

Women's responses to an activity-based introductory physics program^{a)}

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It has been said that women ought to like science courses that are hands-on, collaborative, and afford a high degree of personal attention. In this article we examine this assumption by considering some women's responses to Workshop Physics—a calculus-based introductory course sequence in which lectures are abandoned in favor of activity-based collaborative work enhanced by the use of integrated computer tools. Early in the development of the Workshop curriculum an attitude survey revealed that pre-medical junior and senior women were more negative about their experience than either their male counterparts or freshmen and sophomore students. We explored reasons for this phenomenon by interviewing a group of women who had enrolled in Workshop Physics courses.

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I'd like my students to learn how to learn, to be involved in the process of teaching themselves. And to make commitments—not to be in love with the position, but to be in love with the search, so that if they find themselves not able to hold a position, if it turns out to be untenable, then they should have enough courage to say, "You know what I said last week? I no longer believe that."

Maya Angelou, 1993

I. INTRODUCTION

These are exciting times for physics educators. Ten years ago most physics instructors were largely unaware of the outcomes of research in physics education. Today, there are several curricula that have been developed on the basis of educational research, including Physics by Inquiry and Tutorials in Introductory Physics developed at the University of Washington,¹ Workshop Physics developed at Dickinson College,^{2,3} Tools for Scientific Thinking developed at Tufts University,⁴ and RealTime Physics developed at the University of Oregon.⁵ All of these curricula are activity based and emphasize scientific reasoning and the student's construction of conceptual models. These nontraditional curricula cultivate the development of scientific reasoning ability by engaging students in the process of making predictions and observations and then constructing qualitative models that can help them understand patterns in the observations. These reasoning processes are enhanced by discussions with peers, teaching assistants, and instructors.

One important issue in evaluating the efficacy of new activity-based introductory physics curricula is whether they have the potential to help us close the gap between the number of men and the number of women who choose to major in physics and/or study more science. In a recent study entitled *Women's Ways of Knowing*, Belinky *et al.* state that "Most of the women we interviewed were drawn to the sort of knowledge that emerges from firsthand observation....,"⁶ and that educators should "...stress collaboration over debate."⁷ Specifically, how might constructivist, activity-

based physics courses in which collaborative learning is emphasized affect the attitudes and achievement of women who take them?

Over 40% of the students who have enrolled in the calculus-based Workshop Physics courses at Dickinson College are women—a much larger percentage than is found in most calculus-based courses. Thus we have had an unusual opportunity to study the impact of activity-based courses on women. As part of our ongoing evaluation of the impact of the Workshop Physics curriculum, we asked several questions about the experiences of women in the courses taught at Dickinson College between 1989 and 1992. Are there significant gender differences in the student response to the Workshop Physics courses? Specifically, how do the women feel about scientific reasoning, collaborative work, and the intensive use of computer tools in the Workshop Physics courses? Do freshmen and sophomore women respond differently to the Workshop Physics courses than junior and senior women?

In the first part of this article we describe the design of the calculus-based Workshop Physics curriculum. Next we discuss the impact of these courses on student learning and attitudes. Finally we address questions pertaining to the experiences of the Dickinson College women enrolled in these courses.

II. THE WORKSHOP PHYSICS CURRICULUM

The Workshop Physics project at Dickinson College was designed to address major problems in the teaching and learning of introductory physics courses—the failure to deal effectively with students' profound misconceptions about physical phenomena, the cognitive overload that comes when too much material is covered, and the absence of contemporary computer tools for the construction and communication of scientific knowledge.^{8,9}

Since we believe that it is more important to learn basic scientific inquiry skills than to survey a large number of topics, Workshop Physics courses are therefore cooperative and activity-centered. Observations, direct experience, and the use of the computer help students build the physical

intuition needed to understand vital concepts. The shift to an emphasis on inquiry skills is based on the observation that the majority of introductory physics students do not have enough experience with everyday phenomena to relate concrete experience to scientific explanation. A second reason for emphasizing inquiry skills is that when one is confronted with the task of learning an expanding field of knowledge, the only viable strategy is to acquire independent investigation skills to be implemented as needed.

Although lectures and demonstrations are useful alternatives to reading for transmitting information and teaching specific skills, they do not help students learn how to reason, conduct scientific inquiry, or acquire direct experience with natural phenomena. Peers are often more helpful than instructors in facilitating original thinking and problem solving on the part of students. The time that is often spent passively listening to lectures would be better spent in direct inquiry in collaboration with peers. The role of the instructor is to shape a creative learning environment, lead discussions, and engage in dialogue with students. Computer spreadsheets are used along with sensors and special software for the student-directed collection, analysis, and graphical display of data. Students also use computers for problem solving and mathematical modeling. Since the 1987–88 academic year, all of the introductory physics courses at Dickinson College have been taught in a workshop format.

III. CURRICULAR MATERIALS AND COURSE ORGANIZATION

Students meet in three 2-h sessions each week. Each section has one instructor, two undergraduate teaching assistants, and up to twenty-four students. Each pair of students shares the use of a microcomputer and an extensive collection of scientific apparatus and other gadgets. Although students work in pairs at the computer, they collaborate in groups of four for laboratory observations and experiments. Among other things, students pitch baseballs, whack bowling balls with rubber hammers, break pine boards with their bare hands, build electronic circuits, and ignite paper by compressing air. The Workshop labs are open to students during evening and weekend hours.

The traditional content in the calculus-based courses has been reduced by about 25%. However, new topics in electronics and nonlinear dynamics have been introduced. The material has been broken up into units lasting about one week, and students use an Activity Guide that has expositions, questions, and instructions as well as blank spaces for student data, calculations, and reflections.¹⁰ The Activity Guide has been used with a number of traditional introductory physics textbooks and also without a text at Dickinson College and a number of other institutions. In our two-semester calculus-based course sequence at Dickinson College we complete 27 units spanning topics in mechanics, heat and temperature, and electricity and magnetism.

We often use a four-part learning sequence described by cognitive psychologist David Kolb.¹¹ Students usually begin a topic with an examination of their own preconceptions and then make qualitative observations. After some reflection and discussion, the instructor helps with the development of definitions and mathematical theories. The study of a topic typically ends with quantitative experimentation centered on verification of mathematical theories.

IV. STUDENT LEARNING AND ATTITUDES

Dickinson College is a private, residential four-year liberal arts college with a total enrollment of about 1900 students. From the fall semester of 1987 through the spring semester of 1999, over 450 students have taken the calculus-based Workshop Physics course sequence. About half of these students are freshmen and sophomores considering a major in mathematics, computer science, or one of the physical sciences. Typically, junior or senior students take physics to prepare for medical school or graduate work in chemistry or biology. These two subpopulations have different experiences and reasons for taking physics.

Numerous instruments have been used to assess the Workshop Physics program including: (1) conceptual learning examinations developed at other universities,^{12,13} (2) standard Dickinson course evaluation forms; (3) evaluation of the results of a multi-institution Introductory Physics Attitudes Questionnaire that we designed and administered in the fall of 1989 and the fall of 1990; (4) tracking of student performance on homework and problem sections of examinations; (5) interviews with a cross section of women who were taking or had completed calculus-based Workshop Physics courses; and (6) interviews with transfer students and some of our graduates who had completed the calculus-based Workshop Physics sequence. More recently we have also administered the Maryland University Expectations Survey (MPEX) to the Workshop Physics students.¹⁴

After Workshop Physics was introduced, more students mastered concepts that are considered difficult to teach because many students hold prior conceptions that differ from those of physicists. Students taking traditional courses usually cannot answer certain questions that physics teachers view as obvious. For example, pretests on mechanics concepts show that between 90% and 100% of our introductory physics students at Dickinson believe that just after its release there is a special upward force on a tossed coin. Physicists believe that the only force on the coin as it moves up and then down is the downward force due to the gravitational attraction of the Earth. Post-tests have shown that traditional instruction at Dickinson and elsewhere changes the notions of only about 15 of the students. However, about 80%–90% of the students can answer new questions based on the coin toss concept after taking Workshop Physics. Our studies at Dickinson have confirmed the findings of a number of physics education researchers. In general, a small percentage of students (0%–30%) answer questions that are counterintuitive correctly before the study of physics, and post-tests reveal that traditional instruction affects only 5%–10% of the students who answer these questions incorrectly on pretests. In Workshop Physics courses at Dickinson 50%–90% of the students answer these types of counterintuitive questions correctly on post-tests.

We also know by observation that students who complete Workshop Physics are very comfortable working in a laboratory setting and working with computers. Visitors from other institutions who visit our classrooms during the second semester of our two-semester sequence often note this competency with the tools of exploration and analysis. In order to obtain a comparative evaluation of the impact of the Workshop Physics teaching methods on students, we developed a survey on student attitudes toward various learning experiences in the fall of 1989. This survey was administered in December 1989 to almost 400 students at 8 colleges and universities, and again in December 1990 to more than 2800

students at 14 institutions including Dickinson. Using a 5-point Likert scale, the questionnaire asks students to rate the value of various learning experiences such as textbook reading, attending lectures, using the computer, etc.; to rate self-reported gains in skill level and knowledge; and to make a comparison of attitudes toward the physical sciences as well as computers before and after having taken the first semester of college introductory physics.

One finding of the attitude survey indicates that Dickinson College Workshop Physics students are more positive about the mastery of computer applications than any other aspect of the Workshop Physics courses, and that they view computer skills as useful in many contexts outside of physics. In addition, Workshop Physics students rate a whole range of learning experiences more highly than their cohorts taking traditional courses do. For example, when students are asked to rate the value of 15 learning opportunities such as attending lectures, using computers, watching demonstrations, solving textbook problems or doing experiments, Workshop Physics students rate all of these activities, except working textbook problems, reading the textbook, and attending lectures, more highly than students taking introductory physics courses at other liberal arts colleges. They are significantly more positive about the value of observations and laboratory experiments than students taking traditional courses. This may reflect the fact that observations and experiments account for a larger proportion of their grade.

Although most freshmen prefer the workshop approach, we were disheartened in the first six years of the program to find that about 20% of our students thoroughly disliked the active approach and stated emphatically that they would prefer a return to lectures. In the early years of the program, roughly half of the upper class chemistry and biology majors expressed a desire to have us return to the lecture method. Many students who think they prefer lectures resent having to "teach themselves everything." Fortunately, students who depend on passive learning and memorization to succeed in courses constitute a minority of our students.

In the past few years student complaints have diminished as the curriculum has matured and students are exposed to activity-based methods in introductory mathematics and chemistry courses. Although the percentage of students who dislike Workshop Physics is less than the percentage of students who used to be hostile about our traditional lecture-based courses, we are attempting to achieve a better understanding of why some students are unhappy with the workshop method.

V. HOW WOMEN RESPOND TO WORKSHOP PHYSICS

The enrollment of women in the calculus-based Workshop Physics courses in the 12-year period between the fall of 1987 and the fall of 1999 was over 40%. This is significantly higher than in any of the other courses in the multi-institution attitude survey we conducted in 1989 and 1990. Among the students who took introductory physics during their freshman year and were thereby eligible to major in physics, 41% were women. Between 1990 and 2001 Dickinson College will graduate 89 physics majors, 38% of which are women. An important outcome is that after taking Workshop Physics courses, the proportion of freshmen women and freshmen men choosing to major in physics is roughly the same.

Although the results from the multi-institution attitude survey showed some interesting gender differences, these results are not statistically reliable. The survey was administered in December of 1989 and 1990, but we unfortunately neglected to obtain gender information during the 1989 survey. Since our classes are small at Dickinson College, we had only 24 men and 22 women in the 1990 sample. However, the findings we are reporting for that year were consistent with our impressions and observations made in other years. Thus we have chosen to report these findings in spite of the poor statistical base.

The attitude survey was administered to each group of students only once—at the end of the first semester of physics. However, students were asked to use the 5-point Likert scale (1 = very negative, 3 = neutral, 5 = very positive) to rate how they felt about various aspects of the course just before starting. They were also asked how they felt at the time of the survey. This provides reliable information about both the intensity of feeling and also the degree to which a student's experience was better or worse than initially expected.

One of the most dramatic differences between men and women in the 1990 survey was the improved attitude of freshmen and sophomore women toward the use of computers. At the end of one semester the feelings of these women went from a rather neutral average of 2.5 out of 5, to a quite positive, 4.0 out of 5. In contrast, the average of both the junior and senior women and all of the men started out positive, i.e., 3.7 or 3.8 in each case, and became slightly more positive, i.e., 3.9 or 4.0 in each case.

Gender differences also surfaced in the Dickinson women's attitudes toward laboratory activities. In spite of the fact that the average grades for men and women tend to be about the same, women value their learning opportunities more than men do. However, the women who took calculus-based Workshop Physics at Dickinson in 1990 were less *confident* than the men about their laboratory skills. For example, in the multi-institution survey students were asked to rate the value of five lab experiences on the 5-point scale. These included:

- (1) using sensors attached to the computer,
- (2) using spreadsheet and graphing tools,
- (3) making observations and doing experiments,
- (4) having class discussions, and
- (5) writing lab reports.

All five lab experiences were valued more highly at Dickinson than they were in courses taught at any of the other institutions in the survey. There was no noticeable gender difference in these ratings at other institutions. For example, both 514 men and 170 women at research universities gave their lab experiences a 2.8 rating. However, students taking Workshop Physics at Dickinson in 1990 rated all five experiences more highly, with the women rating these experiences at 3.9 and the men at 3.4. The 24 women who took Workshop Physics in the fall of 1990 rated themselves at 3.0 on learning gains in lab-related skills while their male counterparts rated theirs at 4.2.

We were dismayed to find that the women taking Workshop Physics in December 1990 became significantly more negative about laboratory work after the first semester. Closer examination of the data indicated that this was because the junior and senior women became *very* negative about laboratory experience during the semester while the freshman and sophomore women became slightly more posi-

Table I. Comparison of recalled feelings about laboratory work before taking one semester of calculus-based Workshop Physics to those after taking the course. A 5-point Likert scale was used which 5 is positive, 3 neutral, and 1 negative (Dickinson College Fall 1990).

Group	N	Before	After	Change
Fr/So women	12	3.2	3.6	0.4
Fr/So men	18	3.6	3.5	-0.1
Jr/Sr women	9	3.0	2.0	-1.0
Jr/Sr men	5	2.4	3.4	1.0

tive. These freshmen and sophomore women recalled being less positive than the men, yet ended up with the same feelings about lab work as their male counterparts. The responses of various groups are shown in Table I below.

VI. WOMEN'S VOICES: WHY IS LAB WORK UNPLEASANT?

Two national organizations have published extensive reports describing how teachers inadvertently create a "chilly climate" for women students by treating them differently.^{15,16} Prior to introducing the Workshop Physics courses, we were optimistic that the interactive mode of our lectureless workshop would eliminate some of the problems that contribute to a chilly climate for women. Course evaluations and instructor observations have made us aware that juniors and seniors preparing for medical school or graduate school in biology and chemistry tend to be more negative about the program than the freshmen and sophomores. Thus, we were discouraged but not totally surprised by the fact that according to the 1990 survey, the junior and senior women became more negative about hands-on laboratory work as a result of taking the first semester of the Workshop Physics course sequence. We realized that many of these women, especially the premeds, are under pressure to get top grades and do not see a connection between what they are learning in physics and their professions. We guessed that the extensive use made of computers as part of the lab work might prove to be one of the "turn-offs" for some of these women.

We decided to conduct interviews with groups of women to learn more about their perspectives. Three groups, each comprised of five women, were chosen randomly from a list of students still enrolled at Dickinson College who had taken or were currently enrolled in one of the calculus-based Workshop Physics courses. Participants were informed that their participation in the study would be strictly anonymous and each participant received a modest stipend for her time. Each group met for about an hour in April 1992 for an unstructured discussion. Pam Rosborough, who had experience with group dynamics, moderated the groups.

By means of focused discussions, we were hoping to identify reasons why a segment of women ended up feeling more negative about working in the laboratory than they did before the course began. We discovered that perceptions from all three of the focus groups mirrored those of Dickinson women compiled from the attitudes survey. The pattern was consistent from the standpoint both of individual and collective focus group norms. Specifically, after having taken the course, attitudes toward the computer became more positive for 13 out of 15 women in our study, while remaining the same for 2 women. In the case of feelings toward working in the physics laboratory, 6 out of 15 women revealed a pro-

nounced decrease in positive attitude after having taken the course, 6 out of 15 women indicated a positive change in attitude, and the attitudes of 3 women remained unchanged.

In keeping with the anonymity of the study, we did not track the identities of the women with their tape-recorded comments or their written responses to the "before" and "after" questions. This precluded the possibility of individual continuity in our discussion of the various themes, because we were not able to assign pseudonyms and thereby link, in case-study fashion, an individual's response from one theme to the next. Even though the interviews lacked individual continuity and many of the women interviewed felt positive about working in the laboratory in retrospect, a sufficient number did express negative feelings to enable us to get a clearer sense of negative student perceptions.

Many of the frustrations involved stressful collaborations. The women worked in groups of two to four students whom they either chose or ended up with. Some of these groups included men and others were single sex. Women complained of domineering partners, clashes in temperament, being subjected to ridicule, fears that their partners didn't respect them, and feelings that their partners understood far more than they.

Although the multi-institution survey revealed that the time demands of the Workshop Physics courses were not greater than those of courses at other institutions, a number of women complained about excessive and uncertain time demands. Some participants commented that women are involved in more extra-curricular activities than men are and found it stressful to have to return to the lab at night when an experiment wasn't working. One woman complained,

It's not just the work load and that expectations are high...because that's a given for both men and women. The men have more free time because they tend to be involved with less activities.

Another commented about having to "...put so much time into something that isn't straightforward, when I could be doing so many other things that would be straightforward."

Many of the concerns about time demands were intertwined with issues related to a view of learning as knowing the "right" answers. One woman expressed this beautifully.

Maybe all the time you were putting in would be OK and wouldn't bother you as much if you thought you were getting this really great experience, but that's not evident. It's getting the activity guides done, getting the little things to work. You're never sure if you've learned the right thing.

The problem of being a premed and having the mind set that either their survival depends on knowing "right answers" or learning is inherently about knowing the "right" answers is not unique to women. A number of male premeds have voiced similar complaints. However, the results of the 1990 attitude survey and our impressions in other years lead us to believe that women, more than men, have been encouraged to view learning as straightforward fact gathering or memorization. One interviewee summed this up well.

I found in my class that the upper classmen were more frustrated than the freshmen were because you came in and you had other science classes where you'd been taught in a traditional way and they expect you to learn in a totally different way and it's frustrating. I'm a pre-med and I've talked to a lot of other people who are

premed and we all felt the same way. We've been conditioned to learn in a certain kind of way and we weren't learning that way. When you come in as a freshman, I think it's easier for them. And usually freshmen are carrying all 100-level classes. I didn't have extra time to spend worrying about it.

In spite of these concerns, none of the women complained about the learning atmosphere being competitive, and they felt that after the first few weeks they were as capable as the men when it came to using the scientific apparatus and computers.

VII. CONCLUSIONS

The calculus-based Workshop Physics courses at Dickinson College are more successful than traditional introductory physics courses when the overall improvements in student attitudes and conceptual learning are considered. A woman who takes these courses during her freshman year has the same likelihood of choosing to major in physics as her male counterpart. In 1990 women who completed the Workshop Physics courses felt they were as good as men at working with apparatus and computers. However, in 1990, junior and senior women as a group seemed to feel more negative about the laboratory work in Workshop Physics courses than other students did. From interviews with women who have taken one or more semesters of Workshop Physics in 1990 or before, we discovered that those who are unhappy with Workshop Physics have difficulties with collaborative work, feel stressed about the time demands of physics, and have different understandings of the nature of learning than their instructors do.

Many factors identified by researchers probably contribute to differences in attitudes toward Workshop Physics courses. One factor is related to the findings of Perry¹⁷ and Belinky *et al.*¹⁸ These investigators have found that college students in low stages of intellectual development (i.e., "received knowers"¹⁹) believe that there is only one correct answer to every question. Such students are described as being intolerant of ambiguity and as not wanting to try to understand ideas. Most of the junior and senior women enrolled in the Workshop Physics courses have received good grades in both high school and college-level science courses by working diligently to memorize accepted facts and procedures. Many of these upper-class women believe that received and procedural learning rather than constructed learning define knowledge. In contrast, the freshman and sophomore women who come to the course early in their college careers are considering a major in a physical science or mathematics. They have been told that college is going to be challenging and they seem more open to the process of constructing meaning from their own experiences. Another factor involves the perception of premedical students that getting an "A" in physics is critical to future success while a functional knowledge of physics is not critical. Any attempt to change the rules for succeeding in physics courses is very stressful to students who are not confident intellectually. Research on these problems of motivation, grade orientation, and different understanding of the nature of learning in Workshop Physics are treated in detail by Cross and Steadman¹⁹ based on a teaching case study written by Priscilla Laws.²⁰

The perception among junior and senior women that the time demands of the Workshop Physics courses were unrea-

sonable seems to have some basis in fact. Several upper-class women felt that they are more involved in extra curricular activities than their male counterparts. A Harvard University poll revealed that 41% of the upper-class women and only 31% of upper-class men reported involvement in volunteer activities.²¹

Several of the women whom we interviewed found it stressful to work with others who are assertive. On the one hand this reaction of junior and senior women was surprising because we assumed that women enjoy collaborative work more than men do and are better at it. On the other hand our findings are not surprising in the face of a growing literature about women being more sensitive than men to the opinions of others,²² about women lacking intellectual confidence in the sciences after years of socialization,^{23,24} about the greater sensitivity of women to grade stresses and competition,²⁵⁻²⁷ and about the problems encountered in college courses by both men and women in earlier stages of intellectual development.^{17,18}

Do women who choose to take physics early in their college careers tend to be at higher developmental levels when they come to college than their junior and senior counterparts? Or, are upper-class women who are majoring in chemistry or biology socialized to dislike constructivist activity-based learning in physics as a result of their experience with other relatively "straightforward" college-level science courses? We have no reliable way to gauge the relative influence of these two factors. However, the recent introduction of additional activity-based introductory courses at Dickinson College, *Workshop Calculus with Review* and *Bench Chemistry* have provided us with some confirmation of our hypotheses. We have noted a fairly steady improvement in the attitudes of students toward the Workshop Physics experience among those who have taken the course sequence in the past 6 years. We attribute this both to improvements in the curriculum and our teaching and to the fact that the majority of our juniors and seniors have been exposed to one or more of the new activity-based introductory courses in chemistry and mathematics.

What have we learned from our Workshop Physics experience about the potential for activity-based constructivist science courses to attract more women to the study of science? We don't seem to detect a significant gender gap in attitudes toward the study of science between men and women who take physics as underclassmen. If the negative attitude of upper-class women is related primarily to socialization in other science and mathematics courses, we can close the gender gap for all women. To do this we should expose women to many courses that encourage reasoning and direct observations *early* in their schooling and in their college careers. We must take steps to promote educational reform at all levels and in all subject areas, especially science and mathematics, so that students understand how vital and empowering the process of constructing scientific knowledge can be.

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^{a)}Major portions of this article reprinted with permission from *New Directions for Teaching and Learning*, Number 61, Spring 1995 Jossey-Bass Inc., Publishers.

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⁷See Ref. 6, p. 229.

⁸The project was funded by the Fund for the Improvement of Postsecondary Education (FIPSE) from October 1986 to September 1988 at which point a collaboration began with the Tools for Scientific Thinking project at Tufts University. The two projects were merged from October 1988 to September 1989 and then received a second three-year grant from FIPSE from October 1989 to August 1993. Additionally, project efforts to disseminate the approach through two-week summer seminars held at Dickinson College have been funded by the National Science Foundation. The NSF number for the Student Oriented Science grant is USE-9150589 and the number for the ILI Lab Leadership grant is USE-9153725. The NSF number for the Summer Seminar on Workshop Physics grant is DUE9653372 and the NSF number for the Activity-Based Physics grant is DUE9455561.

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¹³A collection of three examinations (the Force and Motion Conceptual Evaluation, the Heat and Temperature Conceptual Evaluation, and the Electric Circuits Conceptual Evaluation) developed by Ronald K. Thornton of Tufts University and David R. Sokoloff at the University of Oregon are available at the Workshop Physics web site-http://physics.dickinson.edu.

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¹⁸M. F. Belinky et al., in Ref. 6, Chap. 2.

¹⁹"The Captive Audience," *Classroom Research*, edited by K. Patricia Cross and M. Harris Steadman (Jossey-Bass, San Francisco, CA, 1996), Chap. 3, pp. 93–160.

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²⁶E. Seymour and N. M. Hewitt, *Talking About Leaving: Why Undergraduates Leave the Sciences* (Westview, Boulder, CO, 1997), Chap. 5, pp. 231–318.

²⁷S. Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier* (Research Corporation, Tucson, AZ, 1990), p. 69.

To exhibit illustrative experiments, to encourage others to make them, and to cultivate in every way the ideas on which they throw light, form an important part of our duty. The simpler the materials of an illustrative experiment, and the more familiar they are to the student, the more thoroughly is he likely to acquire the idea which it is meant to illustrate. The educational value of such experiments is often inversely proportional to the complexity of the apparatus. The student who uses home-made apparatus, which is always going wrong, often learns more than one who has the use of carefully adjusted instruments, which he is apt to trust, and which he dares not take to pieces.

It is very necessary that those who are trying to learn from books the facts of physical science should be enabled by the help of a few illustrative experiments to recognize these facts when they meet them out of doors.

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