Using the Physics Suite

To suppose that scientific findings decide
the value of educational undertakings is to reverse the real case.
Actual activities in educating test the worth of the results
of scientific results. They may be scientific in some other field,
but not in education until they serve educational purposes,
and whether they really serve or not can be found out only in practice.
John Dewey [Dewey 1929]

We've come a long way since I first introduced the idea of the Physics Suite at the beginning of chapter 1. In subsequent chapters, we talked about some of what is known from research about student thinking and learning, and I described some innovations in curriculum development based on that research. Some of those innovations belong to the Physics Suite, while the others can be adapted to work with Suite elements. We are now ready to revisit the elements of the Suite to consider how you might use them in your teaching.

The materials of the Physics Suite have been set up so that you can either (1) use many of them at the same time, or (2) integrate one or more elements with the materials you are already using. The Suite is not a radical change to the traditional approach to introductory physics teaching. It is meant to provide elements that are both familiar and improved as a result of what has been learned from physics education research and as a result of new developments in educational technology. You can choose to incrementally adopt individual elements of the Suite that are appropriate in your instructional environment.

In this chapter, I begin with a review of the principles behind the Physics Suite. This is followed by a brief recap of the elements of the Suite, along with ideas for using the Physics Suite in different environments. I conclude by presenting four case studies that give specific examples of how various instructors have adopted and adapted elements of the Suite in high schools, colleges, and universities.

THE PRINCIPLES BEHIND THE PHYSICS SUITE

The Physics Suite is predicated on two shifts of perspective from the traditional approach to teaching, one sociological, one psychological.

First, over the years, physics instructors (myself included) have typically assumed that they should present the content in a manner that satisfies themselves and that the students would then take responsibility for doing whatever they needed to do to learn the material. This results in a filter that passes only those students who come to the class with the drive, motivation, and understanding of the study skills necessary to succeed in physics on their own. This turns out to be a small fraction of the students who take physics. With the increasing shift in the emphasis of physics instruction to a service course preparing scientists and engineers who will not necessarily become physicists, we need to shift our assumptions. Now we want to see how much help we can offer students who need to know some physics but who may not know how to learn physics appropriately.

Second, a lot has been learned from educational and psychological research that can help instructors understand how to help students learn how to learn physics. The critical principle is:[1]

> *Principle 1:* Individuals build their knowledge by making connections to existing knowledge; they use this knowledge by productively creating a response to the information they receive.

The implication of this principle is that what matters most in a course is what the students actually do. In order to have effective instruction, we, therefore, have to create learning environments that encourage and enable students to do what they need to do to learn, even if they don"t choose (or know how) to do so spontaneously.

This result is often called upon to justify the creation of "hands-on" or "active learning" environments. Unfortunately, this largely misses the point. Students can actively work with equipment and still not learn very much physics. (See, for example, the discussion of traditional laboratories in chapter 9.) What matters is their pattern of thought as they blend hands-on activities with reflection. We need a more detailed understanding of student learning in order to be able to design environments that effectively encourage appropriate thought and reflection. Further complicating the situation is what we need to do to achieve our goals depends on our goals. And these goals depend on a both external and internal factors: the population we are teaching, the course and its nominal purpose, our own individual goals as instructors,[2] and our model of student thinking and learning.

Our model of thinking and learning is often implicit, tacit, and in contradiction with both fundamental research in cognitive psychology and the observed behavior of students in educational situations. In chapter 2, I have put together a "soft paradigm" (a set of guidelines or heuristics) that can help instructors develop and apply a more sophisticated approach to thinking and learning. The fundamental ideas are that long-term memory is productive, associative, and context dependent. Principles 2–5 in chapter 2 (the context, change, individid-

[1]See chapter 2 for details.

[2]For example, in teaching our engineering physics class, I very much want my students to learn to understand and create arguments based on symmetry. Sagredo wants them to appreciate physics as a creative historical evolution of ideas. Both are noble and justifiable goals but are not required in the classes we teach.

uality, and social learning principles) help us to understand what features of an environment might be appropriate to help students create appropriate understandings.

> *Principle 2:* What people construct depends on the context—including their mental states.
>
> *Principle 3:* It is reasonably easy to learn something that matches or extends an existing schema, but changing a well-established schema substantially is difficult.
>
> *Principle 4:* Since each individual constructs his or her own mental structures, different students have different mental responses and different approaches to learning. Any population of students will show a significant variation in a large number of cognitive variables.
>
> *Principle 5:* For most individuals, learning is most effectively carried out via social interactions.

This model has a number of implications. Principle 1 implies that it helps if we pay careful attention to what students know and how they use that knowledge in creating both their correct and incorrect understandings of what we are trying to teach them. This is the resource component of the model. Principle 2 suggests that it helps if we pay careful attention to *when* students access the knowledge we want them to have. This means teaching them how to use it effectively and to recognize when it is appropriate. This is the linking component of the model. Principle 3 reminds us of the importance of knowing "what they know that ain't so" and provides guidance in building environments that help students get on the right track. The bridging and cognitive conflict approaches discussed in chapter 2 provide two possible approaches. Principle 4 reminds us to provide environments appropriate for a variety of student styles. This is the diversity component of the model. Finally, Principle 5 suggests we pay attention to the design of the social environments in which our students learn. This is the social component of the model.

Chapter 2 also discusses and develops how this model leads us to articulate a particular collection of explicit goals for our physics instruction. Goals that have been considered in the construction of the Physics Suite include:

> *Goal 1: Concepts*—Our students should understand what the physics they are learning is about in terms of a strong base in concepts firmly rooted in the physical world.
>
> *Goal 2: Coherence*—Our students should link the knowledge they acquire in their physics class into coherent physical models.
>
> *Goal 3: Functionality*—Our students should learn both how to use the physics they are learning and when to use it.

The Physics Suite is designed in accordance with this model of thinking and learning so as to help teachers create learning environments that function effectively.

THE ELEMENTS OF THE PHYSICS SUITE

Traditional instructional materials are organized around a content list and a textbook. The Physics Suite is designed to help instructors refocus their courses on learning goals and student activities. The text in the Physics Suite is intended to be supportive, but it is just one component in an array of materials that can help build an effective learning environment. (See Figure 1.2 for a diagram showing the elements of the Suite.)

I briefly describe each element in turn and show how it fits into the overall picture. Since the modifications to the narrative—an important Suite element—are not discussed elsewhere in this volume, I consider these in more detail than the rest.

The Suite's narrative text: Understanding Physics

The narrative for the Physics Suite, *Understanding Physics* (Cummings, Laws, Cooney, and Redish) [Cumming 2003], is based on the sixth edition of the popular *Fundamentals of Physics* (Halliday, Resnick, and Walker) [HRW6 2001]. It is being adapted and modified to an active-learning environment in a number of ways.

1. *Modifications to the text are incremental, not radical.* The next generation of texts may integrate activities directly and be presented on-line. *Understanding Physics* begins with a standard text and takes a step in that direction. Existing in-text activities (Reading Exercises and Sample Problems) are enhanced, and links are indicated where connections to activities are appropriate and relevant. But it still looks enough like a traditional text to be in the "comfort zone" of both students and teachers accustomed to traditional texts. The primary active-learning enhancements come from working with additional Suite elements.

2. *The text is modified to take student difficulties into account.* At the time of this writing, thousands of papers have reported on the difficulties students have in learning physics [Pfundt 1994]. These are summarized in the Resource Letter on the Resource CD associated with this volume [McDermott 1999], and the results are discussed in a number of texts and instructor's guides [Arons 1990] [Reif 1995] [Viennot 2001] [Knight 2002]. In *Understanding Physics*, issues that are well known to confuse students and cause them difficulty are discussed with care. Many traditional texts consider these issues trivial and brush them off with a sentence or use ill-chosen examples that may actually activate classic misconceptions.

3. *Topics are introduced by making connections to personal experience whenever possible and appropriate.* We try to follow the principle "idea first, name later" and to motivate a discussion before it occurs, making contact with the student's personal experience. This helps build patterns of association between the physics students are learning and the knowledge they already have, and helps them reinterpret their experiences in a way that is consistent with physical laws.

4. *Material is explained in a logical order.* We try to follow the "given-new" principle (see chapter 2) and build on ideas the student can be expected to understand, based on the resources they bring from their everyday experiences. Many texts present results didactically, starting a discussion by stating a complex result at a point where a student does not have the resources to understand or interpret it and then explaining it through a complex exposition taking many pages.

5. *Concepts are emphasized.* One of the primary goals in our model is that students make sense of the physics they are learning. This is impossible if they see physics as a set of abstruse equations. We therefore stress conceptual and qualitative understanding from the first and continually make connections between equations and conceptual ideas.

6. *Reading exercises and sample (touchstone) problems are limited and carefully chosen.* In an effort to provide examples and items of interest, physics texts often include large numbers of text boxes, sidebars, and sample problems. This can make the narrative choppy and difficult for the student to follow. In *Understanding Physics,* reading exercises are carefully selected

to provide appropriate thinking and reflection activities at the end of a section. These are often suitable (especially in small classes) as topics for discussion. Sample problems have been transformed to "touchstones"—carefully chosen examples that illustrate key points to help students understand how to use the physics within a problem. Sample problems that only illustrated straightforward equation application and manipulation ("plug-and-chug") have been removed.

7. *Examples and illustrations often use familiar computer tools.* Examples in the text have been expanded and modified to use computer-assisted data acquisition and analysis (CADAA) tools and collection of data from video. Other elements of the Suite—laboratories, tutorials, interactive lecture demonstrations, and Workshop Physics—make heavy use of this technology as well. This has a number of advantages. It connects the text to the student's experiences in other parts of the class; it connects directly to real-world experiences (through video); it uses realistic rather than idealized data; and it connects the narrative to the more active Suite elements.

8. *No chapter summaries are provided.* This is a feature, not a bug! We didn't forget to include the chapter summaries; rather, we removed them intentionally. Students tend to use pre-created summaries as a crutch to grab equations for plug-and-chug purposes and as a shortcut to avoid reading (and trying to make sense of) the text. Providing an "authority-validated" summary in the text both robs the students of the opportunity to construct summaries for themselves and sends the covert message to trust authority instead of building their own judgment. Instructors who feel that summaries are essential (as do I) can assign students to create summaries as a regular part of their written homework.

9. *The order of materials has been modified somewhat to be more pedagogically coherent.* Some of the traditional orderings emphasize the mathematical structure of the material at the expense of the physics or violate the given-new principle. For example, free fall is often included in the kinematics chapter, since constant acceleration problems can be solved algebraically. One result of this approach is that students are often confused by gravity, being unable to disentangle the idea of the gravitational field near the Earth's surface ($g = 9.8$ N/kg) from the gravitational acceleration that results in free fall ($a_g = 9.8$ m/s^2). We treat free fall in chapter 3 after a discussion of force. In order to emphasize the centrality of Newtonian dynamics, Newton's second law is treated in one dimension immediately after the definitions of velocity and acceleration. Momentum is treated as a natural extension of Newton's second law. The concept of energy is delayed until after the discussion of extended objects.

10. *Vector mathematics is handled in a just-in-time fashion.* The dynamics of one-dimensional motion is presented before introducing general two- and three-dimensional vectors. Vectors and vector products are introduced as they are needed, with the dot product being presented in association with the concept of work and the cross product being presented in association with the concept of torque. One-dimensional motion is presented in the context of one-dimensional vectors, with a notation that is consistent with general vector notation to help alleviate a traditional confusion students have between scalars and vector components.

Using the Suite in lab: RealTime Physics

RealTime Physics (RTP) is a set of three published laboratory modules covering the topics Mechanics (12 labs), Heat and Thermodynamics (6 labs), and Electric Circuits (8 labs).[3]

[3]A module on Light and Optics is currently under development.

These labs help students build a good understanding of fundamental concepts through use of a guided inquiry model with cognitive conflict. Experiments rely heavily on computer-assisted data acquisition to enable students to collect high-quality data quickly and easily. This allows students to perform many experiments and to focus on phenomena rather than on data taking. Initial activities with new probes help students "psychologically calibrate" the probes, that is, convince themselves that they understand what the probes' responses mean, even though they may not be clear on how the probes produce their data. Research shows that these labs can be very effective in helping students build concepts. For a more detailed discussion, see chapter 8.

Implementing RealTime Physics requires a laboratory setup with computer-assisted data acquisition equipment for every two or three students.

Using the Suite in lecture: Interactive Lecture Demonstrations

Interactive Lecture Demonstrations (ILDs) help students learn representation-translation skills and strengthen their conceptual understanding through active engagement in a large lecture environment. Students receive two copies of a worksheet: one for making predictions and one for summarizing observations. The instructor goes through a sequence of carefully chosen demonstrations using computer-assisted data acquisition to display graphs of results on a large screen in real time. Students are shown the demonstration without data collection. They are then given the opportunity to make predictions and to discuss their predictions with their neighbors before the results are collected and displayed. The topics and demonstrations rely heavily on research that identifies common misconceptions and difficulties. The worksheets use cognitive conflict and social learning. Research shows that these activities can be very effective in helping students both learn concepts and understand graphical representations. They can also be effective in smaller classes. For a more detailed discussion, see chapter 7.

Implementing Interactive Lecture Demonstrations requires only a single computer (for the lecturer) with computer-assisted data acquisition and a large-screen display. It takes a bit of practice for a traditional lecturer to develop the interactive style that gets students contributing to the discussion in a way that makes these demonstrations most effective. (See chapter 7.)

Using the Suite in recitation sections: Tutorials

Tutorials are a curricular environment for delivering active conceptual development in recitation sections. They have a tight, carefully guided group-learning structure similar in feel to the RealTime Physics labs or the Interactive Lecture Demonstrations. They are based on research on student difficulties and make frequent use of both cognitive conflict and bridging. An extensive set of Tutorials has been developed by the University of Washington Physics Education Group covering a wide range of topics from kinematics to physical optics [Tutorials 1998]. These Tutorials are designed to be usable in environments without computer tools, so they make almost no use of computer-assisted data acquisition or video. A supplementary set of tutorials using computer technology including computer-assisted data acquisition, video display and analysis, and simulations, are available as part of the Suite [ABP Tutorials]. Tutorials have been shown to be effective in improving concept learning compared to classes with traditional recitations. For a more detailed discussion, see chapter 8.

Implementing the UWPEG Tutorials requires some small items consisting of standard physics laboratory equipment and inexpensive materials from a hardware store. Implementing the ABP Tutorials requires a computer and data acquisition tools for every three to four students. Both types of Tutorials require approximately one facilitator per 15 students. These facilitators need training, both to make sure they understand the physics (which can be quite subtle and challenging, even for faculty and graduate students in physics) and to help them learn a "semi-Socratic" approach, in which the instructor guides with a few well-chosen questions instead of explanations.

Putting it all together: Workshop Physics

Workshop Physics (WP) is the most radical component of the Physics Suite. It presumes a complete structural change from the traditional lecture/recitation/lab pattern. Typically, the class is structured into three two-hour laboratory sessions in which the students use sophisticated technology to build their physics knowledge through observation and mathematical modeling. Classes move smoothly back and forth from brief lecture segments, to class discussions, to full-class demonstrations, to small-group experimenting and modeling. An integrated set of computer tools are used for data acquisition, video capture and analysis, and graphing and modeling with spreadsheets.[4] Workshop Physics is extremely effective in classes of 30 or fewer, but it is difficult to deliver to hundreds of students. (See, however, the discussions of the North Carolina State case study below.) For a more detailed discussion of WP, see chapter 9.

Implementing Workshop Physics requires computer equipment, including a variety of data acquisition probes and tool software. One facilitator for every 15 students or so is a must, but if an instructor is present, they can include peer instructors (students who have successfully completed the course in a previous term). Learning to manage the laboratory logistics and to help students shift the expectations they might have developed in high school or other science courses can be a challenge and may take a few semesters before things run smoothly, but the gains both in learning and in student attitudes can be dramatic.

Homework and exams: Problems and questions

As discussed in chapter 4, the problems students solve, both for homework and on exams, are a critical part of the activities students carry out to learn physics. The choice of exam problems is particularly important, since exams send students both overt and covert messages about what they are supposed to be learning in class (whether we intend to send those messages or not). Traditional courses often limit homework or exams to questions that have numerical or multiple-choice answers so as to be easy to grade. This has the impact of undermining any more sophisticated messages we might send in other parts of the course about the richness of learning and thinking about physics and the value of learning to make sense of a physics problem. The Physics Suite includes an enhanced array of problems for homework and exams, including estimation problems, open-ended reasoning problems, context-rich problems, and essay questions.

Implementing more open homework and exam problems requires some structure for grading. Students need the feedback and motivation that grading provides in order for them

[4]These tools are contained on the Resource CD associated with this volume.

to take more complex and open-ended problems with the required degree of seriousness and reflection. This requires someone—an instructor or assistant—to spend some time evaluating questions. This can be difficult in large classes, but grading a small number of such questions (two to three per week, one to two per exam) can have a big impact.

Evaluating instruction: The Action Research Kit

As discussed in chapter 5, over the past 20 years, physics education research has documented student difficulties in a wide variety of topics in introductory physics. Using these results, researchers have constructed standardized conceptual surveys. Many of the items in these surveys are well designed. They focus on critical issues that are difficult for many students and they have attractive distractors that correspond to common student misconceptions.[5] Because of the strong context dependence in the response of novice students, these surveys (and especially a small number of items extracted from a survey) do not necessarily provide a good measure of an individual student's knowledge. A broader test with many contexts is required for that. But these surveys do give some idea of how much a class has learned, especially when given before and after instruction. More than a dozen surveys are provided on the Resource CD associated with this volume.

Suite compatible elements

Three non-Suite elements that can be comfortably used in conjunction with other Suite elements materials are Peer Instruction, Just-in-Time Teaching (JiTT), and Cooperative Problem Solving. These Suite-compatible materials are discussed in detail in chapters 7 and 8.

Peer Instruction

Peer Instruction is a method in which an instructor stops the class every 10 to 15 minutes to ask a challenging short-answer or multiple-choice question. Usually, the questions are qualitative and conceptual and activate a cognitive conflict for a significant number of students. The students choose an answer for themselves and then discuss it with a neighbor. Next, the results are collected (by raising hands, holding up cards, or via an electronic student response system), displayed, and reflected on in a whole-class discussion. Implementing Peer Instruction only requires a good set of closed-ended questions and problems. Choosing appropriate and effective problems is not easy. They must reflect a critical conceptual issue, a significant number of students (>20%) must get them wrong, and a significant number of students (>20%) must get them right. As with Interactive Lecture Demonstrations, learning to run a good Peer Instruction class discussion can take some practice. Mazur's book on the method contains a large number of potentially useful problems and helps in getting a good start with the approach [Mazur 1997]. For a more detailed discussion, see chapter 7.

Just-in-Time Teaching (JiTT)

JiTT is a method in which students respond to carefully constructed questions (including essay and context-rich questions) on-line. The instructor reviews the student answers before

[5] Recall from our discussion of the resource component of our learning model that a "misconception" does not necessarily refer to a stored "alternative theory." It may be produced on the spot by a student using spontaneous associations to inappropriate resources or inappropriate mappings of appropriate resources.

lecture and adapts the lecture to address student difficulties displayed in the answers, sometimes showing (anonymous) quotes for discussion. This method sends the valuable message that the instructor cares about whether students learn and is responding to them. A significant number of appropriately structured problems are contained in the book by Novak, Patterson, Gavrin, and Christian [Novak 1999]. For a more detailed discussion, see chapter 7.

Cooperative Problem Solving

Cooperative Problem Solving is a method for helping students learn to think about complex physics problems and solve them by working in groups of three in a recitation section or small class. The method employs heterogeneous grouping of students and assignment of roles, and it offers the students a structured method to learn to think about how to approach a complex problem. This method is very effective in helping students both develop good conceptual understanding and learn to solve problems. It sends the valuable message that one doesn't have to be able to see how to do a problem immediately in order to solve it, something many students at the introductory level fail to appreciate. A large number of useful problems are available on the website of the Minnesota group that developed the method.[6] For a more detailed discussion, see chapter 8.

All three of these methods are based on underlying cognitive models and goals similar to the Physics Suite and coordinate well with it.

USING THE PHYSICS SUITE IN DIFFERENT ENVIRONMENTS

To use parts of the Physics Suite effectively in your classroom requires two elements: a good match between the Suite elements chosen and the physical classroom conditions, and a good match between the philosophical orientation of the Suite and the orientation of the instructors involved.

Some of the Suite elements (RTP, WP, ABP Tutorials) rely heavily on student interactions with computers and computer-based laboratory equipment. Use of these elements requires approximately one computer station for every three to four students. These can, of course, be run in small sections in parallel. One laboratory with 8 to 10 computer stations can easily serve 400 to 500 students in the course of a week. Some elements of the Suite (RTP, WP, Tutorials) require facilitators—one instructor for every 15 students in the classroom. In these environments, students struggle in small groups with ideas and concepts. They require frequent (but not too frequent) checking, coaching, and guiding. In principle, one instructor with considerable experience in the methods can handle 30 students (or more), but it is difficult to pull off. A summary of these physical constraints is given in Table 10.1.

The role of room layout

The room layout plays an important role in using some of the Suite elements effectively. It is difficult to get students working together effectively in a lecture hall whose chairs are all oriented in one direction and bolted down. It is difficult to interact effectively with students working in a computer laboratory in which students sit individually or in pairs at computers facing in one direction (toward an assumed lecturer) and bolted down in rows. In these kinds of computer rooms, performing laboratory experiments is nearly impossible. Effective

[6] http://www.physics.umn.edu/groups/physed/

TABLE 10.1 Suite Elements Appropriate for a Variety of Environments.

Element	Large Classes (S/F > 50)	Small Classes (S/F < 50)	Facilitator Support (S/F < 20)	No Facilitator Support	Computer Rich (S/C < 3)	Computer Poor (N ≈ 1)
Text (UP)	✓	✓	✓	✓	✓	✓
Lab (RTP)	✓	✓	✓		✓	
Lecture (ILD)	✓	✓	✓	✓	✓	✓
Recitation (UW Tutorials)	✓	✓	✓		✓	✓
Recitation (ABP Tutorials)	✓	✓	✓		✓	
Workshop Physics (WP)		✓	✓		✓	

room layouts for using various elements of the Suite are discussed in chapters 6 through 9. These layouts give students the opportunity for face-to-face interaction in small groups.

The role of facilitators

Another important consideration is that the facilitators have the appropriate philosophy and approach, and that they know how to listen to students and respond appropriately. Despite the best of intentions, this may not be easy. I had been teaching for 20 years before I realized that when students asked me questions, I was responding as a student rather than as a teacher. Having been a student for 20 years, having been rewarded for giving good answers to teachers' questions, and having been successful at getting those rewards, I had a very strong tendency to try to give the best answer I could to any question posed. Once I realized (embarrassingly late in my teaching career) that the point was not getting the question answered correctly but getting the student to learn and understand, I shifted my strategy.

Now, instead of answering students' questions directly, I try to diagnosis their real problem. What do they know that they can build an understanding on? What are they confused or wrong about that is going to cause them trouble? As a result, instead of answering a question right off, I ask some questions back. Often, I discover that students are trying to hide a confusion by creating questions that sound as if they know what they are talking about. Helping them to finding resources within themselves that they can bring to bear often makes all the difference. ("Oh! You mean it's like . . .") Even after 10 years of operating in this new mode, I still detect a strong tendency to want to give "a good answer," and sometimes, I even talk myself into believing that for some students, in some situations, it's appropriate.

Peer and graduate student facilitators may find it particularly hard to be in the right interactive mode. They <u>are</u> still students and tend to easily fall into the mode they use in answering their teachers' questions. When we first began testing Tutorials at Maryland in the mid-1990s, my department helped out by letting me handpick some of our best TAs. This turned out to be a problem. These TAs had developed their reputation by being articulate explainers. Often in that first semester, I had to pry them out from inside a group of four students where they had just spent 10 minutes, with pencil in hand, "showing" the students the answers to all the tutorial questions while the students sat watching, silently.

Finding the right balance of questions and answers, of intervention and "benign neglect," is difficult. The balance depends on so many things—the particular students involved, the task, the set of expectations that have been negotiated between student and instructor, and how tired or frustrated the students are. The key in making the gestalt shift from good student to effective teacher is learning to listen to the students and to consider them, as well as the content being discussed.

The large variety of materials offered in the Physics Suite along with the set of Suite-compatible materials offer instructors a large range of options. Instructors in different environments can use the materials in different ways.

FOUR CASE STUDIES: ADOPTING AND ADAPTING SUITE ELEMENTS

Every high school, college, and university physics class is a unique environment. Each has its own population of students, its own physical environment, its own history of teaching, its own faculty, and its own relations with other parts of its institution. Any implementation of new instructional materials must be adapted to each institution's unique characteristics and constraints. To illustrate how this plays out in real-world situations, in this section, I present four case studies of different kinds of institutions that have implemented various elements of the Physics Suite. The first two cases concern one or a few individuals teaching reasonably small classes: a public high school and a small liberal arts college. The second two concern large research universities that teach many students: one without and one with a physics education research group. These stories are based on interviews with some of the faculty involved in implementing the materials, on examination of their materials, and on data from their websites. I particularly want to thank Maxine Willis, Juliet Brosing, Mary Fehrs, Gary Gladding, Bob Beichner, and Jeff Saul for discussions.

Using Suite elements at a small institution

Gettysburg High School

Gettysburg High School (GHS) is a medium-sized high school in rural Pennsylvania. It serves a county that covers 185 square miles and has about 25,000 people. GHS has about 1200 students in four grades. The population draws from a wide demographic, ranging from the children of professional suburbanites to children who live in rural poverty and who will be the first generation in their family to attend college.

One of the teachers at Gettysburg, Maxine Willis, has been adapting her class to new developments in physics instruction over the past 15 years. She now uses many Suite elements, including *Understanding Physics* (UP), Workshop Physics (WP), Interactive Lecture Demonstrations (ILDs), RealTime Physics (RTP), and the WP Tools.

Maxine teaches both a standard physics class (noncalculus) and an AP physics class.[7] Typically, she teaches 40 to 50 students in standard physics divided into two sections and about 30 students in AP physics, again divided into two sections. The classes are therefore reasonably small and amenable to highly interactive environments with extended class discussions.

Class periods at GHS are 40 minutes long. Physics is taught in double periods five days a week to allow for lab work. Once a week, each class also meets in a single period for problem solving, answering questions, and recitation-like discussions. Since they are using double periods, they complete a standard one-year high school physics course in one semester.

[7]This is equivalent to a calculus-based university course in mechanics in preparation for AP Physics C.

Maxine's classroom is arranged as a Workshop Physics room (see Figure 6.4) and seats up to 28 students. The room has 14 computers for students, plus one for the instructor. The instructor's computer is connected to a flat-plate overhead-projector LCD panel. She is typically able to get peer instructors for each AP class—students who have previously completed the class successfully and who get independent study credit for their participation. According to Table 10.1, this makes GHS a small class with facilitator support and a computer-rich environment. They are therefore able to use all the elements of the Suite.

Maxine has been working with Suite elements in their various development stages since about 1989. By now she has considerable experience with them and can use them flexibly and creatively. In the AP class, she uses the text, extensive Workshop Physics activities and tools, ILDs, and the problem solution book. In the standard class, she uses activities selected for Workshop Physics, RealTime Physics labs (sometimes substituting the simpler Tools for Scientific Thinking labs), and ILDs.

In the AP class, two typical days might include a WP activity and a problem-solving activity. On a WP day, Maxine may begin by explaining some features of the equipment the students need to understand to carry out the task, but most of the period is spent with the students carrying out the activities themselves. Maxine and her peer assistant wander the classroom, asking and answering questions (and "answers" are often guiding questions). If there is time left at the end of the period, they may have a reflective discussion of what has been learned. Otherwise, that discussion takes place at the beginning of the next class.

Typically, WP activities are concept building. Maxine begins a topic with these and doesn't turn to serious problem solving until she feels that her students are clear on the concepts. If WP is not working for them, and in some cases where a WP activity is too complex for high school or uses too much equipment, she will substitute an ILD, taking a full double period to complete it.

On a problem-solving day, the students are supposed to have attempted some homework problems chosen from the text before coming to class.[8] They divide into groups of two to three. Each group is given a piece of whiteboard ($2' \times 2'$) and markers and is assigned a group number. Maxine then passes out the solution manual, and the students check their answers against the solutions in the manual. While they are doing this, she writes the problem numbers on the board. When a group decides that they have had difficulty with a problem, they put their group's attempt at a solution on the board under the problem number. Both the instructor and the class can then see the pattern of difficulties. If the entire class has had difficulty with a problem, Maxine will do a similar example (not the same problem). She then selects the problems most of the class had difficulty with and has the groups work them out on their whiteboards.

There are two critical elements in this activity. First, the students have a pattern they have to follow—they are required to include a diagram and show their line of reasoning. Second, the solutions in the manual usually are incomplete. The solutions in the manual pay little attention to the problem setup and tend to focus on the algebraic manipulations.[9] As a result, the solutions provide hints but don't fill in the critical thinking steps; the students have to do that themselves. By using the hints in the solution book and by working together,

[8] Students who fail to do this have their grades for the missed problems reduced.

[9] In this context, this is a feature, not a bug!

almost all students are able to work out and understand the solutions to all the problems. Typically, a class can do three or four problems per time block.

Maxine's experience with traditional texts in these classes has been poor. Students in the standard class can't make much sense of an introductory physics text, and even the AP students had considerable difficulty with earlier editions of Halliday, Resnik, and Walker. Students felt they couldn't understand it. She helped them by creating reading guides—questions to help them interpret what they were reading—especially in the first few chapters when they were getting started. Maxine reports that since adopting the preliminary edition of *Understanding Physics*, this problem has gone away. Her AP students are reading the text carefully and don't need explicit guidance. (*Understanding Physics* is not appropriate for her standard physics students since it uses calculus.)

Maxine reports that the elements of the Physics Suite work well for her and she is satisfied that student learning has improved—and not just for memorized facts. When I asked her what she thought the overall impact of adopting the Suite approach was, she said, "It's made me not the center of the classroom. The focus is more on the student as learner. More of my students are able to think physically. Once they know it, they have a really strong foundation. I feel like I'm giving future scientists their ABCs. I'm not covering a lot of material, but they're becoming much more powerful analytically than they were before. In addition, they're more confident problem solvers. They go off to competitive colleges and don't feel swamped anymore. This is a big improvement. Many of my students used to start out as science majors in college and then switch out. That doesn't happen nearly as often now."

Pacific University

Pacific University is a private college with professional graduate programs. The professional programs are mostly in the health sciences (occupational therapy, optometry, physician assistants, and psychology). Many of the undergraduates are interested in biology and in health science careers. Pacific is located in rural Oregon, in a small town up against the coastal range. It has about a thousand undergraduates and a thousand students in the professional programs.

The Physics Department is small—four faculty members plus one shared with optometry (3.3 FTEs). The Department teaches three introductory physics classes: conceptual physics, algebra-based physics, and calculus-based physics. Elements of the Physics Suite have been used in the latter two classes for a number of years.

The algebra-based class has become substantially smaller recently, since the Biology Department no longer requires it.[10] The number of students now fluctuates between 20 and 60. It is taught as a two-semester course meeting six hours/week as three one-hour lectures and one three-hour lab period. The three-hour period is split between tutorial instruction and laboratory.

The Pacific Physics Department has been using the RealTime Physics materials in their laboratories for about eight years. Most of the RTP labs are designed for three-hour blocks, so they have adapted them to their environment. Many of the RTP labs come in three parts, each appropriate for a one-hour period. They experimented with a variety of options and wound up choosing two of the three parts of an RTP lab and splitting it over two weeks. In

[10]Mary Fehrs reports that according to the biologists the students have to learn so much new biology that there is no room for courses that are of limited relevance.

each three-hour block, students do a two-hour tutorial and one hour of lab. (They found that their students were able to handle splitting the lab better than they were able to handle splitting tutorials.) The RTP labs follow the new mechanics sequence, which does not jibe with some standard texts. Rather than change the order of reading the text, they keep the text order and rearrange the order of the RTP labs to match. This seems to work OK.

Some course items (such as circuits) are taught in lab and are only mentioned briefly in lecture. The instructors at Pacific have chosen not to use the RTP pre-lab assignments since their students don't use these materials as a probe of their own thinking, as intended, but rather look the material up in the text to be sure of getting the right answers. This preempts the discovery character of the lab learning. The labs work for them without the students having completed the pre-lab materials. They do use the lab homeworks but modify them somewhat to fit the language and content of their lectures.

The instructors have struggled somewhat with the tutorial instruction. The UW Tutorials are designed for a calculus-based class and were too sophisticated for their population. Instructors have been using some problem-solving tutorials developed for the algebra-based class but are not satisfied with them and so are still hunting for appropriate materials that emphasize concept building. They do tutorials as a two-hour block in the three-hour period.

Mary Fehrs reports that in lecture she tries to put the material in context and tie it to concepts, and that she does some problem solving. She also does some ILDs and finds them very helpful. She reports that in ILDs her students can often be coaxed to make a thoughtful prediction—which they don't often do in lab or tutorial. They can be wrong and very confident about their wrong answers. Sometimes they have to see a result twice before they believe it. She tried using some JiTT over the web but gave it up because of difficulties managing their computer environment.

Mary's sense is that the algebra-based students are "good students"—that is, they will do just about whatever you ask of them. Unfortunately, their mode of successful learning up to this class has been to memorize and replay, and traditional lecturing plays right into that mode. The use of RTP and ILDs helps break this pattern and leads to considerable improvement. Mary says, "I've taught for 30 years. From daily walking and talking you get an idea of what they're getting. They get much more this way. They're really starting to think." The class results on FMCE show fractional gains of about 0.5—which is very good compared to the 0 to 0.3 found in a typical lecture-based environment [Wittmann 2001].

In the calculus-based class, the instructors adopt a full workshop model and use the Workshop Physics materials. Typically, they have about 20 students and a few peer instructors (students who have previously taken the course who are paid to facilitate during class and do grading). The physical setup consists of 1950s-style lab rooms with six long tables, set up with four students per table. Each table has a computer and an analog-to-digital converter for data acquisition. The students work in groups of twos, but the setup fosters interactions between two pairs. The classes meet for six hours/week in three two-hour blocks.

In this case, they use the Workshop Physics materials as is, without modification. They haven't used a textbook (though as of this writing they are planning to try the preliminary edition of *Understanding Physics*) and have used WP problems exclusively. They write new problems for exams but do not feel the need to create additional curricular materials. Mary Fehrs says, "[The WP materials] make a coherent whole and good conceptual sense as is."

Some of their exams include components that are laboratory oriented—analysis of data, work with spreadsheets, etc.

When I asked what problems she had encountered, Mary reported two problems with WP: the students have difficulty getting the "big picture" working with WP alone, and she has trouble getting the students to take their predictions seriously and "think hard" about them. In order to help students develop overviews, she has them write weekly summaries describing what they have learned during the week. She reports that this exercise helps them get perspective and organize the material somewhat, but she hopes that having a text will provide the perspective absent in the hands-on-oriented WP activity guide. She continues to work on finding ways to help students understand what she wants them to do in the prediction parts of the lesson. The results on pre-post testing for their WP students are very strong fractional gains—about 0.6 [Wittmann 2001].

Mary is quite satisfied with the use of WP for this class and says she would never go back to lecturing. Her other colleagues have bought in to the method, and she says they would expect any new hires to continue using the approach. She likes the fact that WP "immediately tells the students that learning is active, not passive." She accepts the fact that there is always a diverse response, with some students loving the approach and some hating it. She says, "It's a lot of work and we don't cover as many topics as we used to. But Workshop Physics doesn't let you fool yourself into thinking that your students understand something that they really don't. There is constant feedback that reminds you what they haven't learned yet. It's easy to fool yourself when you lecture."

Using Suite elements at a large institution

In both the case studies discussed above, a small number of instructors (one to three) were dealing with a reasonably small number of students ($<$100). A significant fraction (about a third) of the students in the United States taking physics in a service course at the college level do so in large public research universities. These universities may have between 10,000 and 45,000 students, departments with 15 to 75 faculty members, and graduate students to serve as TAs. Calculus-based physics may serve as many as 500 to 1000 students in each class in each term. Managing the laboratories, recitations, homework, and exams for an operation of this scale can be daunting. Because of the large number of students, large lectures seem inevitable, and often many different faculty members have responsibility for the same class. Although departmental committees often choose textbooks and content may be constrained,[11] faculty are often given considerable leeway in designing their approach to the class. Laboratories may be run independently from the lecture/recitation sections. These strongly held cultural constraints can make implementing lasting reform difficult.

Two large universities that have managed reform even within these constraints are the University of Illinois and North Carolina State University. Both are large engineering schools. The University of Illinois has adopted and adapted a number of Physics Suite elements within the context of the traditional large lecture/recitation/laboratory environment and has created its own

[11]A common textbook and constraints on content permit students to choose different faculty members' classes in different terms in order to handle shifts in the scheduling of their other classes.

web-homework tool. North Carolina State, with the help of an on-site physics education research group, has creatively adapted the workshop approach to a large class environment.

The University of Illinois

At the University of Illinois, Urbana-Champagne (UIUC), in the mid-1990s, the department head, David Campbell, convinced his colleagues that the results coming out of physics education research implied that their large-lecture traditional approach to introductory physics was not as effective as it could be. The motivations and first steps are described in his article "Parallel Parking an Aircraft Carrier: Revising the Calculus-Based Introductory Physics Sequence at Illinois," for the *Newsletter of the Forum on Education of the APS* [Campbell 1997].[12]

The UIUC is a large state university with a large high-quality, research-oriented physics department and is one of the premier engineering schools in the country. The Physics Department at UIUC offers three semesters of calculus-based physics and two semesters of algebra-based physics, teaching all classes every term. A total of about 2500 students register for these classes each semester. The large number of students requires a large number of faculty and a large infrastructure, including TAs and lab managers.

Before they reformed the program, the Physics Department at UIUC taught classes in a traditional fashion with lecture sections of 200 to 300 students for three hours/week and recitation and lab sections of 24 students for three to four hours per week. The lecturer was responsible for all aspects of lecture, recitation, and homework. The TAs planned their sections largely on their own and mostly answered questions on problem solving by demonstrating the solutions themselves at the board. Labs were in the standard "cookbook" model and were the responsibility of a faculty member who had little or no contact with the lecturers.

The result was that neither faculty nor students were happy. Faculty felt that managing a large lecture section with associated homework and TAs was a difficult and unrewarding experience. Students mostly expected to dislike physics and found that the course confirmed their expectations. In pre-post surveys of student attitudes (see Figure 10.1), more than half of the students said they considered physics "negative or awful," with the number increasing in the end-of-semester survey.

In 1995, the faculty agreed to participate in a major reform of the calculus-based physics class. Computers were available in labs, and graduate students were available to serve as facilitators. Available space included traditional large lecture halls with fixed tiered seating, small recitation classrooms with movable chairs, and traditional laboratory space with long tables. Funds were made available to provide computers and data acquisition devices for the laboratory. According to Table 10.1, this makes UIUC a large class with facilitator support and a computer-rich environment. Therefore all of the elements of the Suite can be used with the exception of Workshop Physics.

Since each of the three classes was taught each semester, the reforms had to be implemented "in flight." The schedule of implementation is shown in Figure 10.2.[13] They decided

[12] This article and the other articles in the FED newsletter are available on-line at http://www.aps.org/.

[13] The plan—figuring out what to do, preparing materials, and implementing the results—should be contrasted with the cyclic model displayed in Figure 6.1. The lack of a research-based cycle implies that corrections and updates have to be handled explicitly in some other way.

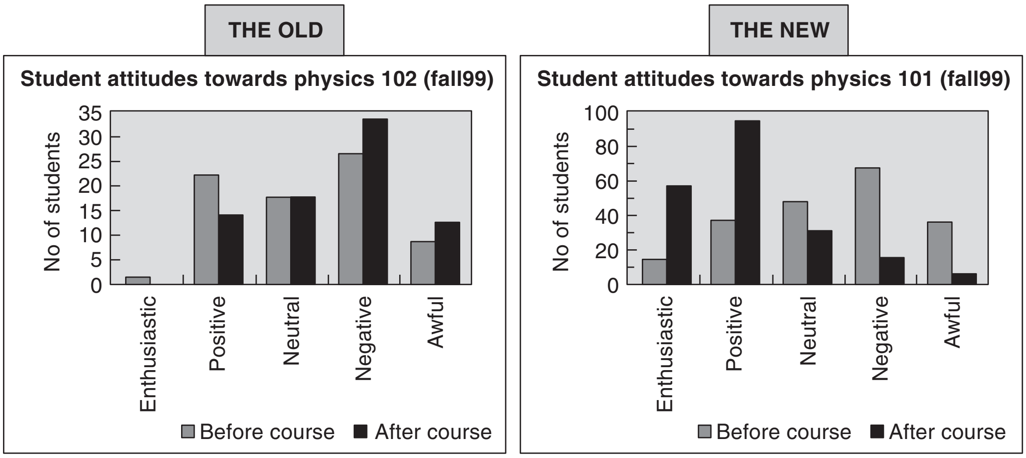

Figure 10.1 Results of pre-post attitude surveys at the University of Illinois—Urbana-Champagne, before and after curriculum reform. Courtesy of Gary Gladding [Gladding 2001].

to restructure the course to provide more active engagement activities for the students and to provide a more balanced load for the faculty. A primary design criterion was to produce a more coherent and integrated course—and one that would be seen as belonging to the department, not whose individual pieces belonged to individual faculty members or TAs.

The calculus-based course was restructured to include two 75-minute lectures, a two-hour recitation, and a two-hour laboratory each week. In the algebra-based course, they restructured to include two 50-minute lectures, a two-hour recitation, and a three-hour laboratory each week. Lecture classes were increased in size so that one of the faculty members formerly assigned to lecture could be assigned to manage the recitations and homework. This resulted in a more balanced teaching load. The decision was made to implement Peer Instruction in lectures, Tutorials and Cooperative Problem Solving (with home-grown

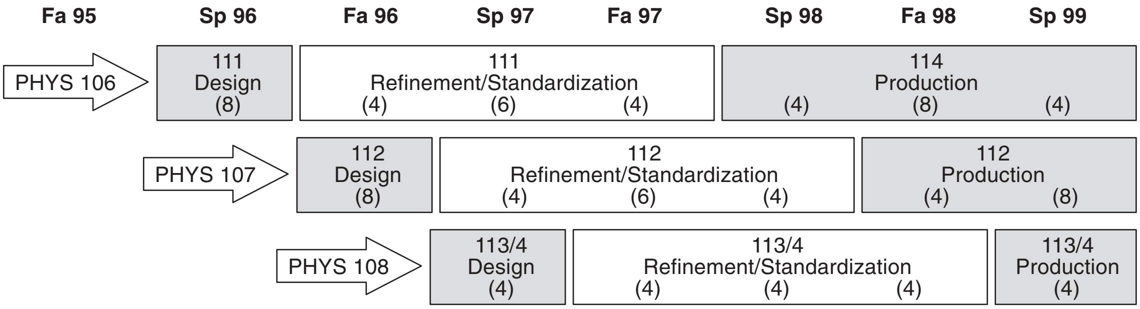

Figure 10.2 Design and implementation schedule used at the University of Illinois—Urbana-Champagne, to reform the calculus-based physics course [Gladding 2001].

problems) in recitation, and RealTime Physics laboratories.[14] In order to create coherence and a sense of common ownership, the working team meets regularly to discuss what is happening in the class. Problems for the cooperative-problem-solving sessions are written in common, as are exam problems. Exams are multiple-choice and machine-graded, and they are delivered in the evenings to all sections at the same time outside of class hours.

A new emphasis on concepts was introduced, and a web-based homework system was developed and maintained by Denny Kane, a full-time staff member. (See [Steltzer 2001].) The web-delivered homework comes in three different formats, each serving a specific pedagogical purpose.

1. Linked quantitative problems around a specific physical situation: Brief hints are available upon request, and immediate feedback (right or wrong) is given.
2. Delayed feedback homework: Similar in structure to the first, but no feedback is given until after the grading deadline. These are like on-line quizzes.
3. Interactive examples: A single multistep quantitative problem with extensive help dialogs.

The UIUC Physics Department made a substantial commitment of both funds and staff in order to implement the program. Existing positions of computer coordination and lecturer were repurposed for the new structure, and a new Associate Head position was created to manage the system.

Both students and faculty are enthusiastic about the results. On pre-post happiness surveys, ratings were dramatically improved. (See Fig. 10.1.) At the end of the first semester, more than 75% reported that they were either positive or enthusiastic about their physics class. (This compares with less than 20% before the reform.) Far more TAs made the campus's "list of excellent TAs" after reform than did before (77% compared to 19% before reforms). Faculty are much more comfortable with the teaching load than previously, and calculus-based physics is no longer considered a "killer" teaching assignment. More details can be obtained from the course website.[15]

North Carolina State University

The University of Illinois began their reforms with the premise that changing a large class involving thousands of students and dozens of faculty required maintaining a lecture-based format, and they adapted many research-based curriculum reforms that fit that model. North Carolina State University began their reforms with a different idea. The Physics Department at NC State contains a physics education research group led by Bob Beichner. Bob felt quite strongly that inquiry-based instructional models such as Workshop Physics could lead to dramatic improvements in learning over lecture-based models, so he set about trying to find a way to implement one.

NC State University, like UIUC, is a large state engineering school with a research-oriented physics department. The Physics Department has between 50 and 60 faculty members

[14] Algebra-based physics labs were adapted from pre-publication versions of RTP, and calculus-based labs were created on site using a predict-observe-explain model similar to RTP, ILDs, and Tutorials.

[15] http://www.physics.uiuc.edu/education/course_revision.html

and instructs more than 5000 students in physics classes each year.[16] The largest class is calculus-based physics, a two-semester course with about 500 to 1000 students in each class in each semester. The reform of the calculus-based introductory physics class was undertaken in quite a different way from the UIUC as a result of the presence of a PER group. The project was begun in the years 1995–1997 with a small class, observers and interviewers from the research group, and standardized survey instruments to measure student progress. In the initial phase of the project, all the students' classes (physics, calculus, chemistry, and introduction to engineering) were done in a coordinated fashion [Beichner 1999]. In later stages, the project developed a stand-alone method for physics referred to as Student-Centered Activities for Large Enrollment University Physics (SCALE-UP). The SCALE-UP project received funding for development and dissemination from U.S. government funding agencies and is currently being adapted at a number of other universities.[17]

In the initial stage of the project, the approach planned was described to entering engineering students, and they were asked to volunteer to participate. Approximately 10% of the students volunteered, and half of those were chosen at random to participate in the experimental class. The other half took the traditional class and were used as a control group.

The class was set up to operate in a workshop/studio mode, and material was adapted from a wide variety of research-based sources, including Workshop Physics, Physics by Inquiry, Cooperative Problem Solving, and Peer Instruction. Students were organized into groups of three heterogeneously and the same groups worked together in all their classes. Roles were assigned, and students received instruction both on how to work in groups and how to approach complex problems.

Large numbers of computers with data acquisition and modeling tools (spreadsheets and Interactive Physics) were available, as were graduate student facilitators. Experimentation with different layouts led them to select round tables with 9 to 12 students and 3 to 4 laptop computers. Before and after views of the physics classroom are shown in Figure 10.3.

Figure 10.3 Views of the physics classroom at NC State before and after the transformations created by the SCALE-UP project.

[16] Number of students enrolled in physics classes each year including summer sessions.

[17] See the NC State SCALE UP website at http://www2.ncsu.edu/ncsu/pams/physics/Physics_Ed/ for current information on the project.

TABLE 10.2 Fraction of Students Who Received Grades of C or Better in All Their Math, Chemistry, Physics, and Engineering Classes.

	1995–1996		1996–1997	
	N	Success Rate	N	Success Rate
Test class	35	69%	36	78%
Control group	31	52%		
Traditional	736	52%	552	50%

Classes are run workshop style, with an intermix of brief lecture elements, discussion, problem solving, laboratory investigations, and modeling. Laboratory segments are often brief—10 minutes or so (though they sometimes grow to blocks of as much as an hour or two)—and in response to questions raised in class discussion. UW Tutorials are used but are broken up into short discussion segments of 10 to 15 minutes. Since there are no formal lectures, students are responsible for reading materials before each class.

Like the reforms at UIUC, the reforms at NC State made significant use of the web, in particular, the *WebAssign* environment, developed and supported at NC State. The web is used for distribution of materials, maintaining the class schedule, and distributing and collecting homework. WebAssign is used both in and out of class to present questions and problems to the students. Use is also made of Java applets, particularly the Physlet collection [Christian 2001].

The classes were initially run with a class size of about 30. They were then increased to 54 and currently run successfully with as many as eight tables and 99 students in a room at once.

The results of the initial attempts showed significant success. The rate of good grades across the group of classes was much higher in the test group than among traditional students (and the control group was close to traditional). (See Table 10.2.)

Student success in physics learning was also better than in the traditional class. The average score on the TUG-K for the test class was 89% ± 2%, while for the traditional students it was 42% ± 2% (standard error of the mean). On the FCI pre-post, the test class had an average fractional gain of 0.42 ± 0.06 and 0.55 ± 0.05 in the two years reported. The control group only achieved an average fractional gain of 0.21 ± 0.04, comparable to the average reported for traditional classes [Hake 1992][Redish 1997]. On the shared midsemester exam, the test class did significantly better than the control group that received traditional instruction (80% to 68%).[18] Pre-post MPEX studies showed no change on most variables (a good result, considering that almost all classes show a significant loss) and a 1.5σ improvement on the coherence variable. On other attitudinal variables, students in the trial class showed substantial improvement in confidence levels, while students in the traditional class showed declines (especially those in the control group).[19]

[18] In the following semester, in which all students received traditional instruction in E&M (electricity and magnetism), no difference was noted between the groups of students.

[19] See the project's annual reports on the NC State website for more details.

As part of the SCALE-UP project, Beichner and his collaborators are building up a large collection of adapted and modified materials, including short hands-on activities, interesting questions to consider, and group-based laboratory exercises that require a lab report. Check the group's website for information on availability of these materials.[20]

CONCLUSION

As these case studies show, there are many paths to reform. The particular path you choose depends on the resources you have available, your constraints, and above all, the opportunities offered by your most important resources—the individuals in your department who show an interest in changing physics instruction at your institution. The Physics Suite offers you and your colleagues tools to work with in your efforts to improve what your students take from their physics classes.

[20] http://www2.ncsu.edu/ncsu/pams/physics/Physics_Ed/.