The science achievement of U.S. high school students is not impressive and has not changed substantially in three decades. Yet policy makers, scientists, and educators agree that high school graduates today, more than ever, need a basic understanding of science and technology in order to live effectively in an increasingly complex, technological society.

Although there has been ongoing debate about the educational purpose and value of science experiments in laboratory classrooms, they have been a part of high school instruction since the late 19th century. Today, students enrolled in science classes spend an average of one class period per week in “the lab,” conducting such investigations as observing and comparing different cell types under a microscope in a biology class or adding a solution of unknown acidity to one of unknown alkalinity in chemistry class. These laboratory classes have been taken for granted for decades and rarely questioned.

Yet there are basic questions about them: Are labs effectively used? What do they contribute to science learning? To explore such questions, the National Science Foundation requested that the National Research Council examine the current status of science laboratories and develop a vision for their role in improving high school science education. America’s Lab Report:
Investigations in High School Science provides a research-based framework for redesigning high school laboratory experiences so that they can fulfill their full potential to help improve science learning.

AN EXPANDED VIEW OF LABORATORY EXPERIENCES

Rapid developments in science, technology, and cognitive research have made the traditional definition of science laboratories—rooms where students use special equipment to carry out well-defined procedures—too narrow and outmoded. Instead, one needs to think about laboratory experiences as any experience that provides students with the opportunity to interact directly with the natural world or with data drawn directly from the natural world. These experiences may take place in a wide variety of settings, from the traditional dedicated science laboratory classroom, to a regular classroom, an athletic field, a nearby woods or pond, or with a computer that provides access to scientific databases.

Understanding of science includes learning not only about the content or “facts” of science but also its process—the methods and processes of conducting scientific research and drawing inferences from scientific data. Laboratory experiences potentially help students learn about both the content and process of science by providing opportunities to interact directly with the material world (or with data drawn from the material world) using the tools, data collection techniques, models, and theories of science.

Laboratory experiences have the potential to advance a broad range of important science learning goals, including:

- mastery of content knowledge and information;
- development of scientific reasoning;
- understanding of the complexity and ambiguity of the empirical work that scientists do;
- development of practical skills, such as making observations and taking measurements;
- understanding of the nature of science;
- cultivation of students’ interest in science; and
- development of teamwork skills.

A wide range of different laboratory experiences can be designed to focus on one or more of the goals.

A DISAPPOINTING STATUS QUO

Though there are a range of innovative examples that suggest the potential of different kinds of laboratory experiences to improve high school science learning, little systematic research is available about their effectiveness. Moreover, the evidence about what typical high school laboratory instruction looks like today suggests that not much has changed for the average high school student.
Quality of Lab Experiences

Unfortunately, the quality of laboratory experiences for most students in U.S. high schools today is poor. One major problem is that for most students, laboratory experiences are an “add-on”: they are not integrated with what those students are learning in the rest of their science class. Instead of focusing on the learning goals of the lab, teachers and lab manuals often emphasize the procedures to be followed, leaving students uncertain about what they are supposed to be learning and how it connects to what they are learning in class. Traditional laboratory experiences often focus students more on following procedures and verifying known scientific concepts than on helping them learn to interpret and understand results. In addition, most high school students participate in a limited range of laboratory activities that do not fully reflect the range of science processes.

Several factors contribute to this unsatisfactory situation. One is the state of undergraduate education: it does not prepare future science teachers for the demanding task of directing laboratory experiences, which requires sophisticated knowledge of science content and process. Teachers are rarely trained to lead laboratory experiences that are based on research about how students learn, and few teachers have access to curricula that integrate laboratory experiences with science instruction. Other factors are scheduling and resource constraints, which may impede teachers’ and administrators’ implementation of effective lab instruction. Yet another factor is a state’s science standards: if standards are interpreted as encouraging the teaching of extensive lists of many science topics, teachers may feel too pressed to spend the time needed to teach lab experiences well. Finally, current state science assessments are not designed to measure student attainment of many of the goals of laboratory experiences, which means that effects on student science learning may not be reflected in standardized test results.

Availability of Laboratory Experiences

Another major problem in high schools is uneven access to laboratory experiences of any kind. Students in schools with high concentrations of minorities spend less time in lab instruction than do students in other schools. Access also is related to course-taking—students in lower-level science classes spend less time in labs than do students in higher-level science classes. In addition, schools with high concentrations of poor or minority students are less likely to have adequate lab facilities than other schools, and rural schools have much lower budgets for laboratory supplies than urban or suburban schools. Some students have no access to any type of laboratory experience.
STRENGTHENING LABORATORY EXPERIENCES

Promising New Strategies

Promise for the design of more effective laboratory experiences is emerging from new research. "Integrated instructional units" focus on clear learning goals, carefully sequence laboratory experiences with other science class work, and encourage students to discuss and reflect on their laboratory observations. For example, one such unit focuses on the concept of conservation of matter by engaging students in causing a series of chemical reactions—burning, rusting, the decomposition of water, and the volcanic reaction of baking soda and vinegar—interwoven with other science instruction. Although there are only a few studies of these integrated science units, they show promising gains for diverse groups of students in mastery of subject matter, development of scientific reasoning skills, and boosting interest in science.

Integrated instructional units demonstrate four key principles of instructional design:

- Design science laboratory experiences with clear learning outcomes in mind.
- Thoughtfully sequence lab experiences in the flow of science instruction.
- Integrate learning science content with learning about the processes of science.
- Incorporate ongoing student reflection and discussion.

These principles provide a practical framework for enhancing the effectiveness of laboratory experiences and making improvements in laboratory experiences today.

WHAT NEXT? RESEARCH, DEVELOPMENT, AND IMPLEMENTATION

Much more work is required to enable laboratory experiences to achieve their potential. Teachers, researchers, scientists, and curriculum developers will need to work together to develop and implement improved approaches to laboratory education, with attention to assessment, effective laboratory teaching, school organization, and diverse populations of science learners. Improving the quality of high school laboratory experiences will require focused and sustained attention. In particular, improving high school science teachers’ capacity to lead laboratory experiences effectively is critical to meeting the educational goals of these experiences.

Such improvement will require major changes in undergraduate science education and more comprehensive systems of support for practicing teachers. The definition, goals, and instructional design principles of America’s Lab Report: Investigations in High School Science offer an organizing framework to begin the difficult work of redesigning laboratory experiences for high school students in the 21st century.
EXAMPLES OF LAB EXPERIENCES

- Physical manipulation of real-world substances: for example, students can carry out chemistry experiments, animal dissections, and investigations and identification of rocks or minerals.
- Interactions with simulations in which computerized models can represent phenomena that cannot be observed directly: for example, students can manipulate simulations of cells, animal or plant systems, wave motion, weather patterns, or geological formations.
- Interaction with real-world data: for example, students analyze photographs of the moon or other heavenly bodies or emission and absorption spectra in the light from stars.
- Access to large databases: for example, using the Internet, students can access and analyze data from such sources as genome databases, astronomy image collections, databases of climatic events over long time periods, and biological field observations.
- Remote access to scientific instruments and observations: for example, by using the Internet, students can have access to an environmental scanning electron microscope or an automated telescope.

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Copies of America’s Lab Report: Investigations in High School Science are available for sale from the National Academies Press at (800) 624-6242 or (202) 334-3133 (in the Washington, DC metropolitan area) or via the NAP homepage at www.nap.edu. Full text of the report, a free PDF copy of the Executive Summary, and this report brief, are also available at www.nap.edu.

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