an explicit problem solving strategy,
- use of realistic context-rich problems, and
- use of testing and grading practices to reinforce desired student behavior.

One of the key elements of the course is that the students are taught an explicit problem solving strategy (similar to the GOAL protocol) based on expert problem solving strategies. The student groups apply this strategy in solving problems in the recitation. In order for the groups to function properly, the choice of problems is crucial.[33] The problems need several characteristics to encourage the students to work together to solve the problem.[34] Namely,

- They need to be challenging enough that a single student cannot solve it, but not so challenging that a group cannot solve it.
- They need to be structured so that the groups can make decisions on how to proceed with the solution.
- They should be relevant to the lives of the students.
- They cannot depend on students knowing a trick nor can they be mathematically tedious.

Because many textbook problems did not meet these criteria, Heller et al. designed their own complex problems incorporating these characteristics which they call context-rich problems. They are designed to focus students' attention on the need to use their conceptual knowledge of physics to qualitatively analyze a problem before they begin to manipulate equations. They are essentially short stories that include a reason for calculating some quantity about a real object or event. In addition, context-rich problems may have one or more of the following real world characteristics:

1. The problem statement may not explicitly identify the unknown variable,
2. There may be more information available than is needed to solve the problem,
3. Some information may be missing from the problem statement but may be easily estimated, and
4. Reasonable assumptions may be needed to solve the problem.

The majority of lecture time is spent in the traditional manner. Some lecture time is used to initially present the problem-solving strategy and to periodically model its use for the students. In recitation, the students practice the strategy by using it to solve context-rich problems in groups. Each recitation section of 18 students is broken into groups of three based on their ranking in the class. Each group has one student each from the top third, the middle third, and the bottom third of the class. The students are reassigned into new groups after each exam, two to three times a quarter. A typical recitation section has three parts: introduction, task, and closure. First, the TA briefly goes over the learning goals for the session. Then the TA passes out the assigned context rich problem and assigns the roles of Manager, Recorder/Checker, and Skeptic to the three members of each group (the roles are rotated each week). The students have 30 minutes to complete the problem in their groups. The TA observes the groups and intervenes only when a group is making no progress or when the students have drifted from their roles. At the end of the session, the TA begins a class-wide discussion on the problem by randomly calling on one member from each group to write their solution on the board. The similarities and differences of the solutions are then discussed. Then the students are given five minutes to evaluate how they worked together and what they could do to improve next time. Students are given a complete written solution to the class problem at the end of the session. Part of each exam is a group problem that is worked in the recitation section.

Several factors have been found to be important in making *CGPS* an enhanced learning experience. First, the instructor must assign the students into mixed-ability groups as described above. A group size of three has been found to optimize student participation. Groups of two have trouble making decisions and often don't have the critical mass of knowledge needed to solve the context-rich problems. In groups of four or more, at least one member of the group participates significantly less than the others. Groups will function more smoothly if women and minority students are not placed in groups where they are outnumbered two to one. Second, although this approach works best if members can face each other, it can also be implemented in rooms with fixed seats with two students sitting in the first row and a third student sitting one row behind them. Third, it is important to rotate the group roles each week. The group roles represent three aspects of the problem solving process: decision making, recording and checking, and skepticism to prevent one from going to far astray. Rotating the roles lets each student further develop these three aspects as well as preventing one student from dominating the group. Last, it is important that both the group and individual students be held accountable for learning the material. There needs to be a tangible reward for the groups efforts without letting the weaker students coast through the group activities. At University of Minnesota, this is accomplished by having one group problem in addition to the individual problems on the exams. For the group problem, the group submits one solution that is worth 20-25% of the exam's total score. The remainder of the exam is worked individually, but consists of context-rich problems similar to the group problems used in recitation. The combination of group and individual problems on the test provided strong motivation for students to work well both individually and in groups.

There are several things instructors need to be aware of in implementing the *CGPS* approach.[35] First, the approach requires additional time from the lecturers to manage, coordinate, and observe the TAs. Second, the TAs must be educated in the story line of the course, students' common sense belief and everyday use of physics language, the problem solving strategy, cooperative group learning and their role as coaches, and constructive grading practices. Thirty hours of pre-course training are needed for new TAs at University of Minnesota to begin to be effective and comfortable in their role. In addition, each new TA is assigned a mentor TA who observes them in class and gives feedback. Third, as with the other research-based teaching methods, both the lecturers and the TAs must break the cycle of teaching-as taught. They must be aware of the course structure and strategy as well as the student difficulties while preparing to teach this way. Also, as with tutorials the TAs must learn to guide and coach in a semi-Socratic manner similar to that used in tutorials and not just tell the students how to do it right.

The results from several years of implementation of the *CGPS* approach at Minnesota are quite impressive. The physics education group at Minnesota obtained the following results:

- Group problem solutions were better than individual solutions by the best students in each group on problems judged of equal difficulty. This indicates that the best students are not just carrying their group and that even these students are learning something from working in a group.
- The problem solving abilities of all students improved at approximately the same rate for students for students of high, medium, and low ability. The *CGPS* approach is also equally effective in improving the problem-solving skills of men and women.
- The *CGPS* students outperformed students in conventional lecture courses on common traditional (not context-rich) problems on the final exam. The *CGPS* students averaged 20% higher scores and wrote more expert-like solutions. (Note that traditional exam problems had to be used because the instructors in the conventional lecture class judged all of the context-rich problems to be too hard to be used as exam problems for their students.
- The most pronounced improvement in students' problem solving skills was in qualitative analysis of the problem and in understanding the underlying physics concepts. Students' improved understanding of physics concepts was also demonstrated by improved gains on standard diagnostic tests.

Instructors interested in the *CGPS* method are encouraged to read the articles published by Heller and her group[36] and to visit their website.[37]

Active Learning in the Laboratory

The laboratory component of the introductory physics course offers the same opportunities for implementing active learning as the recitation section except that the lab period is longer and offers the additional opportunity of doing experiments. Although labs are inherently a group activity, many labs do not meet the criteria to be active-learning tasks. The lab approaches described below demonstrate three ways in which active-learning experiments can be implemented in the laboratory component of an introductory physics class. All three are intended as replacements for traditional laboratory experiments and written materials are available for all three. Note that the student learning in both lab and lecture is enhanced if the labs are integrated with the lecture part of the course. That is, students will have a better grasp of the material if the material coverage is timed so students cover the same topic at roughly the same time and if the lecture makes use of the students' experiences in lab.

Socratic Dialogue Inducing (SDI) Labs

Socratic Diologue Inducing labs are a series of active-learning laboratory experiments developed by Richard Hake at the University of Indiana. SDI Labs emphasize hands-on experience with simple mechanics experiments and facilitate students' active learning with course material. They are designed to promote students' mental construction of concepts through:

1. conceptual conflict,
2. kinesthetic involvement,
3. extensive verbal, written, pictorial, diagrammatic, graphical, and mathematical analysis of simple, concrete Newtonian experiments,
4. repeated exposure to experiments at increasing levels of sophistication,
5. group discussion, and
6. Socratic diologue with the instructors.

The lab activities consist of fairly simple physical activities (such as pushing a block or pulling on a spring). The equipment is fairly basic (iron disks, wooden blocks, springs, strain gauges, etc.) During the lab, the students work in groups through a series of questions that ask them to analyze and explain their observations. The questions are designed to elicit well-known student preconceptions (see the section in part II of the introduction on students conceptual understanding) and to provoke group discussions. When students are stuck, they call an instructor whose role is not to answer questions, but to ask questions in a Socratic fashion. The instructor tries to guide the students to a correct interpretation of their experiment by asking leading questions about the conflicts and what they observed. Students record their responses in their lab manual that is collected at the end of the lab period. The labs are annotated but not graded. Instructors may request students to repeat deficient work or discuss confused responses during the next lab period. The lab grade is determined from lab exams with questions that demand a good conceptual understanding of experiments similar to those conducted in the lab. In this approach, lectures do not attempt to introduce material through derivations or by paraphrasing the text. Students are responsible for reading the text material on their own. Lectures concentrate on problem solving based on qualitative analysis, contrasting different conceptual views, and demonstrations. Note that SDI labs could in principle be used with a more traditional lecture approach.

Students taught with SDI labs at Indiana demonstrate better understanding of basic physics concepts (as measured by standard diagnostic tests) than student who were taught with traditional labs. The critical features of this method are the focus on building a good conceptual understanding of simple physical phenomena and the group discussions. Instructors interested in this approach should read Hake's articles in the *American Journal of Physics*[38] and *The Physics Teacher*[39] and visit the University of Indiana website.[40]

Microcomputer-Based Laboratory (*MBL*)

Since the advent of personal computers in the early 1980s, considerable effort has been spent looking at how computers could be used to teach physics more effectively, particularly in the lab. This has led to the development of the *MBL* approach to active learning. Here, *MBL* refers not simply to the use of a microcomputer to collect and display data, but to active-learning laboratory activities using microcomputers that engage students intellectually and help them understand the relevant concepts. *MBL* activities have been found particularly helpful for improving students' conceptual understanding, especially in linking graphs to physical situations.

In addition to the *Interactive Lecture Demonstration* and *Workshop Physics* curricula described above and below respectively, Ron Thornton, David Sokoloff, and Priscilla Laws have developed two laboratory curricula using *MBL* activities, *Tools for Scientific Thinking* (*TST*) and more recently *RealTime Physics* (*RTP*). *TST* is a small collection of individual lab activities that can be incorporated into the traditional laboratory component of an introductory physics course. *RTP* is a complete laboratory curriculum replacement that incorporates the best aspects of *TST* and *Workshop Physics.* Thornton et al.'s learning objectives for the *RTP* curriculum include:

- Helping students acquire an understanding of a set of related physics concepts;
- Providing students with experience using microcomputers (PCs) for data collection, display, and analysis;
- Enhancing laboratory skills
- Reinforcing topics covered in lectures and readings through quantitative experiments.

In addition to the curriculum materials, Thornton *et al.* also developed an *MBL* interface with software tools and sensor probes to be used with their curricula. The laboratories and the associated equipment are available commercially from Vernier Software. However, the lab curriculum can also be used with PASCO Scientific's *MBL* equipment as well.

The *RTP* lab activities are similar to the *SDI* labs in that they focus on basic physical phenomena rather than on more elaborate experiments that require detailed analysis. Like the *SDI* labs, the activities pay attention to student preconceptions documented in the literature to promote better conceptual understanding. In addition, they use a guided-discovery approach to encourage students to construct physics knowledge from observations. In many cases, the lab activities require the groups of 2-4 students to make and discuss predictions about what will happen before conducting the experiment. The students often have heated arguments on the physics of the experiment rather than on what procedure or what equation to use. The arguments used are often rough and subject to error, but this type of discussion with the experiment as arbiter is what makes this curriculum effective. The activities are sequenced and integrated so that they build on what students learned in previous labs and prepare students for next weeks activity. Note that with these *MBL* tools, no prior computer experience is necessary.

The mechanics labs mainly use an ultrasonic motion detector and force probes. The motion detector determines the distance to an object. Numerical integration is then used to produce velocity and acceleration vs. time graphs in addition to a position vs. time graph. In the first lab activities, students use the motion detectors to graph their own motion. This type of psychological calibration helps the students learn to understand and trust the motion sensor. The structured questions lead the students to understand velocity and acceleration as they study the motion of a cart on a track. Activities using the force probes show that force is proportional to acceleration and that Newton's third law holds for the collision of two carts equipped with force probes. Many students that do not believe that Newton's third law holds for a moving car hitting a stationary truck. Diagnostic test results show that the *MBL* experiments are particularly convincing in helping students overcome this preconception.

Each *RTP* lab activity provides material for a two hour per week lab with extensions to provide more in-depth coverage if more time is available. Each lab activity includes a homework assignment where students rethink what they learned in lab. Thornton *et al.* recommend that instructors lead a discussion of the homework before beginning the next activity.

Students taught with *MBL* materials at several universities including University of Oregon, University of Maryland, and Tufts University demonstrate greatly improved understanding of Newtonian ideas of force and motion on standard tests. Note that it is not just the computer tools, but the curriculum using the tools that is primarily responsible for the improved student understanding. Thornton and Sokoloff suggest five reasons why their *MBL* activities are effective:

1. Students are able focus on the physical world without having to spend a lot of time learning to use complicated tools.
2. Immediate feedback is available. The student is better able to associate the shape of the graph with what is happening in the experiment.
3. Collaboration is encouraged.
4. Powerful tools reduce unnecessary drudgery allowing students to focus on the physics of the experiment rather than on the process of collecting data.
5. Students learn to understand specific and familiar examples before moving to the more general and abstract concepts.

Instructors interested in the *Microcomputer-Based Laboratory* curriculum should read Thornton and Sokoloff's articles in the literature[41] and contact Vernier Software[42] and/or PASCO Scientific for materials and equipment.[43]

Problem Solving Labs:

The *Problem Solving Lab* approach was developed at University of Minnesota to extend their *Cooperative Group Problem Solving* ideas into the laboratory. Like the *CGPS* recitation sections, the student work on problem in structured group. The difference is that the lab problem requires students to perform an experiment and make measurements to answer the problem. The students are given a problem, given the apparatus, and then determine for themselves how to use the apparatus to solve the problem.

The laboratory problems are designed to allow students to apply the problem solving strategy to concrete situations and to help them confront their preconceptions. The learning process can be described as predict/explore/measure/explain. The lab manual is divided into 4 two to three week units, an equipment appendix, and five technique appendices. Each unit is comprised of an introduction page and several related problems. The lab activities are coordinated with the other parts of the course to address the same content at the same time. The lab manual contains no theory or background information on the experiments and few specific directions. This is intentional to emphasize that the laboratory is an integral part of the entire course. The write up for each problem refers to the relevant sections in the textbook. A computer check out is used to make sure that each student has a basic understanding of the necessary theory before coming to class.

To focus students' group discussions on the physics of the situation, the students are required to qualitatively analyze the situation and make group predictions about all measurements before they begin data collection and quantitative analysis. The student groups must decide what data to collect, how the data should be collected, and how the data should be analyzed to solve the experimental problem. The purpose of this is to get the students to make an intellectual commitment to the lab, not to make sure the students know the right answers at this point.

The lab format is similar to that of the discussion section: introduction, task, and closure. The main difference is that there is no set number of problems to complete; although, the goal is for each group to complete at least 2 problems in four hours over two lab periods. The students have the opportunity to return to a problem if their measurements conflict with their predictions. The role of the TAs is to coach the student groups through difficulties and weaknesses.

There are two kinds of lab problems, quantitative and qualitative. The quantitative problems require students to create a mathematical expression that they feel describes the system being investigated. The qualitative or 'exploratory' problems require students to use their intuition to predict how the system being investigated behaves. The labs do not currently use any computer data acquisition or analysis; however, the Physics Education Group at University of Minnesota has recently begun implementing problem solving labs that use *MBL* tools and video analysis.

Since *Problem Solving Lab*s are usually used in conjunction with other active-learning methods, it is hard to separate evaluation of the labs from the rest of the curriculum. However, in one class, at least two thirds of the *CGPS* students agreed that the laboratory activities were well coordinated with the course and that the laboratory experiments helped me to understand the concepts covered in class. In both cases, the numbers represent the most student response the instructor had experienced.

Instructors interested in learning more about *Problem Solving Lab*s are encouraged to read the articles published by Heller and her group[44] and to visit their website.[45]

Workshop/Studio/SCALE-UP approaches:

All the above research-based methods improve instruction by adapting the structure of the traditional large lecture class to make use of active learning group activities while keeping the large lecture. But is the large lecture format, even with the modifications described above, the best way to teach physics? Priscilla Laws *et al.* decided to try another way. She and her colleagues at Dickinson College developed *Workshop Physics*, an activity-based laboratory curriculum. The primary goal of the designers for this curriculum was to help students acquire transferable skills of scientific inquiry based on real experiences. More specifically as stated in her recent dissemination project,[46] the goal of *Workshop Physics* is ". . . to enable students to:

- construct conceptual models of phenomena and relate these to mathematical models;
- learn enough scientific to be able to learn without formal instruction;
- develop proficiency with computers and other research tools;
- appreciate science and want to learn more; and
- be able to engage in the further study of science."

In *Workshop Physics*, the distinction of separate lecture, recitation, and laboratory is eliminated in favor of an integrated class that meets for three 2-hour sessions per week in a specially designed classroom. Instead of spending time in lectures and separate laboratory sessions, *Workshop Physics* students make predictions and observations, do guided derivations, and learn to use flexible computer tools (including spreadsheets, *MBL*, and digital video analysis) to develop mathematical models of phenomenon. They also use devices that allow students to experience motions and forces with their own bodies (kinesthetic physics).[47] The use of *MBL* and digitized video allows the students to see graphical representations of physical systems in real time and to see how changing the conditions of an experiment affect the graph. Spreadsheets are used to create mathematical models that can be compared with the digitized data from experiments. The instructors still lecture at the beginning of each class, approximately one hour out of six per week, but the bulk of the time in class is spent performing and analyzing guided-discovery experiments working in groups of two to four students each. Part of the lecture time is spent going over homework problems. The course material is broken up into weekly units that have four parts:

1. exploration of the students preconceptions,
2. qualitative observations,
3. development of definitions and mathematical models, and
4. quantitative experiments centered on the mathematical models.

The lab activities are based on worksheets contained in activity guide which is a combination textbook, laboratory manual, and notebook In addition, to working out the labs in the activity guide, the students also do homework problems out of a traditional text. Textbook-style problems are included as part of each exam. Students are allowed to use their activity guide on exams. The activity guide is a combination textbook, laboratory manual, and notebook. In addition to their weekly homework and classroom activities, the students are required to do a term physics project involving video analysis each semester. Past student projects have included the physics of Michael Jordan's lay-up and an analysis of cartoon motion.

Because of the additional time needed for learning by doing and discovery, it is not possible to include all the topics that would be included in a traditional course. The *Workshop Physics* course[48] at Dickinson College covers about 25% less material than was covered in the traditional calculus-based introductory physics course it replaced. However, the Dickinson *Workshop Physics* course does include some contemporary physics topics like chaos, radon monitoring, and digital electronics. Note that many instructors that have successfully adopted the *Workshop Physics* approach at other college have changed the order of some topics and completely eliminate others.

The classroom is specially designed to be conducive to group activities, classroom discussion, and demonstrations. A typical class size is 24 students. The role of the instructor is important to the success of the course. Each class has an instructor and an undergraduate TA (UTA) available during group work to listen, give hints or suggestions if the students are frustrated, and to help but not to give answers. The UTAs are selected from students who have previously completed the *Workshop Physics* course. They receive no other training.

Based on the results of "conceptual questions," a greater percentage of students master concepts that are considered difficult to teach because they involve classic student misconceptions. These conceptual questions range from multiple choice questions from concept tests such as the FMCE to qualitative exam problems. Performance of *Workshop Physics* students in upper-level physics classes and in solving traditional textbook problems is as good as that of students who had the traditional lecture course. Also, from observations by instructors and off-campus observers, the students who complete *Workshop Physics* are more comfortable working in a laboratory setting and more comfortable working with computers.

The *Workshop Physics* method at Dickinson College is very resource intensive in terms of equipment and instructors. The curriculum makes heavy use of digitized video, computers and sensor probes in addition to the standard laboratory equipment. There are at least two facilitators, the instructor and an undergraduate TA, in class at all times. Since the course is laboratory-based instead of lecture-based, class size is very limited.

Following the success of the *Workshop Physics* curriculum, Jack Wilson at RPI developed a similar introductory course called *Studio Physics* that can accommodate 50 students per class.[49] More recently Robert Beichner, one of the authors of the text, and John Risley have begun developing an active-learning curriculum along similar lines called *SCALE-UP* that is designed for classes with up to 100 students. Like *Workshop Physics*, both *Studio Physics* and *SCALE-UP* use dedicated classrooms that are designed to promote cooperative group learning in a multimedia environment while allowing instructors to interact with each group. *Studio Physics* and *SCALE-UP* both use more structured activities than *Workshop Physics* to account for the larger number of students per instructor and both require extensive training of faculty and TAs.

Instructors interested in learning more about *Workshop Physics* are encouraged to read the articles published by Laws and Pfister.[50] Instructors interested in learning more about *Studio Physics* should read the articles published by Wilson and Cummings.[51] Instructor interested in learning more about *SCALE-UP* should visit the website at North Carolina State University.[52]

Cooperative Learning Groups

> "The best answer to the question, 'What is the most effective method of teaching?' is that it depends on the goal, the student, the content, and the teacher. But the next best answer is, 'Students teaching other students." McKeachie, W. (1994) *Teaching Tips*, 9th ed. Lexington, MA, Heath & Co.

As you might guess from the name, cooperative learning (CL) involves students working in groups on structured tasks. However, CL is *not* students sitting around a table studying together or assigning group projects where one student ends up doing most of the work. According to countless studies, there are five absolutely critical aspects of successful cooperative learning. Omit one or more of the items on the following list and group work will almost certainly fail in your classroom. The five defining aspects of CL are:

1. *Positive interdependence*. Team members have to rely upon one another.
2. *Individual accountability*. Each member is responsible for doing their own fair share of the work and for mastering all the material.
3. *Face-to-face interaction*. Some or all of the group effort must be spent with members working together.
4. *Appropriate use of interpersonal skills*. Members must receive instruction and then practice leadership, decision-making, communication, and conflict management.
5. *Regular self-assessment of group functioning*. Groups need to evaluate how well their team is functioning, where they could improve, and what they should do differently in the future.

These criteria can be found throughout the literature. If you are interested in more details visit Richard Felder's website http://www2.ncsu.edu/effective_teaching/ or read D.W. Johnson, R.T. Johnson, and K.A. Smith, *Active Learning: Cooperation in the College Classroom*, 2nd Ed. Edina, MN, Interaction Book Co., 1998. Many of the ideas listed here come from these two sources.

There is quite a bit of educational psychology behind why CL techniques work so well (if all 5 aspects are present). These include the fact that the learning is done in an active manner, groups keep going when individuals might give up, students see alternative problem-solving approaches, more and higher quality questions are produced, there is less fear in class, and as noted above, people learn best when they teach.

There are basically two different strategies for implementing cooperative learning: informal and formal. The informal methods can be put into practice "on the fly" during class with students working in groups with their nearest neighbors or selecting their own groups. All the curricula described above except *Cooperative Group Problem Solving* use informal CL methods. *CGPS* uses many of the formal CL methods discussed below.

Additional activities with informal CL structures

These activities are similar to those in the *Peer Instruction* and *Think/Pair/Share* curricula. For all of these techniques, be sure you clearly explain the task, randomly call on students to report, and circulate around the room and listen.

- In-class teams: Divide students into groups of 2 to 4 students and choose a recorder ("Who has the longest last name in your group?", "Who got up earliest this morning?" or similar questions are icebreakers and automatically select a variety of recorders.) Give the teams a couple of minutes to recall prior material, answer a question, start a problem solution, work out the next step in a derivation, think of an example or application, figure out why a given result may be wrong, identify underlying assumptions in a solution, brainstorm possible answers to a question, generate an exam problem, summarize material, etc. Collect some or all the answers.
- Cooperative Note-Taking Pairs: At the beginning of class, pair up the students. Every once in a while during class, pause and have one partner summarize their notes to the other. The other person can add information, ask for clarification, or make corrections. The goal is for everyone to improve his or her note taking ability.
- Guided Reciprocal Peer Questioning: Have students work in teams of three or four give them a collection of "generic question" stems like these:

  How does . . . relate to what I've learned before?
  What conclusions can I draw about . . .?
  What is the difference between . . . and . . .?
  What are the strengths and weaknesses of . . .?
  What is the main idea of . . .?
  What is a new example of. . .?
  What is the best . . . and why?
  What is . . . important?
  What if . . .?
  Explain why . . .
  Explain how . . .
  How are . . . and . . . similar?
  What is the meaning of . . .?
  How would I use . . . to . . .?
  How does . . . affect . . .?

  Have each student prepare several thought-provoking questions. Form groups of two or three and have members answer the individually-created questions. Bring the whole class together to discuss particularly interesting or problematic questions. For additional ideas, see King, A. (1993). "From sage on the stage to guide on the side," *College Teaching*, **41** (1), 30-35.

- TAPPS (Thinking Aloud Pair Problem-Solving): Have students do this with key problems or an important derivation. This activity takes a lot of time, but it is very powerful. It works well in conjunction with the different steps of the GOAL problem-solving protocol. Start by forming pairs, with one student being the problem-solver and the other the listener. Present the problem to the teams and assign a specific portion to be the focus of effort. The solver talks through the first part of the solution while the listener questions, prompts the solver to keep talking (that's the thinking aloud part), and gives a few clues, if needed. After a few minutes, collect partial solutions from several listeners (not solvers) and reach a classwide consensus. Reverse the roles and have the teams continue. More detailed instructions can be found in Lockhead, J. & Whimbey, A. (1987). "Teaching analytical reasoning through thinking aloud pair problem solving. In J. E. Stice (Ed.), *Developing critical thinking and problem-solving abilities: New directions for teaching and learning, No. 30*, (Jossey-Bass, San Francisco CA, 1987).

Formal CL Structures

One thing you don't want to do when getting ready to implement formal CL approaches is to let students select their own groups. In order for everyone to be treated fairly, the groups must be heterogeneous in ability. This can be done by reviewing GPA or other background information provided by your university. Another method that is useful is to give students a diagnostic test at the beginning of the semester. Not only will this help you form groups, but it gives you a "before snapshot" so that you (and your students) can see how far they've come by the end of the semester. Once you have a ranked list of students in a class, simply divide them into top, middle, and bottom thirds. (Don't tell the students how the groups were selected or they'll spend the rest of the semester worrying about whether they are the "slow kid on the team.") Select a student from each ability level to form groups of three. There are additional constraints on these selections:

1. Don't pick people you know are already friends to be teammates. The other person in the group may not fit in well.
2. If you can collect schedule information, try to make sure there are common times the teams can get together outside of class.
3. Don't let underrepresented populations (usually women or minorities) be outnumbered in a group. Studies have shown that this precaution reduces the tendency for contributions from these students to be minimized.

You will need to explain to your students why you are having them work in groups. This may be a new idea to them. If they are engineering students, simply remind them that they must work with other people before they can get their professional license. This is certainly the way the workplace operates now. There are numerous employee surveys illustrating that team skills are a top hiring criterion. If nothing else, explain how it will help them learn!

Once groups are formed, keep them intact for at least a month while students work out the any difficulties that arise. Again, remind them that they generally won't get to pick who they work with on the job. With guidance from you, have each team write a contract listing goals and expectations. Have each member sign their contract, make copies for the team, and submit the original for your files. It helps to have samples available. Brainstorming characteristics of a successful group is also a useful exercise. You will almost certainly need to provide teamwork instruction. Visit the excellent Collaborative Learning Website at http://www.wcer.wisc.edu/nise/cl1 or download the *Team Training Workbook* from http://www.eas.asu.edu/~asufc/teaminginfo/teams.html.

Make a concerted effort to support the five criteria for cooperative learning mentioned earlier. To help promote positive interdependence, assign different roles (manager, recorder, skeptic) to group members. Give critical information only to the manager. Rotate roles periodically or for each assignment. Provide one set of resources and require a single product. Don't forget to require individual accountability—use primarily individual testing. Have someone in the group routinely checking everyone's understanding. Call on individuals to present and explain results (while groups are working and after work is complete). Make groups responsible for seeing that non-contributors don't get credit. Get each member to rate everyone's contribution, including their own. Make sure they explain their ratings. Provide last resort options of firing a group member or quitting. Although this seems silly, if a substantial portion of the grade comes from group work, there is considerable motivation to be part of a group if that is the only way those assignments can be submitted.

It is especially important that you do not curve course grades. It should be possible for everyone in the class to earn an "A" (or an "F"). If students know that their grade depends on them doing better than others in the class, there isn't much motivation for cooperation. Establish a set of objectives for each topic and provide students with a syllabus that clearly delineates cutoff points. Students are much more motivated to perform if they know exactly what is required of them and the consequences of not performing.

Several activities using formal CL structures to facilitate collaborative learning are listed below. More can be found in the references noted throughout this section and on the web.

- Team homework: Assignments are completed and handed in by teams. (Only active participants' names are included on materials submitted for grading.) One grade is given for the entire team, although it is possible to adjust the academic score by incorporating members' "teamsmanship" scores. For problems sets, it is a good idea to have each individual outline a solution to each problem before getting together to complete the solutions. You can enforce this by occasionally collecting everyone's outlines. Beware of the tendency of groups to "divide and conquer" an assignment by having individuals finish entire problems on their own and simply collecting the results. They don't get the benefit of group thinking and it's hard to make sure that everyone understands all aspects of the assignment.
- Team projects: You can illustrate the value of groups by giving assignments that would be too difficult or too much work for an individual to complete in a reasonable amount of time. These can include designing something, creating web pages discussing the physics of familiar devices or situations, giving presentations to the class, etc. See the Jigsaw technique for a way to facilitate this type of effort. Each team gets a single grade that may be adjusted for individual contributions.
- Jigsaw: Individual group members have access to resources that the others don't have. These could be something as simple as a handout describing a specific portion of their task or even specialized instruction that only one member of a team receives. This fosters interdependence within the group and encourages learning as each individual shares what they know with the others. To set up the "expert areas" within each group, give each team member a number: 1, 2, or 3. Gather all the #1 people together and give them their particular set of information. Do the same with the #2 and #3 people. Then they can get together (either in class or out of class) to complete the task. This approach also works nicely when students study for a test. Each member becomes an expert on a particular topic and makes sure his or her teammates thoroughly understand it.
- Group bonus: If the average exam score for a group is above 80 or some other value you decide upon in advance, each member of the group gets an additional 5 points added to their score. (Do *not* require that each individual score be above the cutoff. This puts tremendous pressure on the lower performing student.) This technique has been very successful in promoting learning. It is a wonderful way to motivate the more advanced student to participate in group work rather than feel "pulled down" by the others in the team. Of course, if you recall from when you first taught a course, it is in teaching others that we really gain understanding. So the brighter student benefits at least as much as the others in the group.
- Individual Test followed by Group Test: Hand out exams as you normally do. After a specified time, collect the tests but then allow teams to work together on the same problems. Incorporate performance on the group test into the individual scores, perhaps by giving a bonus if the group test is above 90% or add some fraction of the points earned on the group test.

Frequently Asked Questions about Active-Learning

Do active-learning methods really work? Do they work for instructors other than the developers? Will teaching methods that emphasize conceptual understanding have an adverse effect on problem solving?

Students taught with the curricula described above demonstrate better understanding of physics concepts than students taught with passive lectures with no decrease in traditional problem-solving ability. This has been demonstrated both with concept tests and exam problems. Concept tests are multiple-choice tests based on Physics Education Research. The two most commonly used concept test address students conceptual understanding of mechanics, the Force Concept Inventory (FCI) and the Force and Motion Conceptual Evaluation (FMCE). The FCI was designed by Halloun *et al.* to measure students' belief in the Newtonian laws of motion vs. the students' common sense beliefs. The FMCE, developed by Thornton and Sokoloff to evaluate Workshop and *MBL* curricula, covers similar topics but is limited to linear motion and has a stronger emphasis on graphical representations. Both tests have questions that were designed to trigger and identify specific student common-sense beliefs identified in the research literature. The tests are typically given at the beginning and end of the first term of the introductory course to measure improvements in student understanding.

In his recently published study of FCI results from over 6500 students, Hake found that the appropriate figure of merit for gains in students' conceptual understanding in a class was the normalized gain *h*, where the Hake factor *h* is defined as follows,

$$h = \frac{\text{actual gain}}{\text{possible gain}} = \frac{\text{positive average \%} - \text{preaverage \%}}{100\% - \text{preaverage \%}}$$

Hake collected FCI data to see if active-learning curricula were more effective for teaching Newtonian mechanics than traditional lecture methods. He found the following result:

Traditional Lecture classes (14 classes, N = 2084 students) $h = 0.23$ (0.04 (std. dev.)

Active Learning Classes (48 classes, N = 4458 students) $h = 0.48$ (0.14 (std. dev.)

where *h* is averaged over classes, not students. The average normalized gain of the PER-based classes is twice as great as the average gain for traditional classes. Hake's study includes classes man of the active-learning methods discussed previously. Note the narrow widths and large separation of the two distributions.

Although the Hake study yields an impressive general result, his method of collecting data may have introduced some bias. For example, his method does not account for students dropping the class, whether the post—course test was given as a diagnostic or as part of an exam, and a possible selection bias since instructors only contributed their scores after knowing the results. In addition, Hake did not look at the results of specific curricula or look specifically at results from schools that adopted an active-learning curriculum as opposed to developing one.

A more recent study of FCI results conducted by the Physics Education Research Group at University of Maryland addressed these issues. The study began by comparing regular introductory physics classes with classes where traditional recitation sections were replaced with *Tutorials in Introductory Physics.* The study was later extended to FCI and FMCE data from over 2000 calculus-based introductory physics students at ten colleges and universities. The data are matched—meaning each student took the tests at the beginning and end of the course. Both tests were given as ungraded quizzes where the students received participation credit, but their scores did not count towards their grades. Also, instructors agreed to participate before they were aware of the results, only a small fraction of the classes were taught by members of the development team, and most of the active-learning classes were in their first two years of implementation.

At Maryland, seven of the classes were taught with regular recitation and nine of the classes were taught with *Tutorials*. A histogram of the normalized gains from 774 students taught by 10 different instructors is shown in Figure 1a. below. Note that the worst tutorial gains are as good as the best traditional class. The best tutorial class and the best two traditional class gains come from classes taught by award winning lecturers. Also note that two of the other lecturers taught classes in both modes. These instructors found that their normalized gain improved by 0.15 when they used tutorials.

The extended study included classes taught with *Workshop Physics* and *Cooperative Group Problem Solving*. The results are shown in Figure 1b and Table 1 below. Even though only a small fraction of the active-learning classes were taught by members of the curriculum development teams, the active-learning classes had significantly higher normalized FCI gains (> 2 std. errors). Similar FMCE results from 3 additional schools are shown below in Table 2. The results were consistent with Hake's study.

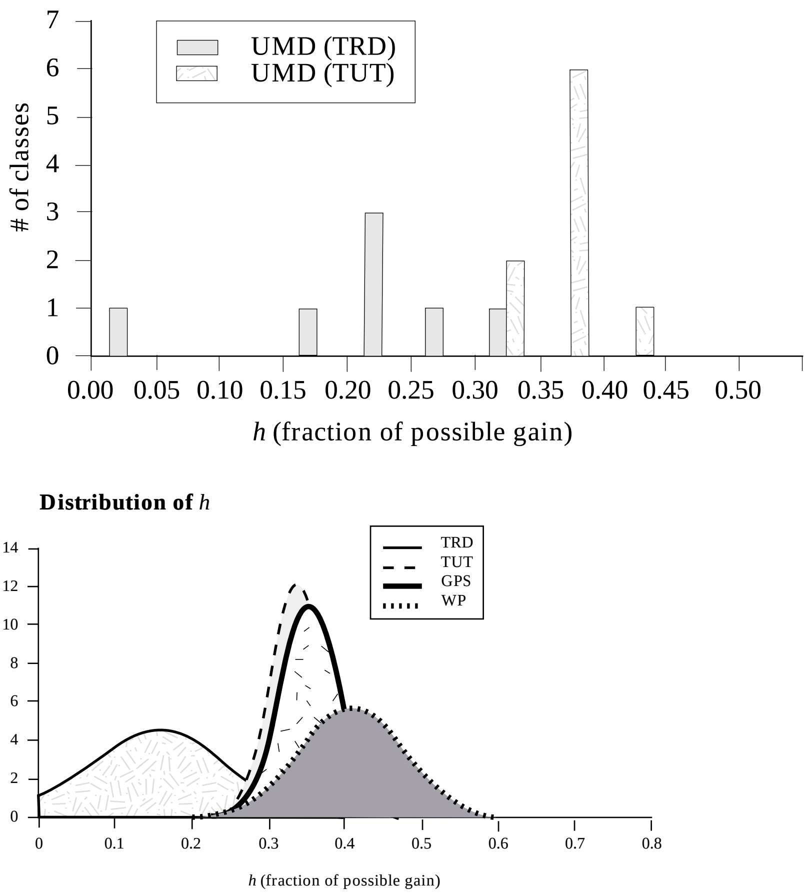

Figure 1. Gains in conceptual understanding of Newtonian force and motion. (a) Histogram of normalized Force Concept Inventory gains for traditional (TRD) and *Tutorial* (TUT) calculus-based introductory physics classes at University of Maryland, College Park. (b) Gaussian fit to distribution of normalized FCI gains from traditional (TRD), *Tutorial* (TUT), *Cooperative Group Problem Solving* (GPS), and *Workshop Physics* (WP) classes at eight colleges and universities.

Type of Instruction	**Average *h* from FCI**	**Average *h* from FMCE**
Traditional lecture	0.16 ± 0.03	0.15 ± 0.06
Lecture with Tutorials	0.35 ± 0.03	
Cooperative Group Problem Solving	0.34 ± 0.01	
Workshop Physics	0.41 ± 0.02	0.65 ± 0.03

Table 2. Normalized gains from Force Concept Inventory and Force and Motion Conceptual results from 10 colleges and university using traditional, tutorial, *Cooperative Group Problem Solving,* or *Workshop Physics* instruction (gain ± std. error).

This study showed that although classes taught by instructors who developed an active-learning curriculum get some of the best results, even instructors at schools adopting an active-learning curricula developed elsewhere will get significant gains in student learning in the first two years of implementation (if the curriculum is implemented as the developers intended). In addition, evaluation studies show that problem solving skills of students taught with active learning methods are at least as good as traditionally taught students, even when less time is spent explicitly on problem solving. Students taught with active-learning methods do at least as well as those from traditional classes and in some cases significantly better on traditional physics exam problems. For example, students taught with tutorials and *Peer Instruction*, which emphasize conceptual understanding, have demonstrated improved performance on both quantitative and qualitative problems. Students taught with *Cooperative Group Problem Solving* typically work problems that are considered too hard for regular classes.

Will active learning affect how much I material I can cover?

The answer to this is that it depends on the curriculum and what you do with it. Although in general, most instructors find it useful to decrease content by 10-20%, many instructors are able to cover the same amount of content using active-learning methods as with traditional lecture. In Mazur's class at Harvard using *Peer Instruction*, he estimates that he covers about one third less material in lecture. However, he is able to cover the same amount of material by not doing derivations or example problems in class and requiring students to read the book and handouts. Since McDermott's *Tutorials in Introductory Physics* mainly target the recitation section, they need not have a significant impact on content coverage (although instructors who make explicit connections between the lecture and the tutorial material in lecture may achieve better results). University of Minnesota's full implementation of the *Cooperative Group Problem Solving* approach does require instructors to restructure their lectures and requires more instructor time to manage and coordinate the course, but it does not significantly affect content coverage.
On the other hand, because the *Workshop Physics* method makes heavy use of guided discovery lab activities, the curriculum cannot cover as much as a normal one-year introductory course. However, the *Workshop Physics* instructors feel the benefit of students learning physics by doing physics is more important than the reduced content.

While it is not always necessary to reduce content using active-learning instruction, many faculty do reduce content coverage because they feel that their students benefit from learning fewer topics well, rather than many topics poorly. Instructors should also keep in mind that several of these active-learning methods require more time at the beginning of the introductory course; however, this allows faster coverage of material later because students have a better grasp of the basics.

How do I get students to cooperate?

This is not a trivial question. The three most important things instructors can do to get their students to cooperate are to make the class believe that their active-learning approach is the normal (if not the best) way to learn physics, to help the student groups develop the skills to successfully complete the group activities, and to hold the students accountable for their own learning. The reason this is not trivial is that in general, student in university (calculus-based) introductory physics classes are more resistant to group work than students in college (algebra / trig.-based) physics courses. Many of the calculus-based physics students have been conditioned to think they must work independently as they compete with their classmates for good grades. However, introducing active-learning methods from the beginning of the introductory course can be very effective since most students don't know what to expect from a physics class and are willing (sometimes grudgingly) to try doing what the instructor wants. Thus, physics faculty have the opportunity to co-opt introductory physics students to active learning if they stick to an active-learning format and present it to students as the way things are. An alternative is to explain at the beginning of the class that this class will be different but studies show that these methods help students learn more effectively and perform better on tests. After an active-learning curriculum has been implemented for a few years, many students will know what to expect from people who have already taken the course.

The reason students resist is that active-learning approaches are very different than what they are used to, and they require students to do something they try to avoid, think deeply about the material they are learning. Resistance can be stronger if students have experiences that cause them to believe that they don't need active learning to learn physics effectively. This is why junior and senior undergraduates tend to resist innovative teaching methods more than freshman and sophomores and why it can be difficult to introduce active learning after most of the students have completed one semester of traditional physics instruction.

Even so, roughly 70-80% of the students learn to appreciate an active-learning curricula after one year of active-learning instruction. Typically this transition follows a change in which the student realizes that understanding the concepts is important for learning physics and problem solving. Some students make this transition after a few weeks, some take a year, and some never make the transition while in the introductory course. This is one reason why student evaluations may be less favorable after one term of an active-learning curriculum. However, if the implementation of curriculum is working, evaluations at the end of the sequence should be at least as good as those from traditional instruction.

An important aspect of successful implementation is are the student groups are staying on task and learning to work together effectively. For approaches that use formal cooperative group methods, to work together effectively means the student groups must meet the five criteria discussed in the previous section on cooperative learning. For approaches that use informal cooperative group methods, this means meeting the following criteria:

- All students must participate in the discussion
- Students learn to appreciate that explanations are just as important as answers.
- Students appreciate that understanding a group task is more important than finishing it quickly
- In addition, grading on an absolute scale rather than a curve can help encourage students to work in groups and help one another since their grade no longer depends on how well an individual does compared to the rest of the class.

One way to give students an incentive for staying on task and trying to understand the material they are working through, particularly in lectures where instructors cannot easily interact with each group, is to hold students accountable by calling on them in class to explain their answers or to give homework based on the in class group activity. In addition, at least one problem on each exam should be based on in-class group activities. This lets students know they are being held responsible for learning from these activities and that their grade depends on it. When calling on students in class, call on them by name as opposed to calling on only those who raise their hands. This lets students know that at any time they may need to be prepared to discuss their answers and their reasoning.

Will students really read the text?

Yes. Again this is a matter of holding students responsible for their learning. In an active-learning environment, if class time is to be used for practicing physics rather than presenting new material, then the text becomes the students' primary resource for information ó for facts, discussion of new ideas, and examples of how to apply their knowledge. In order for this to work, students need to make an initial reading of the material before it is discussed in class. Even though this runs counter to most instructors' experience, students will read the text if you make your expectations clear and continue to run class based on the expectation that they have done the reading. If you once begin to lecture because students do not seem to have read the material, they will know you were not serious and learn to depend on you rather than read the material for themselves. On the other hand if you use reading and vocabulary quizzes to check to see if they are keeping up with the reading, the students will have more incentive to read ahead of the class. In addition, as not all students read the text the same way (see Part II of the introduction), it may be useful to give hints in class on how to read a chapter and what to look for. Instructors in community colleges, colleges, and universities have reported success in getting their students to read the text in this way.

While it is unusual in physics, reading ahead of the class in preparation for discussion of the material is common in other classes on campus. Mazur notes that if we were teaching a class on Shakespeare's plays, we would not consider it sufficient to just read the play to the students. As instructors, we would expect the students to read the play before hand so we could discuss the meaning and implications of the play to help the students develop a deeper understanding of it.[53] (The quote from Mazur can be found in Part II of the introduction).

Who will active learning really help?

Many instructors believe that active learning will only benefit the good students or benefit the weak students at the expensed of the good students. The evidence shows that all students can benefit from an active-learning approach. Although best students can learn physics well with or without active learning in the classroom (they usually have the motivation and skill to learn the course material without special instruction), even they benefit from group learning by explaining their reasoning to their peers and addressing their questions. Studies have shown that students from the top, middle, and bottom third of the class all benefit. Arons has noted that if a concept is addressed in four or five different contexts, up to 80% of the students can learn to master that concept.[54] In most physics classes, the top 10-20% of the students will learn physics regardless of how it is taught; the bottom 10-20% will probably not learn physics unless considerable time and resources are expended. The remainder are the students who can be reached by effective instruction.

I don't have the right personality, will this work for me?

Yes, active learning can work for you. There is no special personality needed to teach using active learning, just a willingness to try and the flexibility to adapt. Most instructors have experience interacting with our colleagues and even our students effectively one on one. This type of communication is also effective for teaching with active learning, although we're not used to doing it in a classroom. The hardest thing for most instructors is learning not to answer student questions directly, but rather learning to ask leading questions to help students construct their own understanding. While not all instructors using a particular active-learning method get the same results, almost all are able to see improvements in student learning and few go back to traditional lecture. Most instructors begin thinking about how to introduce active learning into their other classes.

One note of caution: Many instructors begin implementing active learning by inventing their own approach or by implementing a patchwork of methods from scanning the literature. The active learning methods discussed previously were carefully constructed over several years and owe at least part of their success to the continuity of the approach and other subtle factors that may not be obvious to the reader. Instead, instructors are encouraged to pick a method from the previous section or from the literature that looks like it might fit your situation, check the references to learn more about it, and then try to teach it as the developer intended. As you gain experience with an active learning curriculum and learn what does and does not seem to work with your students, then you are ready to begin fine tuning the approach to make it truly your own.

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