

Free Executive Summary



America's Lab Report: Investigations in High School Science

Susan R. Singer, Margaret L. Hilton, and Heidi A. Schweingruber, Editors, Committee on High School Science Laboratories: Role and Vision, National Research Council

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Laboratory experiences as a part of most U.S. high science curricula have been taken for granted for decades, but they have rarely been carefully examined. What do they contribute to science learning? What can they contribute to science learning? What is the current status of labs in our nation's high schools as a context for learning science? This book looks at a range of questions about how laboratory experiences fit into U.S. high schools: What is effective laboratory teaching? What does research tell us about learning in high school science labs? How should student learning in laboratory experiences be assessed? Do all students have access to laboratory experiences? What changes need to be made to improve laboratory experiences for high school students? How can school organization contribute to effective laboratory teaching? With increased attention to the U.S. education system and student outcomes, no part of the high school curriculum should escape scrutiny. This timely book investigates factors that influence a high school laboratory experience, looking closely at what currently takes place and what the goals of those experiences are and should be. Science educators, school administrators, policy makers, and parents will all benefit from a better understanding of the need for laboratory experiences to be an integral part of the science curriculum—and how that can be accomplished.

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Executive Summary

Most people in this country lack the basic understanding of science that they need to make informed decisions about the many scientific issues affecting their lives. Neither this basic understanding—often referred to as science literacy—nor an appreciation for how science has shaped the society and culture is being cultivated during the high school years. For example, over the 30 years between 1969 and 1999, high school students' scores on the science portion of the National Assessment of Educational Progress (NAEP, the “nation’s report card”) remained stagnant. In addition, high school students' performance on a different NAEP national science assessment, first administered in 1996, was weaker four years later in 2000. 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 function effectively in an increasingly complex, technological society. Increasing this understanding will require major reforms in science education, including reforms in the laboratories that constitute a significant portion of the high school science curriculum.

Since the late 19th century, high school students in the United States have carried out laboratory investigations as part of their science classes. Educators and policy makers have periodically debated the value of laboratories in helping students understand science, but little research has been done to inform those debates or to guide the design of laboratory education. Today, on average, students enrolled in science classes spend about one class period per week in such laboratory investigations as observing and comparing different cell types under a microscope in biology class or adding a solution of known acidity to a solution of unknown alkalinity in chemistry class. To assess how these and similar laboratory activities may contribute to science learning, the National Science Foundation (NSF) requested the National Research Council (NRC) to examine the current status of science laboratories and develop a vision for their future role in high school science education.

DEFINITION AND GOALS OF HIGH SCHOOL SCIENCE LABORATORIES

Questions about the value of high school science laboratories stem in part from a lack of clarity about what exactly constitutes a “laboratory” and what its science learning goals might be. For example, “laboratory” may refer to a room equipped with benches and student workstations, or it may refer to various types of indoor or outdoor science activities. Today and in the past, educators, policy makers, and researchers have not agreed on a common definition of “laboratory.”

This lack of clarity about the definition and goals of laboratories has slowed research on their outcomes. In addition, mechanisms for sharing the results of the research that is available—both within the research community and with the larger education community—are so weak that progress toward more effective laboratory learning experiences is impeded.

Conclusion 1: Researchers and educators do not agree on how to define high school science laboratories or on their purposes, hampering the accumulation

of evidence that might guide improvements in laboratory education. Gaps in the research and in capturing the knowledge of expert science teachers make it difficult to reach precise conclusions on the best approaches to laboratory teaching and learning.

Rapid developments in science, technology, and cognitive research have made the traditional definition of science laboratories—only as rooms where students use special equipment to carry out well-defined procedures—obsolete. Rather, the committee gathered information on a wide variety of approaches to laboratory education, arriving at the term “laboratory experiences” to describe teaching and learning that may take place in a laboratory room or in other settings.

While the committee found that many laboratory experiences involve students in carrying out carefully specified procedures to verify established scientific knowledge, we also learned of laboratory experiences that engaged students in formulating questions, designing investigations, and creating and revising explanatory models. Participating in a range of laboratory experiences holds potential to enhance students’ understanding of the dynamic relationships between empirical research and the scientific theories and concepts that both result from research and lead to further research questions.

Committee Definition of Laboratory Experiences

To frame the scope of the study while also reflecting the variety of laboratory experiences, the committee defined laboratory experiences as follows:

Laboratory experiences provide opportunities for students 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.

This definition includes student interaction with astronomical databases, genome databases, databases of climatic events over long time periods, and other large data sets derived directly from the material world. It does not include student manipulation or analysis of data created by a teacher to simulate direct interaction with the material world. For example, if a physics teacher presented students with a constructed data set on the weight and required pulling force for boxes pulled across desks with different surfaces and asked them to analyze these data, the students’ problem-solving activity would not constitute a laboratory experience in the committee’s definition.

In the committee’s view, science education includes learning about the methods and processes of scientific research (science process) and the knowledge derived through this process (science content). Science process centers on direct interactions with the natural world aimed at explaining natural phenomena. Science education would not be about science if it did not include opportunities for students to learn about both the process and the content of science. Laboratory experiences, in the committee’s definition, can potentially provide one such opportunity.

Goals of Laboratory Experiences

In our review of the literature, the committee identified a number of science learning goals that have been attributed to laboratory experiences, including:

- Mastery of subject matter;
- Developing scientific reasoning;
- Understanding the complexity and ambiguity of empirical work;
- Developing practical skills;
- Understanding the nature of science;
- Cultivating interest in science and interest in learning science; and
- Developing teamwork abilities.

Helping all high school students achieve these science learning goals is critical to improving national science literacy and preparing the next generation of scientists and engineers.

Although no single laboratory experience is likely to achieve all of these learning goals, different types of laboratory experiences may be designed to achieve one or more goals. For example, the committee studied a sequence of laboratory experiences included in a larger unit of instruction. Students predicted the temperatures of everyday objects, tested their predictions using temperature-sensitive probes connected to computers, and developed and revised scientific explanations for their results. Students participating in the laboratory experiences and other learning activities increased their understanding of subject matter (thermodynamics) and their interest in science in comparison to students who participated in the traditional program of science instruction. Some of the science learning goals presented above, particularly understanding the complexity and ambiguity of empirical work, can be attained only through laboratory experiences.

EFFECTIVENESS OF LABORATORY EXPERIENCES

The committee's review of the evidence on attainment of the goals of laboratory experiences reveals a recent shift in research, reflecting some movement in laboratory instruction. Historically, laboratory experiences have been disconnected from the flow of classroom science lessons. Because this approach remains common today, we refer to these separate laboratory experiences as "typical" laboratory experiences. Reflecting this separation, researchers often engaged students in one or two experiments or other science activities and then conducted assessments to determine whether their understanding of the science concept underlying the activity had increased. Some studies compared the outcomes of these separate laboratory experiences with the outcomes of other forms of science instruction, such as lectures or discussions.

Over the past 10 years, a new body of research on the outcomes of laboratory experiences has been developing. Drawing on principles of learning derived from the cognitive sciences, researchers are investigating *how* to sequence science instruction, including laboratory experiences, in order to support students' science learning. We propose the phrase "integrated instructional units" to describe these sequences of instruction. Integrated instructional units connect laboratory experiences with other types of science learning activities, including lectures, reading, and discussion. Students are

engaged in framing research questions, making observations, designing and executing experiments, gathering and analyzing data, and constructing scientific arguments and explanations.

Integrated instructional units are designed to increase students' ability to understand and apply science subject matter (often focusing on one important concept or principle) while also improving their scientific reasoning, interest in science, and understanding of the nature of science. Students are encouraged to discuss their existing ideas about the science concept and their emerging ideas during the course of their laboratory experiences, both with their peers and with the teacher. The sequence of laboratory experiences and other forms of instruction is designed to help students develop a more sophisticated understanding of both the science concept under study and the process through which scientific concepts are developed, evaluated, and refined.

The earlier body of research on typical laboratory experiences and the emerging research on integrated instructional units yield different findings about the effectiveness of laboratory experiences in advancing the goals identified by the committee. Research on typical laboratory experiences is methodologically weak and fragmented, making it difficult to draw precise conclusions. The weight of the evidence from research focused on the goals of developing scientific reasoning and enhancing student interest in science shows slight improvements in both after students participated in typical laboratory experiences. Research focused on the goal of student mastery of subject matter indicates that typical laboratory experiences are no more or less effective than other forms of science instruction (such as reading, lectures, or discussion).

A major limitation of the research on integrated instructional units is that most of the units have been used in small numbers of science classrooms. Only a few studies have addressed the challenges of implementing—and studying the effectiveness of—integrated instructional units on a wide scale. The studies conducted to date indicate that these sequences of laboratory experiences and other forms of instruction show greater effectiveness for these same three goals (compared with more traditional forms of science instruction): improving mastery of subject matter, increasing development of scientific reasoning, and enhancing interest in science. Integrated instructional units also appear to be effective in helping diverse groups of students progress toward these three learning goals.

Due to a lack of available studies, the committee was unable to draw conclusions about the extent to which either typical laboratory experiences or integrated instructional units might advance the other goals identified at the beginning of this chapter—enhancing understanding of the complexity and ambiguity of empirical work, acquiring practical skills, and developing teamwork skills.

The committee considers the evidence emerging from research on integrated instructional units sufficient to conclude:

Conclusion 2: Four principles of instructional design can help laboratory experiences achieve their intended learning goals if: (1) they are designed with clear learning outcomes in mind, (2) they are thoughtfully sequenced into the flow of classroom science instruction, (3) they are designed to integrate learning of science content with learning about the processes of science, and (4) they incorporate ongoing student reflection and discussion.

CURRENT HIGH SCHOOL LABORATORY EXPERIENCES

Most science students in U.S. high schools today participate in laboratory experiences that are isolated from the flow of classroom science instruction (referred to here as “typical” laboratory experiences). Instead of focusing on clear learning goals, teachers and laboratory manuals often emphasize the procedures to be followed, leaving students uncertain about what they are supposed to learn. Lacking a focus on learning goals related to the subject matter being addressed in the science class, these typical laboratory experiences often fail to integrate student learning about the processes of science with learning about science content. Typical laboratory experiences rarely incorporate ongoing reflection and discussion among the teacher and the students, although there is evidence that reflecting on one’s own thinking is essential for students to make meaning out of their laboratory activities. In general, most high school laboratory experiences do not follow the instructional design principles for effectiveness identified by the committee. In addition, most high school students participate in a limited range of laboratory activities, and those they do participate in do not help them to fully understand science process.

Several factors contribute to the prevalence of typical laboratory experiences. These include a lack of preparation of—and support for—teachers, disparities in the availability and quality of laboratory facilities and equipment, interpretations of state science standards, and the lack of agreement on definitions and goals of laboratory experiences. Students in schools with higher concentrations of non-Asian minorities spend less time in laboratory instruction than students in other schools, and students in lower level science classes spend less time in laboratory instruction than those enrolled in more advanced science classes. And some students have no access to any type of laboratory experience. Taken together, these factors weaken the effectiveness of current laboratory experiences.

Conclusion 3: The quality of current laboratory experiences is poor for most students.

Teacher Preparation for Laboratory Experiences

Teachers play a critical role in leading effective laboratory experiences. By carefully introducing the experiences in ways that are aligned with the learning goals of the science course and leading discussions and answering questions, the teacher can support students in linking their laboratory experiences to underlying science concepts. By selecting laboratory experiences that are clearly related to the ongoing flow of classroom science instruction, the teacher can integrate student learning of both the processes of science and important science content. Yet the undergraduate education of future high school science teachers does not currently prepare them with the pedagogical and science content knowledge required to carry out such teaching strategies. Undergraduate science departments rarely provide future science teachers with laboratory experiences that follow the design principles derived from recent research—integrated into the flow of instruction, focused on clear learning goals, aimed at the learning of

science content and science process, with ongoing opportunities for reflection and discussion.

Once on the job, science teachers have few opportunities to improve their laboratory teaching. Professional development opportunities for science teachers are limited in quality, availability, and scope and place little emphasis on laboratory instruction. In addition, few high school teachers have access to curricula that integrate laboratory experiences into the stream of instruction, although such curricula might help them in improving the instructional quality of laboratory experiences. Few high schools support science teachers in improving their laboratory teaching by providing appropriate, ongoing professional development, well-designed science curricula, and adequate laboratory facilities and supplies.

Conclusion 4: Improving high school science teachers' capacity to lead laboratory experiences effectively is critical to advancing the educational goals of these experiences. This would require major changes in undergraduate science education, including providing a range of effective laboratory experiences for future teachers and developing more comprehensive systems of support for teachers.

Laboratory Facilities and School Organization

The capacity of teachers and schools to advance the learning goals of laboratory experiences is affected by laboratory facilities and supplies and the organization of schools.

Direct observation and manipulation of many aspects of the material world require adequate laboratory facilities, including space for teacher demonstrations, student laboratory activities, student discussion, and safe storage space for supplies. Schools with higher concentrations of non-Asian minorities and schools with higher concentrations of poor students are less likely to have adequate laboratory facilities than other schools. In addition to lacking such adequate spaces for laboratory activities, schools with higher concentrations of poor or minority students and rural schools often have lower budgets for laboratory equipment and supplies than other schools. The disparity in facilities and supplies may contribute to the problem that students in schools with high concentrations of non-Asian minority students spend less time in laboratory instruction than students in other schools.

The ability of schools to address the pressing need for improvements in laboratory teaching is constrained by the way many schools are organized. Often, administrators, teachers, and students become accustomed to routines in class schedules, teachers' schedules, the allocation of space, supplies, and budgets, and teaching approaches. When such routines become rigid, they tend to reinforce existing knowledge and teaching practices, limiting teachers' and administrators' motivation and ability to try out new, more effective approaches to laboratory education. For example, routines in teacher scheduling and space allocation may limit science teachers' ability or willingness to collaborate with other teachers in shared lesson planning, reflection, and improvement of laboratory lessons. Teachers and administrators who are accustomed to their existing science texts and laboratory manuals may not seek information about new science

curricula that effectively integrate laboratory experiences, or they may hesitate to implement such curricula. Rigid school schedules may discourage teachers from adopting new, more effective approaches to laboratory instruction when such approaches require extended classroom time for students and teachers to discuss and reflect on the meaning of laboratory investigations.

Conclusion 5: The organization and structure of most high schools impedes teachers' and administrators' ongoing learning about science instruction and ability to implement quality laboratory experiences.

State Standards and Accountability Systems

Most states have developed science standards to guide instruction and large-scale assessments to measure attainment of those standards. These standards could be used as flexible frameworks to guide schools and teachers in integrating laboratory experiences into the flow of instruction in order to help students master science subject matter while also developing scientific reasoning and advancing other learning goals. However, this rarely happens. Instead, state and local officials and science teachers often see state standards as requiring them to help students master the specific science topics outlined for a grade level or science course. When they view laboratory experiences as isolated events that do not contribute to mastery of topics and science class time is short, laboratory experiences may be limited. For example, research on integrated instructional units has shown that engagement with laboratory experiences and other forms of instruction over periods of 6 to 16 weeks can increase students' mastery of a complex science topic, including the relationships among scientific ideas related to that topic. But teachers who try to "cover" an extensive list of science topics included in state science standards within a school year may have only a few days for each topic, precluding use of such potentially effective instructional units.

The interpretation and implementation of state science standards may also limit attainment of the educational goals of laboratory experiences in other ways. When state standards are seen primarily as lists of science topics to be mastered, they support attainment of only one of the many goals of laboratory experiences—mastery of subject matter. Some state standards call for students to engage in laboratory experiences and to attain other goals of laboratory experiences, such as developing scientific reasoning and understanding the nature of science. However, assessments in these states rarely include items designed to measure student attainment of these goals.

Conclusion 6: State science standards that are interpreted as encouraging the teaching of extensive lists of science topics in a given grade may discourage teachers from spending the time needed for effective laboratory learning.

Conclusion 7: Current large-scale assessments are not designed to accurately measure student attainment of the goals of laboratory experiences. Developing and implementing improved assessments to encourage effective laboratory teaching would require large investments of funds.

WHAT NEXT? RESEARCH, DEVELOPMENT, AND IMPLEMENTATION OF EFFECTIVE LABORATORY EXPERIENCES

Laboratory experiences have the potential to help students attain several important learning goals, including mastery of science subject matter, increased interest in science, and development of scientific reasoning skills. That potential is not being realized today.

The committee does not recommend any specific policies or programs to enhance the effectiveness of laboratory experiences, because we do not consider the research evidence sufficient to support detailed policy prescriptions. A serious research agenda is required to build knowledge of how various types of laboratory experiences (within the context of science education) may contribute to specific science learning outcomes. Research partnerships may be the best mechanism to carry out this agenda, building the knowledge base for improvements in laboratory teaching and learning. Specifically, we suggest that teachers, researchers, scientists, and curriculum developers work together to answer the following questions. Addressing these questions will help to guide schools, education policy makers, and researchers in developing appropriate responses to the findings and conclusions in this report:

1. Assessment of student learning in laboratory experiences—What are the specific learning outcomes of laboratory experiences and what are the best methods for measuring these outcomes, both in the classroom and in large-scale assessments?

2. Effective teaching and learning in laboratory experiences—What forms of laboratory experiences are most effective for advancing the desired learning outcomes of laboratory experiences? What kinds of curriculum can support teachers in students in progress towards these learning outcomes?

3. Diverse populations of learners—What are the teaching and learning processes by which laboratory experiences contribute to particular learning outcomes for diverse learners and different populations of students?

4. School organization for effective laboratory teaching—What organizational arrangements (state and district policy, funding priorities and resource allocation, professional development, textbooks, emerging technologies, and school and district leadership) support high-quality laboratory experiences most efficiently and effectively? What are the most effective ways to bring those organizational arrangements to scale?

5. Continuing learning about laboratory experiences—How can teachers and administrators learn to design and implement effective instructional sequences that integrate laboratory experiences for diverse students? What types of professional development are most effective to help administrators and teachers achieve this goal? How should laboratory professional development be sequenced within a teacher's career (from pre-service to expert teacher)?

The available research literature suggests that laboratory experiences will be more likely to help students attain science learning goals if they are designed with clear learning outcomes in mind, thoughtfully sequenced into the flow of classroom science instruction, and follow the other instructional design principles identified by the committee. These design principles can serve as a guide to research, development, selection, and implementation of high school science curricula. They can also guide improvements in the undergraduate science education of future teachers and professional development of current science teachers.

The committee envisions a future in which the role and value of high school science laboratory experiences are more completely understood. The state of the research knowledge base on laboratory experience is dismal but, even so, suggests that the laboratory experiences of most high school students are equally dismal. Improvements in current laboratory experiences can be made today using emerging knowledge. Documented disparities to access should be eliminated now.

Systematic accumulation of rigorous, relevant research results and best practices from the field will clarify the specific contributions of laboratory experiences to science education. Such a knowledge base must be integrated with an infrastructure that supports the dissemination and use of this knowledge to achieve coherent policy and practice.

Improving the quality of laboratory experiences available to U.S. high school students will require focused and sustained attention. By applying principles of instructional design derived from ongoing research, science educators can begin to more effectively integrate laboratory experiences into the science curriculum. The definition, goals, design principles, and findings of this report offer an organizing framework to begin the difficult work of designing laboratory experiences for the 21st century.

**America's Lab Report:
Investigations in High School Science**

Committee on High School Science Laboratories: Role and Vision

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Foreword

It will soon be 25 years since Terrell H. Bell, Secretary of Education in the Reagan administration, commissioned a task force to examine the state of education in the United States. The work of this commission resulted in the 1983 report *A Nation at Risk: An Imperative for Educational Reform*, which detailed what was then a shocking report card on American education. The report became not only rallying cry for an improved and equitable system of education but also an early framework for education reform. Regarding high school science education, *A Nation at Risk* made the following recommendation:

The teaching of science in high school should provide graduates with an introduction to: (a) the concepts, laws, and processes of the physical and biological sciences; (b) the methods of scientific inquiry and reasoning; (c) the application of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development. Science courses must be revised and updated for both the college-bound and those not intending to go to college. (p. 25)

In the science education community, we continue to be challenged by the goals for science education set out in *A Nation at Risk*. The call for students to be familiar with the methods of science inquiry and reasoning and to understand the concepts and processes of the sciences remains a visible, but largely unmet, national educational goal. Indeed, this book describes what we know and do not know about the potential of laboratories to serve as effective science learning environments. The book defines such environments as places in which students can practice scientific inquiry and reasoning, come to understand different kinds of knowledge claims that scientists make, and build their knowledge of science content.

Since *A Nation at Risk* was released, the remarkable advances in science and technology have produced even greater public concern over the quality of science education. One has only to think about the human genome project. Completed in April 2003, it provides the complete genetic blueprint for humans. It is hard to comprehend the long-term effects of this kind of scientific advancement. In educational terms, however, such discoveries raise local, state, and national expectations for science education. Today a majority of policy makers, scientists, educators, and parents agree that high school graduates must have a sophisticated grasp and appreciation of science and technology to participate fully in the work place, to understand their everyday decisions on matter ranging from health to energy resources to climate, and to participate as informed citizens in the civic realm.

Interest in science education is shared around world, whether the country is industrialized or developing. It seems universally understood that effective science education is a critical component for advancing scientific and societal development. In the United States laboratories have been a part of science education since the late 1800's. Though educational goals for labs have shifted over time as have instructional materials

and laboratory equipment, their presence as part of high school science has been consistent. Given the long history of laboratories in school science, the absence of consistent and well-ground research on high school labs is troubling. *America's Lab Report* begins to fill this important void.

America's Lab Report is the first consensus study to be completed under the guidance of the Board on Science Education. On behalf of the Board, we want to thank the ten experts who served on the study committee. Each study committee member brought a wealth of knowledge about the nature and enterprise of science, the teaching and learning of science, and the institutions of schools and schooling to their deliberations. It was a very thoughtful group of committee members who took their charge very seriously.

Chair of the study committee, Susan Singer, warrants special acknowledgment. Being chair for an NRC study is a time-consuming commitment and one that invites patience. Susan's persistence and insight into the process engendered a great deal of respect. The entire committee process was helped by the skillful work of Margaret Hilton, study director, and research associate Heidi Schweingruber. Each brought a unique set of talents to their work for which I am very grateful.

Finally, on behalf of the Board on Science Education, we want to thank the National Science Foundation staff for their initial conversations on this very challenging topic, their turning to the board to undertake this work, and recognition of the board as the right oversight group, and their support of this study.

America's Lab Report: Investigations in High School Science is born of hours of sustained examination of a broad body of evidence by a diverse and uniquely qualified group of experts. The result is a previously unavailable synthesis of research that supports a compelling discussion of the evolving role of laboratories in advancing the goals of science education. Our hope for the report is that, in the spirit of *A Nation at Risk*, it will catalyze informed debate about laboratories and school science that leads to improvement of science education for our nation's high school students.

Carl E. Wieman
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Acknowledgments

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Individually and collectively, members of the committee benefited from discussions and presentations by the many individuals who participated in our three fact-finding meetings. At the first meeting, the following individuals informed the committee about key issues affecting teaching and learning in high school science laboratories: David Hammer, associate professor of physics and of curriculum and instruction, University of Maryland; Sean Smith, senior research associate, Horizon Research, Inc.; Gerald F. Wheeler, executive director, National Science Teachers Association; Warren W. Hein, associate executive director, American Association of Physics Teachers; Angela Powers, senior education associate, teacher training, American Chemical Society; Michael J. Smith, former education director, American Geological Institute. We also thank Janet Carlson-Powell, associate director, Biological Sciences Curriculum Study, Robert Tinker, president, The Concord Consortium; Jo Ellen Roseman, director, Project 2061, and George De Boer, deputy director, Project 2061, American Association for the Advancement of Science, for briefing the committee on the role of science curriculum materials and technology on laboratory activities in high school science classrooms.

At its second meeting, the committee learned about a variety of factors influencing high school science laboratories, ranging from the nature of science to technology to state science assessments. We are grateful to each of the presenters, including: Jane Maienschein, professor and director of the Center for Biology and Society, Arizona State University; Robin Millar, professor of science education, University of York; Arthur Lidsky, president, Dober, Lidsky, Craig and Associates; Adam Gamoran, professor of sociology, University of Wisconsin; Marcia Linn, professor of development and cognition, University of California, Berkeley; Kefyn Catley, assistant professor of science education, Vanderbilt University; Mark Windschitl, associate professor, College of Education, University of Washington; Audrey Champagne, professor, Department of Educational Theory and Practice and Department of Chemistry, State University of New York at Albany; Thomas Shiland, science department chair, Saratoga Springs High School, New York; and Arthur Halbrook, senior project associate, Council of Chief State School Officers. We also thank the individuals who participated in panels addressing how financial and resource constraints and school organization influence laboratory teaching and learning. The panelists include: Daniel Gohl, principal, McKinley Technical High School, Washington, DC Public Schools; Shelley Lee, science education consultant, Wisconsin Department of Public Instruction; Lynda Beck, former assistant head of school, Phillips Exeter Academy; and Kim Lee, science curriculum supervisor, Montgomery County Public Schools, Virginia.

We thank the following individuals who shared their expertise on student science learning with the committee at its final fact-finding meeting: Philip Bell, associate professor, College of Education, University of Washington; Richard Duschl, professor of science education, Rutgers University; Norman Lederman, professor of mathematics and science education, Illinois Institute of Technology; Okhee Lee, professor, School of Education, University of Miami; Sharon Lynch, professor of secondary education, George Washington University; Kenneth Tobin, professor of urban education, Graduate Center of City College, New York; Samuel Stringfield, principal research scientist, Johns Hopkins University Center for the Social Organization of Schools; Ellyn Daugherty, lead teacher, San Mateo High School Biotechnology Careers Pathway Program; Elaine Johnson, director, Bio-Link, City College of San Francisco; Robert Tai, assistant professor of science education, University of Virginia. At its last open session, the committee talked with a panel of master science teachers to learn about their approaches to laboratory teaching. We are grateful to each member of the panel, including Nina Hike-Teague, Curie High School, Chicago; Gertrude Kerr, Howard High School, Howard County, Maryland; Margot Murphy, George's Valley High School, Maine; Phil Sumida, Maine West High School, Des Plaines, Illinois; and Robert Willis, Ballou High School, Washington, DC.

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report: Brian Drayton, Science Education, TERC, Cambridge MA; Kevin Dunbar, Department of Education, Dartmouth College; James W. Guthrie, Department of Leadership, Policy, and

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Michael E. Martinez, Department of Education, University of California, Irvine, and May Berenbaum, Department of Entomology, University of Illinois. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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