CHAPTER 9

Workshop and Studio Methods

I had become thoroughly disillusioned
by the ineffectiveness of the large general lecture courses
of which I had seen so much in Europe and also in Columbia,
and felt that a collegiate course in which laboratory problems
and assigned quiz problems carried the thread of the course
could be made to yield much better training, at least in physics.
I started with the idea of making the whole course self-contained . . .
I abolished the general lectures.
This general method of teaching . . . has been followed
in all the courses with which I have been in any way connected since.
Robert A. Millikan [Millikan 1950]

The Millikan quote in the epigraph shows that dissatisfaction with traditional lectures is not a new story. Although Millikan's Autobiography, from which the quote is taken, was published in 1950, the course he is describing was introduced in the first decade of the twentieth century. Many physicists, myself included, have the strong intuition that the empirical component in physics is a critical element and one that introductory students often fail to appreciate. This failure may occur in part because traditional lectures tend to be a series of didactic statements of "discovered truth" followed by complex mathematical derivations. An occasional ex-post-facto demonstration or laboratory experiment "to demonstrate the truth of the theoretical result presented in lecture" does little to help the student understand the fundamental grounding and development of physical ideas and principles in careful observation.

There are clearly many possible ways of remedying this oversight. Lectures could begin with the phenomena and build up the concepts as part of a need to describe a set of phenomena. Laws could be built from observed systematics in the behavior of physical systems. Laboratories could be of the guided discovery type and could introduce the material before lecture.

But perhaps the most dramatic modification of an introductory physics course is to adopt Millikan's method, in which "laboratory problems and assigned quiz problems carried the thread of the course." In the modern era, this approach has been developed under the rubric of *workshop* or *studio* courses, courses in which lecture plays a small (or nonexistent) role. All the class hours are combined into blocks of time in which the students work with laboratory equipment for most of the period.

Perhaps the first modern incarnation of this approach is *Physics by Inquiry* (PbI), a course for pre- and in-service teachers developed by Lillian McDermott and her collaborators at the University of Washington over the past 25 years [McDermott 1996]. In this class, there are no lectures at all. Students work through building the ideas of topics in physics using carefully guided laboratory manuals and simple equipment. Although PbI is explicitly designed for pre-service teachers and other nonscience majors, it is deep and rich enough that many of the lessons provide valuable ideas for the development of lessons even for calculus-based physics.

The PbI method was adapted for calculus-based physics in the late 1980s by Priscilla Laws of Dickinson College under the name *Workshop Physics* (WP). Since problem solving and developing quantitative experimental skills are goals not shared by the pre-service teacher class, Laws expanded McDermott's vision to include substantial components of modern computer-based laboratory tools, including computer-assisted data acquisition and data acquisition from video. (She and her collaborators developed many of these tools themselves.)

As set up at Dickinson, Workshop Physics runs in classes of 25 to 30 students. This is possible at a small liberal arts college like Dickinson where few students take introductory calculus-based physics.[1] Research-based institutions with engineering schools might have as many as 1000 students taking calculus-based physics in any particular term. Two attempts to bring something like WP to environments with large numbers of students occurred in the 1990s at Rensselaer Polytechnic Institute (*Studio Physics*) [Wilson 1992] [Wilson 1994] and North Carolina State University (*SCALE-UP*). The latter is described as a case study in chapter 10.

PHYSICS BY INQUIRY

Environment: Workshop.

Staff: One trained facilitator per 10–15 students.[2]

Population: Pre- and in-service K-12 teachers; underprepared students; nonscience majors.

Computers: Limited use.

Other Equipment: An extensive list of traditional laboratory equipment.

Time investment: Large.

Available Materials: A two-volume activity guide [McDermott 1996]. The Washington group runs a summer workshop to help interested instructors learn the approach.[3]

[1] Though the numbers grew substantially after the introduction of WP requiring the creation of multiple sections.

[2] In a remarkable experiment, the course has been taught with reasonable success using a single experienced instructor for 70 students [Scherr 2003].

[3] A video (*Physics by Inquiry: A Video Resource*) is available that provides illustrative examples of the materials being used. Contact the UWPEG for information.

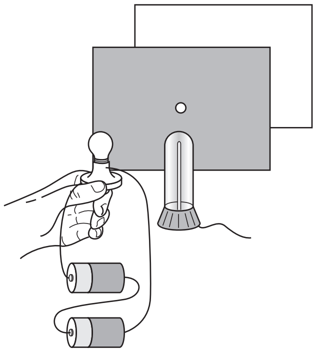


Figure 9.1 A simple apparatus from Physics by Inquiry.

One of the earlier modern prototypes of a full studio course was *Physics by Inquiry* (PbI), developed by Lillian McDermott and her colleagues at the University of Washington [McDermott 1996]. The course was developed for students studying to be teachers (*preservice teachers* in the American terminology) and is a full guided-discovery laboratory. There is no lecture; students meet for three laboratory periods of two hours each per week. During these periods, students work in pairs with simple equipment and are guided to reason through physical examples with simple apparatus and carefully prepared worksheets. A sample apparatus for the unit on light is shown in Figure 9.1.

In PbI, students learn a few topics deeply

An assumption built into the material is that it is more important for the students to learn a few topics deeply and to build a sense of how the methods of science lead to "sense-making" about the physical world than to cover a large number of topics superficially. The materials emphasize specific concepts and specific elements of scientific reasoning such as control of variables and the use of multiple representations. The material is structured into independent modules (see Table 9.1), so a one- or multisemester term can be built by selecting two to three units per term. This has the advantage that if one permutes the choice of modules in successive years, in-service teachers can return to take the class in multiple terms without repeating material.

The worksheets are based on research in student understanding[4] and often use the cognitive conflict model in the *elicit/confront/resolve* form described in the discussion of Tutorials in chapter 8. The worksheets guide the students through observing physical phenomena, constructing hypotheses to explain the phenomena, and the testing of those hypotheses in new experiments. Trained facilitators (approximately one for every 10 to 15 students) help students to find their own path to understanding by guiding them with carefully chosen questions. Specific places are indicated in the lessons called *checkouts*. Students are instructed to check their results with a facilitator at this point before going on.

[4]Surprisingly, the Washington group has published very little of their research that has gone into the construction of Physics by Inquiry. Much of the group's published work on Tutorials (see references in [McDermott 1999] contained in the Appendix) on qualitative reasoning carries implications for PbI, despite the difference in populations.

TABLE 9.1 Modules in Physics by Inquiry

Volume I	Volume II
• Properties of Matter	• Electric Circuits
• Heat and Temperature	• Electromagnets
• Light and Color	• Light and Optics
• Magnets	• Kinematics
• Astronomy by Sight: The Sun, Moon, and Stars	• Astronomy by Sight: The Earth and the Solar System

During my sabbatical at the University of Washington (1992–1993), I participated in facilitating PbI classes. I was particularly impressed by the activity in the Astronomy module in which students made their own observations of the phase of the Moon and its position relative to the Sun over the entire term. Near the end of the term, the class's data were collected and discussed, and a model for how the Moon was lit was developed. Many students were surprised that they could see the Moon in the daytime, and many believed that the phases were caused by the Earth's shadow—a belief they could not sustain in light of the evidence. I myself realized for the first time that I could tell directions from the phase and position of the Moon, even after sunset.

Students may need help in changing their expectations for PbI

Physics by Inquiry is quite challenging for many students (even physics graduate students), as the goals, the structure of the learning environment, and the activities expected of the student differ dramatically from those they have learned to expect in traditional science classes. Some students at first resent the idea that they are not being given answers to memorize but that they have to work them out for themselves and have to understand how the laws and principles are supported by experiment. Students can exert considerable pressure on an instructor to change this. Careful facilitation is needed throughout the course to help students pay attention to what they are supposed to be doing—thinking, reasoning, and making sense of what they see in a coherent and consistent fashion. The first few weeks of a PbI class can be quite tumultuous, but it is worth riding out the storm. The Washington group offers both extended summer workshops in Seattle and short workshops at meetings of the American Association of Physics Teachers to help would-be PbI-ers learn the ropes.

Evaluations of PbI show it to be very effective

Although there is not a large body of published literature on the success of PbI, the observations of a few researchers on secondary implementations of PbI are worth mentioning.

In a recent paper, Lillian McDermott and her colleagues reported on a secondary implementation of PbI for pre-service elementary school teachers at the University of Cyprus [McDermott 2000].[5] They evaluated the performance of students on direct current circuits

[5] The classes that used PbI used it in Greek translation.

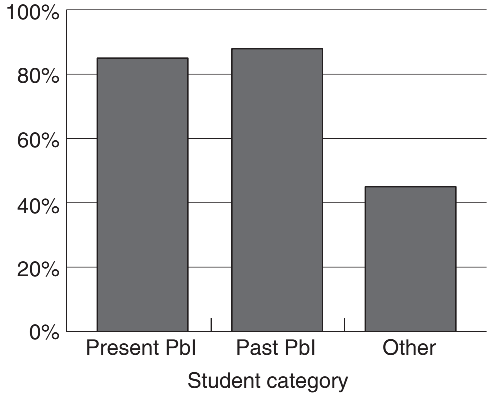


Figure 9.2 Post-test results on the DIRECT concept survey given to students at the University of Cyprus recently completing PbI, completing PbI in the previous year, and recently completing a more traditional constructivist physics course for teachers [McDermott 2000].

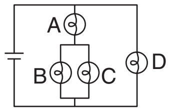
using the DIRECT conceptual test of understanding of DC circuits. (The DIRECT survey is on the Resource CD associated with this volume.) Three groups of students were compared: 102 students who had just completed the electric circuits module of the PbI course; a group of 102 students who completed the module in the previous year; and a group of 101 students who had just completed the topic in a course using constructivist pedagogy but not using the findings of discipline-based research or the research-redevelopment cycle. (See Figure 6.1.) The results are shown in Figure 9.2.

Beth Thacker and her colleagues at the Ohio State University compared student success on a qualitative circuits problem in her secondary implementation of a PbI class with the same pair of problems given to engineering physics students, students in an honors physics class, and a traditional physics class for nonscience majors [Thacker 1994]. One problem they referred to as a synthesis problem. It required only qualitative reasoning. (See Figure 9.3.) A second problem they referred to as an analysis problem. It required quantitative (algebraic, not numeric) reasoning. (See Figure 9.4.) The instructor in the engineering class thought that the problem was exactly appropriate for his students and that they should have little difficulty with it. The instructor in the honors physics class thought the problem was too easy but was willing to give it as extra credit.

The PbI students scored significantly better than either of the other groups on the synthesis (qualitative) problem and significantly better than the engineers on the analysis problem. (See Figure 9.5.) Note that an answer was not considered to be correct unless the student gave an explanation that included a reason. A restatement of the result (e.g., "Bulb D is unaffected.") was not considered sufficient.

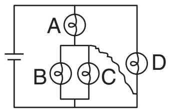
A preliminary study of the Ohio State PbI students using the MPEX showed significant gains on the concept variable [May 2000].

(Synthesis A). All of the bulbs in the figures below have the same resistance R. If bulb B is removed from the circuit, what happens to the current through (brightness of) bulb A, bulb D and the battery? Indicate whether it increases, decreases, or remains the same. Explain your reasoning.



(a)

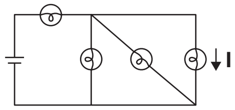
(Synthesis B). A wire is added to the circuit in the figure below. What happens to the current through (brightness of) bulb A, bulb D and the battery? Indicate whether it increases, decreases, or remains the same. Explain your reasoning.



(b)

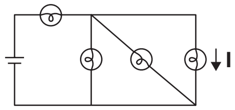
Figure 9.3 A qualitative reasoning (synthesis) circuits problem given to test Physics by Inquiry students [Thacker 1994].

(Analysis A) What is the total resistance of the network shown in the figure below? (All of the bulbs have the same resistance.) Show your work.



(a)

(Analysis B) What is the current through (brightness of) each bulb and through the battery? (All of the bulbs have resistance R and the current through the bulb on the right is I as indicated.) Show your work.



(b)

Figure 9.4 A quantitative reasoning (analysis) circuits problem given to test Physics by Inquiry students [Thacker 1994].

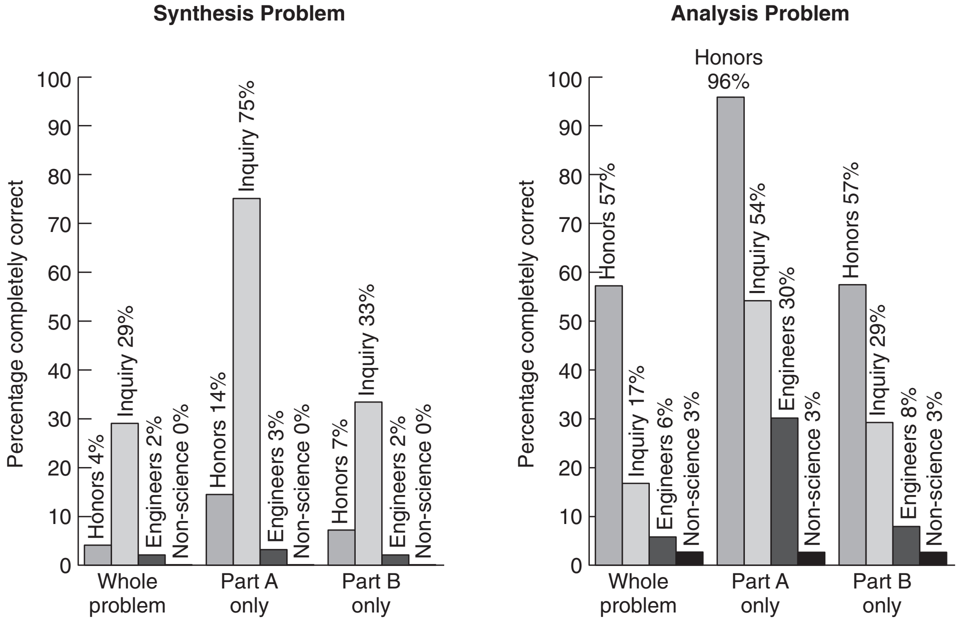


Figure 9.5 Results on the electric circuit synthesis and analysis problems given to honors physics, PbI, engineering physics, and physics for nonscience classes [Thacker 1994].

WORKSHOP PHYSICS

Environment: Workshop.

Staff: One trained facilitator per 15 students.

Population: Introductory calculus-based physics students.

Computers: One for every two students.

Other Equipment: Computer-assisted data acquisition devices (ADCs) and probes, spreadsheet software, *Videopoint*™ (video data analysis tools), standard laboratory equipment.

Time investment: Large.

Available Materials: An activity guide [Laws 1999]. Extensive sets of homework problems and other resources are available at the WP website: http://physics.dickinson.edu/ A listserve promotes discussions among WP users.

The Workshop Physics (WP) class was developed by Priscilla Laws and her collaborators at Dickinson College [Laws 1991] [Laws 1999] using the research-redevelopment cycle discussed in chapter 6. In the mid-1980s, Laws became deeply involved in the use of the computer in the laboratory, developing laboratory tools for working with Atari computers. In the late

1980s, Laws and Ron Thornton of Tufts University, working with a number of fine young programmers, developed a "stable platform" for microcomputer-based laboratory activities. The Universal Laboratory Interface box (ULI) is an analog-to-digital converter.[6] One end connects to the computer's serial port and the other to a "shoebox full" of probes—motion detectors, force probes, temperature sensors, pressure gauges, voltage probes, and so on. (The ADCs from Vernier and Pasco are shown in Figure 8.10. The Vernier motion detector is shown in Figure 8.11.) Software, available for both Wintel and Mac environments, allows the students to display graphs of any measured variables against any others, to fit the graphs with various mathematical functions, to read values off the curves, to integrate the curves between chosen limits, and so on. Spreadsheets (and perhaps symbol manipulators) provide the students with tools for mathematical modeling of their experimental results.

Students in WP build their concepts using technology

What it is the students actually do in this class is hinted at by the structure of the classroom, shown in Figure 6.4. The students function in groups as in the inquiry-style classroom, each pair working with a computer workstation with the computer-assisted data collection structure and modeling tools described above. Classes are held in three two-hour periods per week. During these classes, most of the student time is spent with apparatus—making observations and building mathematical models of their results. The classroom contains a central area for common demonstrations, and many class periods may include brief lecture segments or whole-class discussions.

Students are guided through the process of carrying out, making sense of, and modeling their experiments with worksheets contained in an Activity Guide [Laws 1999]. In addition to the Activity Guide, students are assigned reading in a text and homework problems. Although the homework may include traditional end-of-chapter problems, the WP group has developed a series of context-rich problems, many of which use video or other computer-collected data. An example is given in Figure 9.7.

Figure 9.6 Computer-assisted data-acquisition setup showing, from right to left, computer, Vernier ULI and motion detector, PASCO cart on track.

[6]The design of this box was based on previous devices developed by Bob Tinker and his colleagues at TERC.

In the early spring of 1995, the quarterly Radcliffe College Alumnae magazine featured a cover story of working women in the 1990s. The unusual cover depicts a young woman pushing up on a glass ceiling. Assume that she is not moving. Give three reasons why the woman's position in this photo is impossible. What physical laws or principles are being violated? How do you think this photograph might have been made?

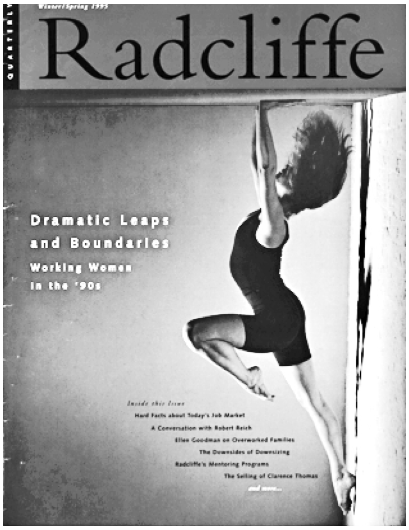


Figure 9.7 A sample of a context-rich Workshop Physics problem.

WP is developed through and informed by education research

Although the Dickinson group focuses on development rather than on basic educational research, the development of the Workshop Physics materials relies heavily on published physics education research and on careful local observations using the research-redevelopment cycle. An excellent example of how this works is given on the WP web pages. Upon reading the research papers on student difficulty with direct current circuits published by McDermott and Shaffer [McDermott 1992] [Shaffer 1992], Laws began modifying her WP materials on the subject. She evaluated students' conceptual learning on the topic using the ECCE developed by Sokoloff and Thornton and included on the Resource CD associated with this volume. She compared her results with those obtained by Sokoloff at the University of Oregon after students received traditional lectures on the topic. Pre-tests at both Dickinson and Oregon showed that students entered the class with little knowledge of the subject, missing about 70% of the questions. Lectures helped little, reducing the error rates to about 65%. Students in Workshop Physics did substantially better, attaining average error rates of as low as 40%. However, after reading the McDermott-Shaffer papers, Laws redesigned the WP activities. The results were a substantial improvement, with error rates falling to less than 10%. These results are shown in Figure 9.8. Similar results are displayed on the WP website http://www.physics.dickinson.edu for topics in kinematics, dynamics, and thermodynamics.

WP changes the frame in which students work

Implementing Workshop Physics can be a nontrivial activity as the workshop-style class may violate a number of student expectations. Students who come to a physics class expecting a

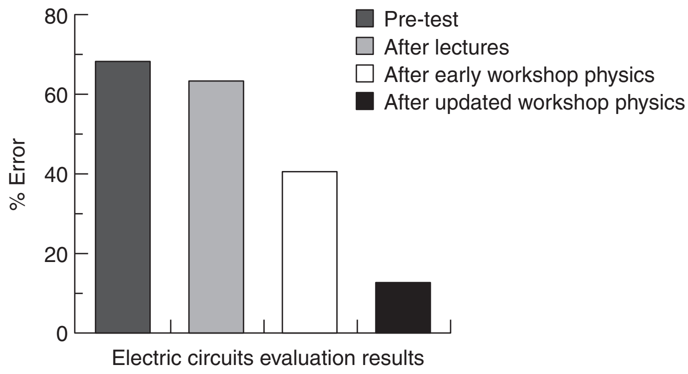


Figure 9.8 Error rates on the ECCE after traditional lecture (University of Oregon) and after Workshop Physics, before and after research-based modifications.

lecture and lots of plug-and-chug homework problems may be dismayed by the amount of thinking involved. Students who have had high school physics may expect their physics to be math-dominated rather than experiment-dominated. And students who are unaccustomed to group work may have trouble interacting appropriately.

Workshop Physics is an attempt to seriously change the framework of learning to have students focus more strongly on understanding and on the experimental basis of the physics. Getting students to understand not just the physics but how to make this shift of mental frame can be difficult. Implementing a course like Workshop Physics effectively requires that the instructor be sensitive to all these complex issues and be aware of the need to renegotiate the instructor–student social contract.

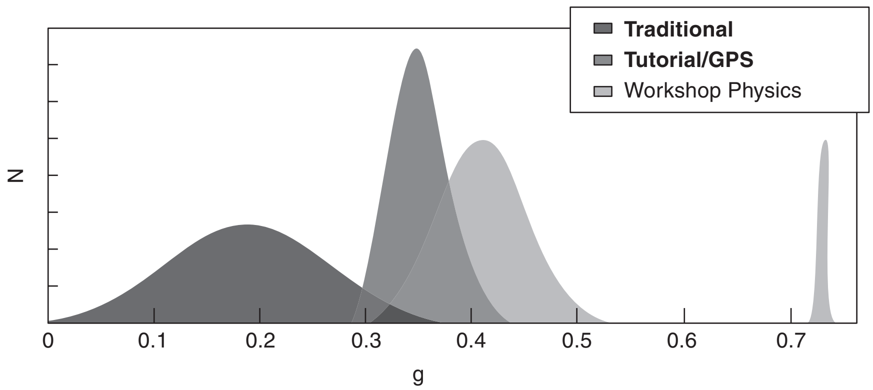


Figure 9.9 Distribution of fractional gains on pre-post FCI and FMCE for traditional, recitation modifications (Tutorial and CGPS), and Workshop Physics. The histograms for each group are fit with a normalized Gaussian. The spike at the right corresponds to WP at Dickinson College.

Evaluations of WP show it to be highly effective in building concepts

Jeff Saul and I carried out an independent evaluation of student learning in Workshop Physics as part of the WP dissemination project (supported by FIPSE) [Saul 1997]. Our study included seven colleges and universities implementing Workshop Physics for the first or second time. Student learning was evaluated with pre-post FCI or FMCE, with common exam questions, and through interviews with 27 student volunteers at three of the dissemination schools. Student expectations were measured with the MPEX.

The results from the pre-post FCI/FMCE are schematically shown in Figure 9.9. The secondary WP implementation averaged fractional gains of 0.41 ± 0.02 (SEM) compared to 0.20 ± 0.03 for the traditional classes and 0.34 ± 0.01 for the recitation modifications. (The mature primary implementation of WP at Dickinson College typically attains fractional gains on these tests of 0.74.)

MPEX averages in the traditional classes showed the pre-post deterioration described in chapter 5. The early secondary implementations showed no significant loss and occasional small gains on the reality link measure. WP at Dickinson College shows significant gains on the cognitive cluster of independence-coherence-concepts.