

Appendix 1.

Goals of the Introductory Physics Laboratory

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 give us hints. But also needed is imagination to create from these hints the great generalizations — to guess at the wonderful, simple, but very strange pattern beneath them all, and then to experiment to check again whether we 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.

Goal 1. The Art of Experimentation: The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigation.

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 laboratory 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 student 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 to develop 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 combination 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 understand the role of direct observation in physics and to distinguish between inferences based on theory and 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, research are finding that educational collaboration I 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.

References

1. R. P. Feynman, *The Feynman Lectures on Physics*, (Addison-Wesley, Reading, MA, 1964), Chap. 1.
2. A.B. Arons, *A Guide to Introductory Physics Teaching* (Wiley, New York, 1990).
3. L.C. McDermott, "Guest comment: How we teach and how students learn — A mismatch? *American Journal of Physics*, 61, 295-298 (1993)
4. R.K. Thornton and D.R. Sokoloff, "Assessing and improving student learning in Newton's laws parts I and II," (Accepted for publication in the *American Journal of Physics*)
5. P. W. Laws, "Calculus-based physics without lectures," *Physics Today*, 44, (December 1991).
6. M. Rothman, *Discovering Natural Laws: The Experimental Basis of Physics* (Doubleday, New York, 1972), p. 8.
7. See Fig. 6 in Patrick J. Mulvey and Elizabeth Dodge, 1995 Bachelor's Degree Recipients Report, American Institute of Physics, pub. R-211.27, 1996).
8. Patricia Heller, Ronald Keith, and Scott Anderson, "Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving and Part 2: Designing problems and structuring groups." *American Journal of Physics*, 60(7), July 1992.