

Goals of the Introductory Physics Laboratory^{a)}

American Association of Physics Teachers

The principle of science, the definition, almost, is the following: *The test of all knowledge is experiment.* Experiment is the *sole judge* of scientific “truth.” But what is the source of knowledge? Where do the laws that are to be tested come from? Experiment, itself, helps to produce these laws, in the sense that it gives us hints. But also needed is *imagination* to create from these hints the great generalizations—to guess at the wonderful, simple, but very strange patterns beneath them all, and then to experiment to check again whether we have made the right guess. *Richard Feynman*¹

Laboratory work is essential in the study of physics. The primary goals of introductory physics laboratories have been evolving over the past century. The current impetus for changes in laboratory instruction stems from new research on student learning and technology, as well as

changes in the overall goals of physics instructors.

The purpose of this document is to develop a set of common goals for laboratory instruction that can serve as a guide to those responsible for designing and evaluating introductory physics laboratory programs.

Summary of Introductory Physics Laboratory Goals

(A detailed discussion of these goals is printed below)

- I. The Art of Experimentation:** The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.
- II. Experimental and Analytical Skills:** The laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.
- III. Conceptual Learning:** The laboratory should help students master basic physics concepts.
- IV. Understanding the Basis of Knowledge in Physics:** The laboratory should help students to understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments.
- V. Developing Collaborative Learning Skills:** The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors.

Many of the goals are not explicit in traditional laboratory programs. However, the American Association of Physics Teachers believes that laboratory programs should be designed with these five fundamental goals in mind.

DISCUSSION OF INTRODUCTORY PHYSICS: LABORATORY GOALS

Goal I. The Art of Experimentation: The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.

For many students an early experience with a stimulating scientific process in which they control the steps of an investigation can be a critical “turn-on” to physics and other sciences. Students completing the introductory laboratory should understand that physics is an experimental science and that observation and experimentation are as important as concepts and theories.

Although the physics community believes that there is no best way to achieve this goal, the following considerations are important:

(1) A conscious distinction should be made between labora-

tory exercises and lecture demonstrations on the one hand, and laboratory experiments on the other hand. The former provide critical experience with phenomena under the control of the instructor; whereas in the latter case, student decisions on how to design and conduct the experiment influence its outcome.

- (2) Laboratory investigations should encourage students to add some of their own ideas to experiments and their interpretation. Even in conventional investigations, instructors can “program in” unexpected surprises and applaud those special moments when students achieve intellectual discoveries or develop experimental techniques on their own.
- (3) Laboratory investigations should engage students in the process of formulating and asking an interesting question of nature. Students then select the methods and apparatus needed to make progress toward finding an answer. A portion of each laboratory course can be reserved for

student-designed projects. With guidance and monitoring by faculty and teaching assistants, these projects can provide a creative climax to a laboratory course. Careful planning can make this a viable option even in large laboratory sections and programs.

Goal II. Experimental and Analytical Skills: The laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.

While it is imperative that students have a broad experience with techniques using laboratory equipment, it is impossible to prescribe precisely which equipment should be used in all introductory laboratory courses. The learning objectives of each laboratory experiment should determine the equipment to be used. At the same time, it is advisable to have students use many different types of basic laboratory apparatus to make observations.

Computers, when used as flexible tools in the hands of students for the collection, analysis, and graphical display of data, can accelerate the rate at which students can acquire data, abstract, and generalize from real experience with natural phenomena. The digital computer is an important tool for an inquiry-based course in physics because it has become the most universal tool of inquiry in scientific research. However, computer simulations should not be used as substitutes for direct experience with physics apparatus. All laboratory students should have an opportunity to gain confidence in their ability to “troubleshoot” and tinker with mechanical, thermal, optical, and electrical systems.

Students should have experience in analyzing experimental results at various levels of sophistication, ranging from purely qualitative to highly quantitative. Students should be able to graph data and describe the relationships between quantities both in their own words and in terms of the mathematical relationship between the variables. Students should understand the uncertainty associated with measurement and the distinction between experimental uncertainties and mistakes in reading or recording information. Students should learn enough about uncertainties to understand the inherent limitations of measurement processes.

Goal III. Conceptual Learning: The laboratory should help students master basic physics concepts.

A growing body of research in physics education indicates that a majority of students have difficulty learning basic physical concepts in a course built around traditional lectures, textbook problems, and verification experiments.^{2,3} These studies indicate that for improved learning, students must actively confront difficult concepts. Effective learning may also be assisted by close interaction of students with their peers in this process. The laboratory can be an excellent environment for active learning.^{4,5}

The laboratory has long been considered useful for developing conceptual understanding, but some recent courses have been developed that rely heavily on laboratory experience, in contrast to lecture, for the primary development of conceptual understanding of physics. In such programs, conceptually oriented laboratory experiences may constitute a portion of the laboratory program, the entire laboratory program, or the entire course.

The use of computers with laboratory interfaces allows real-time recording and graphing of physical quantities. The qualitative use of real-time graphing in microcomputer-based laboratories (MBL) has increased interest in using the laboratory to enhance conceptual understanding. The combina-

tion of two factors—laboratory course design based on an understanding of the preconceptions students bring to the study of physics from their past experience, and the continuing development of MBL and other laboratory technology—has the potential to significantly improve the effectiveness of laboratory instruction.

Goal IV. Understanding the Basis of Knowledge in Physics: The laboratory should help students to understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments.

Physics is a complex structure of concepts, hypotheses, theories, and observations that are interrelated in such a way that it is often difficult to separate inferences based on theory from direct observations based primarily on laboratory experiments.⁶ Students should understand that experimental evidence is the basis of our knowledge of the laws of physics and that physics is not merely a collection of equations and textbook problems.

The majority of students enrolled in introductory physics at both the high-school and college level do not have sufficient concrete experience with everyday phenomena to understand the subtle interplay between observation and the construction of physics theories. The processes of observing phenomena, analyzing data, and developing qualitative verbal models and mathematical models to explain observations afford students a unique opportunity to relate concrete experience to scientific theories.¹

Goal V. Developing Collaborative Learning Skills: The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors.

A recent survey by the American Institute of Physics indicates that physics graduates named cooperative skills and complex real-world problem-solving skills as the two most vital skills in their professional lives.⁷ In addition, researchers are finding that educational collaboration in small groups is a very efficacious way of designing a learning environment for physics students. The American Association of Physics Teachers recommends that specific attention be given to the quality of the small-group collaborations in introductory physics laboratory programs.⁸

Evaluating Laboratory Achievement

Ultimately, success in achieving laboratory goals is demonstrated by communicating results. Students should develop expertise in clear, cogent reporting of experimental design, observations, analysis, and conclusions in a variety of formats ranging from informal discussion and oral presentations to formal laboratory papers and reports that adhere to accepted guidelines for formal presentation.

Conclusion

These goals are intended to stimulate further development of laboratory programs in introductory physics. Research on the efficacy of different approaches to laboratory teaching and ongoing discussion of the relative merits of various approaches are vital to the improvement of laboratory teaching.

Excellent laboratory programs do not happen by chance but require thought and planning. Achieving these goals is a worthy challenge, and their broad implementation will require the best efforts of the physics community.

^{a)}This document, prepared by members of the American Association of Physics Teachers Committee on Laboratories (Gerald Taylor, Jr., Chair), along with the Apparatus Committee, the Two-Year College Committee, the Committee on Physics in Undergraduate Education, and others, was approved as a policy statement for AAPT by the Executive Board at its October 1997 meeting in College Park, Maryland.

¹R. P. Feynman, *The Feynman Lectures on Physics* (Addison-Wesley, Reading, MA, 1963), Vol. I, Chap. 1.

²A. B. Arons, *A Guide to Introductory Physics Teaching* (Wiley, New York, 1990).

³Lillian C. McDermott, "Guest Comment: How we teach and how students learn—A mismatch?," *Am. J. Phys.* **61** (4), 295–298 (1993).

⁴Ronald K. Thornton and David R. Sokoloff, "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the

Evaluation of Active Learning Laboratory and Lecture Curricula," *Am. J. Phys.* **66** (4), 338–352 (1998).

⁵P. W. Laws, "Calculus-based physics without lectures," *Phys. Today* **44** (12), 24–31 (1991).

⁶M. Rothman, *Discovering Natural Laws: The Experimental Basis of Physics* (Doubleday, New York, 1972), p. 8.

⁷See Fig. 6 in Patrick J. Mulvey and Elizabeth Dodge, *1995 Bachelor's Degree Recipients Report*, American Institute of Physics, pub. R-211.27, 1996.

⁸Patricia Heller, Ronald Keith, and Scott Anderson, "Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving," *Am. J. Phys.* **60** (7), 627–636 (1992); Patricia Heller and Mark Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups," *Am. J. Phys.* **60** (7), 637–644 (1992).

TEACHING VS. RESEARCH?

I have been several times of late years called on to recommend candidates for professorships in the line of Physical Science and in one case to nominate a Professor and I have adopted the rule of giving the preference to a person who has made some advance in the way of original research provided his qualifications in other respects were adapted to the situation. I do not agree with the opinion expressed by our Friend Professor Olmsted in his address to a meeting of teachers that the man who would make his name known in Foreign Countries must be content to be a man of one idea and to become an inferior teacher.

Joseph Henry, letter to Benjamin Silliman, Jr. (1846), in *The Papers of Joseph Henry*, edited by Marc Rothenberg (Smithsonian Institution Press, Washington, 1992), Vol. 6, pp. 474–475.

SNEERING AT REDUCTIONISM

In a recent article in these pages Freeman Dyson described reductionism in physics as the effort "to reduce the world of physical phenomena to a finite set of fundamental equations." I might quibble over whether it is equations or principles that are being sought, but it seems to me that in this description Dyson has caught the essence of reductionism pretty well. He also cited the work of Schroedinger and Dirac on quantum mechanics in 1925 and 1927 as "triumphs of reductionism. Bewildering complexities of chemistry and physics were reduced to two lines of algebraic symbols." You might have thought that these illustrious precedents would inspire a general feeling of enthusiasm about the reductionist style of scientific research. Far from it. Many science kibitzers and some scientists today speak of reductionism with a sneer, like post-modernists talking about modernism or historians about Whig historiography.

Steven Weinberg, "Reductionism Redux," *The New York Review of Books*, 5 October 1995, pp. 39–42.