

# The CUPLE Physics Studio

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By Jack M. Wilson

The introductory physics course at many large universities can be an intimidating experience for the new student. This is not only because of the difficulty of the material, but also due to the experience of sitting in the large non-interactive lectures with a lecturer who is statistically unapproachable even when personally approachable. The format of large lecture, smaller recitation, and separate laboratory continues to be the dominant method of instruction at large institutions. The recitations are often taught by mixes of teaching assistants (TAs) and faculty, with that mix varying widely from university to university. In spite of the uneven quality found in recitations, it is likely that most learning of physics takes place in the recitation and problem-solving sessions. The laboratories are a more dismal case. Often taught by TAs who have minimal or no training, the laboratories are universally panned by the students. This negative perception, combined with the expensive resources required to run laboratories, has motivated several larger universities to abandon lab sessions altogether. Tobias has written one of the best chronicles of student reactions to the usual introductory course.<sup>1</sup>

Recognizing the shortcomings of the current system, faculty and staff at many universities have devoted extraordinary attention to improvements. Each meeting of the American Association of Physics Teachers is filled with ideas on how to invigorate the lecture, ranging from the spectacular to the humorous. Faculty, students, and even the general public love and remember the best demonstrations and best demonstrators. Over the years we have turned to audio, video, and now computers to make the lectures more interesting and instructive. Unfortunately, later interviews with students often reveal that the memory of the demonstration is often not accompanied by an understanding of the physics of that demonstration.

Many efforts to improve the introductory course start from an assumption that there are “good lecturers” and “bad lecturers,” and that students can learn more from the good lecturers. The strategy then is to improve the bad or replace it with the good. Indeed, many applications of technology are efforts to improve or replace the lecturer with electronic forms of lecture. Some institutions replace the traditional pre-laboratory lecture with videotapes of good lecturers who can articulate in clear English the goals and procedures for the laboratories. Others (including this author) have created computer-based pre-laboratories<sup>2</sup> toward the same end. With the creation of the “Mechanical Universe,” this approach of using technology to replace the lecturer may have reached its highest form.

These are all worthy efforts toward noble goals, and many students have undoubtedly benefited, but perhaps it is time to do a more serious re-examination of our assumptions and approaches. Over the last few decades, evidence for needed change has been pouring in from those doing research in science education, but it seems to have had little effect. Those who defend the status quo in the large universities often advance three rationales.

## Rationales for the Status quo

The first is: “Lectures can be an educationally effective method of teaching.” Readers of *The Physics Teacher*, the *American Journal of Physics*, the *Journal of College Science Teaching*, or any of the educational research journals know that the evidence is overwhelming against this contention. Unfortunately, few faculty at large research universities read such material. As a start in their re-education, I often provide faculty with a series of four articles to read. I begin with David Hestenes’ (Arizona State University) article on “The Initial Knowledge State of College Physics Students,”<sup>3</sup> which provides a well-thought-out approach to testing student learning and the dismal results of doing so. Students are learning far less than expected. The second article, “The Force Concept Inventory,”<sup>4</sup> follows the first and expands the result to many other universities. Ron Thornton’s (Tufts) article,<sup>5</sup> “Learning Physical Concepts with Real Time Laboratory Measurement Tools,” is particularly interesting because compares more interactive methods using microcomputer based laboratories (MBLs) with traditional lecture approaches and shows that the interactive methods can reduce student error rates spectacularly. The fourth article chronicles Eric Mazur’s (Harvard) work from the beginning when he felt that his students were really learning in his lectures. His application of the Hestenes test to his classes led Mazur to develop innovative interactive techniques for use with large enrollment courses.<sup>6</sup>

This is a very small subset of the material that might be read, but it provides a nice conceptual development of the discovery and application of ideas in research in science education and does so in the context of the large research universities.

The second rationale is that “*Although the lecture is usually ineffective, outstanding lecturers can turn the lecture into an effective learning environment.*” The articles just cited and many others provide both statistical and anecdotal evidence to contradict this statement. Mazur’s article provides an honest personal anecdote illustrating the statistical evidence amassed by Hestenes,<sup>3</sup> Laws,<sup>10</sup> Sokoloff,<sup>7</sup> and Thornton.<sup>5</sup> Certainly there are significant differences in the affective domain showing that students enjoy the course more, appreciate the subject, and come away with improved attitudes to the discipline. This can probably be linked to student retention and recruitment of majors, and perhaps even to increased learning through other areas of the course such as reading, problem solving, and laboratories. Providing good lectures is obviously superior to providing poor lectures, but still does not lead directly to increased learning.

A standard counter-argument is that “lectures must work, because students have been learning that way for centuries.” The problem with this approach is that it neglects to take into account the many other ways that students learn. Frequently it is also based upon a generalization from the speaker’s own experiences, which are (by definition) atypical.

The third rationale is often the last bastion of defense against change. “*The traditional course is the most cost-effective way to educate hundreds or thousands of students per semester.*” I confess to believing this myself until I was coerced into doing a detailed cost analysis for our introductory courses. Our introductory courses in physics, calculus, and chemistry, each educate 600 to 1000 students per

semester. The traditional approach until recently was to divide the courses into two lecture sections with 300 to 500 students each, and then subdivide further into about 25 to 30 recitation sections of fewer than 30 students, and 30 to 40 labs of fewer than 25 each. The lectures are team-taught by two or more faculty; the labs are taught by TAs, and the recitations use a mix of faculty and TAs. The mix varies from discipline to discipline, with physics about evenly divided between faculty and TAs. We have two laboratory support staff and one lecture demonstration support person. After compiling the actual cost for all this in 1993, I was surprised to see just how expensive it was. We were able to identify several alternatives that were economically competitive and promised far better educational effectiveness.

## Designing an Alternative

In the spring semester of 1993, we convened a meeting of national experts on course innovation drawn from the three disciplines. Among these were Priscilla Laws (primary architect for Workshop Physics), Bill Graves (Director of the Institute for Academic Technology), and Joe Lagowski (Editor of the *Journal of Chemical Education*). We invited six architects who had gained national attention for their innovative designs for educational facilities. To complete the mix we added representatives from Perkin Elmer, General Electric, IBM, United Technologies, and Boeing. With such a diverse group we thought that we might be able to get a variety of perspectives on the issues, but despaired at reaching any kind of a consensus. We were wrong.

Indeed there were a variety of perspectives introduced by the participants, but there were also strong areas of consensus. Among these was the need to reduce the emphasis on the lecture, to improve the relationship between the course and laboratory, to scale up the amount of doing while scaling back the watching, to include team and cooperative learning experiences, to integrate rather than overlay technology into all of the courses, and above all to do so while reducing costs!

## Course Structure

The meeting of experts led us to a course design that was a natural combination and extension of the CUPLE system,<sup>8</sup> the M.U.P.P.E.T. materials,<sup>9</sup> the Workshop Physics program,<sup>10</sup> and use of cooperative group-learning techniques.<sup>11</sup> The approximately 700 students enrolled in the large lectures would be divided into 12 sections of 50 to 60 persons each. The course was reduced from six contact hours (two lecture, two recitation, and two lab) to four contact hours and taught either in two 2-hour periods or two 1.5-hour plus one 1-hour period. The reduction from six to four contact hours is an important aspect of stewardship of faculty resources. Each course is led by a team of one faculty member, one graduate student, and one or two undergraduates. The mentoring of graduate students and undergraduate students is an important side effect of the redesigned course structure.

The re-engineering of the course led directly to a redesigning of facilities. Now we have one classroom that accommodates 64 students and a second for about 50

students, both in a comfortable workshop setting. There are 6-ft worktables, each designed for two students, with open workspace and a computer workstation. Often the tables also contain the equipment for the day's hands-on lab. The tables form three concentric partial ovals with an opening at the front of the room for the teacher's worktable and a projection screen. The workstations are arranged so that when students are working together on an assigned problem, they turn away from the center of the room and focus on their own small group workspace. The instructor is able to see all workstation screens from the center of the oval, and thereby receives direct feedback on how things are going for the students.

In the physics course, the workstations run the CUPLE system, have full access to networked multimedia, and include an MBL system for data acquisition, analysis, and visualization. When the instructor wants to conduct a discussion or give a mini-lecture, the students turn toward the center of the room. This removes the distraction of having a functioning workstation directly in front of the student during discussion or lecture, yielding a classroom in which multiple foci are possible. Students can work together as teams of two, or two teams may work together to form a small group of four. Discussion and interaction are facilitated by the semi-circular arrangement of student chairs. All students have a clear view of both the instructor and projected materials. This "studio" approach is friendly even to those instructors who lean toward the traditional teacher-centered rather than student-centered classroom.

As a facility in which the instructor acts more as a mentor/guide/advisor, such a "theater-in-the-round" classroom is unequaled. Rather than separating the functions of lecture, recitation, and laboratory, the instructor can move freely from lecture mode into discussion, assign a computer activity, ask the students to discuss their results with their neighbors, or ask them to describe the result to the class. Laboratory simply integrates with classroom activities. This course uses the latest in computing tools and incorporates use of cooperative learning approaches. We have created a powerful link between the lecture materials, the problem solving, and the hands-on laboratories. This is a link that is tenuous at best in the traditional course. Research faculty who taught in pilot courses report that the studio approach reminds them far more of an undergraduate research setting than it does of the large-enrollment lecture classes.

## A Typical Course Day

Usually our students come to class with a homework assignment of three to six problems to turn in. They almost always have questions about the assignment and, since it is collected and graded, most have actually attempted the problems. The first 20 minutes or so is like a recitation. As we go over questions about the problems, we often call on students to present their solutions; other students then comment on the problem.

Next we present a topic with a five-minute discussion followed by a laboratory on that topic. For example, we set up a video camera and have a student throw a ball. The video is directly digitized into the computer and available over the network to each work area. Students then analyze the motion using the CUPLE digital video tool and create a spreadsheet containing the position-versus-time

data. The analysis proceeds in the usual fashion, resulting in graphs of position versus time, velocity versus time, and acceleration versus time for each component. Final laboratory reports remain in electronic format, although we often have our students record observations on a written worksheet.

Other laboratories are performed entirely at each work area. When we introduce Newton's second law, the students calibrate a force probe and then hang a spring and mass from the probe with an ultrasonic range finder under the mass to measure the position. Figure 2 shows the actual data with a graph of distance versus time, force versus time, and force versus distance. From this the students can calculate the acceleration versus time and compare the force divided by the mass.

You may notice that this experiment foreshadows the introduction of Hooke's law and the topic of oscillations, both of which come later in the course. There are questions on the worksheet that ask the students to observe and comment upon each of these phenomena, but we do not attempt to name them or introduce theory at this time. We take this approach with most concepts.

In both examples given here, the laboratory data acquisition and analysis tools are embedded in a hypermedia text that introduces the topic, links the students to related materials, and poses questions for the students to answer with the tools. These hypermedia activities are being created by the CUPLE consortium of schools led by Rensselaer and the University of Maryland. Funding has come from the Annenberg/Corporation for Public Broadcasting, the IBM Corporation, and the National Science Foundation. Most of these materials were created by teams of faculty and students working together. Student involvement has added a fresh approach to much of the materials, a quality appreciated by the students taking the course.

Figure 3 shows a page from the first laboratory on work. This is the summary page for the experiment that is covered in more detail in later pages. In the earliest experiments, the lab is explained in some detail, whereas in later experiments the student is expected to provide most of the experimental design.

Notice that the student has access to the full range of CUPLE facilities during the session. She may annotate the book with marginalia by pressing the yellow "Post-It" note button. This allows her to insert yellow typed notes or freehand scrawls across the pages. The GL button brings up a large glossary of physics terms, some of which came from a glossary developed by Gordon Aubrecht. The Swiss army knife launches the CUPLE toolbox that allows the student to use MAPLE, Excel, the CUPLE mathematical function tools, or any of a variety of references. References include an electronic periodic table, the String and Sticky Tape low-cost experiments, *the Lecture Demonstration Handbook*, and even access to all of the materials in the Physics InfoMall<sup>12</sup> (purchased separately).

The Window on Physics (WinPhys) object-oriented modeling system provides both a collection of models and materials for constructing an individual's own models and simulations. The object-oriented nature of the WinPhys system provides for all functions to inherit certain behaviors, among them the ability to differentiate or integrate themselves.

Figure 4 shows the graph of the  $\sin(x)/x$  function with the integral displayed both graphically and numerically. The ability to read out, differentiate, integrate, and take the Fourier transform is useful to the student in both laboratory and problem solving. Of course the early laboratories have the student calculate this explicitly, just to assure that they understand the process.

As you can see from the experiment illustrated in Fig. 2, hands-on activities are an integral part of the CUPLE Physics Studio. In fact there are more than twice as many hands-on laboratories than in the traditional course. Each activity is shorter than the traditional laboratory, but it is tightly integrated with both homework and class discussion. The laboratory portion of the class ranges from 20 to 40 minutes and is often combined with a computational activity.

Lab activities fall into three major categories: microcomputer-based laboratories as previously described, video laboratories, and modeling and simulation projects. The video laboratories allow students to take live video of an event (from a handi-cam) directly into their computer and then play that event back as video on their computer screen. They bring up a graphical overlay on the screen and place points on the graph directly over the object as it moves. Those of us old enough to have done this with spark marks on waxed tape or with a Polaroid camera will recognize that this is conceptually quite similar and leads to the same kinds of data analysis that we performed. On the other hand, the relationship between the marks and the moving object is far more obvious to the student than it was in the earlier cases. Since we use pretty much the same equipment each week, set up for this lab is limited to bringing in the handi-cam plugging it into the network. This is also far less cumbersome and less expensive than the specialized equipment that we used to do the spark tapes or strobed Polaroid pictures.

The class ends with a discussion of the material assigned for the next class. At this time we often call attention to the “foreshadowing” that has occurred in the problem-solving session and laboratories and pull this together to introduce the next topic.

## Conclusion

Our experiences thus far with the CUPLE Physics Studio have been very encouraging. Students have been quite enthusiastic about the course, as measured by the responses on the end-of-semester surveys. Nearly twice as many students agree that they enjoyed the studio courses as compared to the traditional lecture/recitation/lab format.

The studio mathematics course was the first of the freshman courses to be conducted and has been through one complete cycle of evaluation. The physics course is one semester behind. One question on an external survey conducted by the dean of the undergraduate school last semester stirred quite a bit of interest among administrators and faculty. When students were asked whether they would cite this particular course as “a positive reason to attend Rensselaer,” 93% agreed! This compares with 63% who agreed with this proposition in the other mathematics courses that had been downsized but did not abandon the traditional lecture approach. When student responses were controlled for popularity of the

teacher and course, there were significant (actually spectacular) gains in student satisfaction.

Our initial experiences indicate that faculty are rated far higher in the teaching evaluations in the studio courses, but we want to collect data over a longer period of time to be sure that this is not due to a Hawthorne effect. Teaching evaluations are a significant issue at institutions such as Rensselaer where student evaluations and research results play equally major roles in salary promotion, and tenure decisions. More and more large research universities are revamping promotion and tenure criteria to re-emphasize the teaching aspects of the professor's role; this trend is expected to continue and even accelerate in the next few years.

Students in these courses are performing as well or better than students in the traditional courses in spite of the one-third reduction in class contact time. This was demonstrated by student performance on tests matched in difficulty, length, and content to tests from previous years and those given this year in the traditional course. In both mathematics and physics, more topics were covered in studio courses than in the lecture courses.

Next year we intend to use the Hestenes test in both studio and traditional courses to compare these students with one another, and also to compare with results obtained at universities using various instructional situations, including MBLs and Workshop Physics. We will also follow the progress of students from the studio courses as they enter upper-level courses in physics and engineering to compete with those from the traditional sections. We recognize just how difficult it will be to measure and document these changes and also just how challenging it will be to convince the physics community to consider restructuring these courses. The preliminary results are so encouraging that we are beginning to be optimistic.

## Notes

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<sup>1</sup> S. Tobias, *They're not Dumb, They're Different* (Research Corporation, Tucson, AZ, 1990).

<sup>2</sup> J.M. Wilson, "Experimental simulation in the modern physics laboratory," *Am. J. Phys.* **48**, 701 (1980).

<sup>3</sup> I. Halloun and D. Hestenes, "The initial knowledge state of college physics students," *Am J. Phys.* **53**, 1043 (1985).

<sup>4</sup> D. Hestenes, M. Wells, and G. Swackhamer, "Force concept inventory," *Phys. Teach.* **30**, 141 (1992).

<sup>5</sup> R. Thornton, "Learning physical concepts with real-time laboratory measurement tools," *Am. J. Phys.* **58**, 858 (1990).

<sup>6</sup> E. Mazur, "Understanding or memorization: Are we teaching the right thing?" *Proc. Resnick Conf. on Intro. Course* (At press).

<sup>7</sup> D. Sokoloff, "Engaging students with interactive microcomputer based demonstrations," *AAPT Announcer* **24** (2), 92 (1994).

<sup>8</sup> J.M. Wilson, E.F. Redish, and C.K. McDaniel, "The comprehensive unified physics learning environment: Part I. Background and system operation," *Comput. Phys.* **6** (2), 202 (March/April 1992); "The comprehensive unified

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physics learning environment: Part II. The basis for integrated studies,” *Comput. Phys.* **6** (3), 282 (May/June 1992).

<sup>9</sup> W.M. MacDonald, E.F. Redish, and J.M. Wilson, “The M.U.P.P.E.T. Manifesto,” *Comput. Phys.* **1** (1), 23 (July/August 1988).

<sup>10</sup> Priscilla Laws, “Workshop Physics: Learning introductory physics by doing it,” *Change Mag.*, 20 (July/August 1991).

<sup>11</sup> Phillip Uri Treisman, “Teaching mathematics to a changing population,” Report of the Professional Development Program at the University of California, Berkeley (1990); “Mathematics achievement among African American undergraduates at the University of California, Berkeley: An evaluation of the mathematics workshop program,” *J. Negro Educ.* **59** (3), 31 (1990).

<sup>12</sup> R. Fuller and D. Zollman, Physics InfoMall. Information is available from R. Fuller, Department of Physics, University of Nebraska, 109 Ferguson Hall, Lincoln, NE 68588-0111.