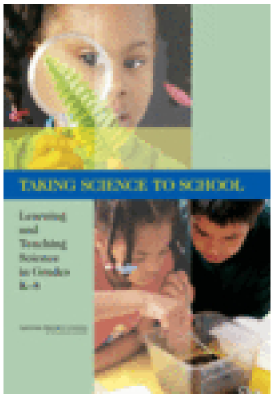
Free Executive Summary



Taking Science to School: Learning and Teaching Science in Grades K-8

Committee on Science Learning, Kindergarten through Eighth Grade, Richard A. Duschl, Heidi A. Schweingruber, and Andrew W. Shouse, Editors

ISBN: 978-0-309-10205-6, 404 pages, 7 x 10, hardback (2007)

What is science for a child? How do children learn about science and how to do science? Drawing on a vast array of work from neuroscience to classroom observation, Taking Science to School provides a comprehensive picture of what we know about teaching and learning science from kindergarten through eighth grade. By looking at a broad range of questions, this book provides a basic foundation for guiding science teaching and supporting students in their learning. Taking Science to School answers such questions as:&#8226 When do children begin to learn about science? Are there critical stages in a child's development of such scientific concepts as mass or animate objects?&#8226 What role does nonschool learning play in children's knowledge of science?&#8226 How can science education capitalize on children's natural curiosity?&#8226 What are the best tasks for books, lectures, and hands-on learning?&#8226 How can teachers be taught to teach science?The book also provides a detailed examination of how we know what we know about children's learning of science—about the role of research and evidence. This book will be an essential resource for everyone involved in K-8 science education—teachers, principals, boards of education, teacher education providers and accreditors, education researchers, federal education agencies, and state and federal policy makers. It will also be a useful guide for parents and others interested in how children learn.

Executive Summary

At no time in history has improving science education been more important than it is today. Major policy debates about such topics as cloning, the potential of alternative fuels, and the use of biometric information to fight terrorism require a scientifically informed citizenry as never before in the nation's history. Yet after 15 years of focused standards-based reform, improvements in U.S. science education are modest at best, and comparisons show that U.S. students fare poorly in comparison with students in other countries. In addition, gaps in achievement persist between majority group students and both economically disadvantaged and non-Asian minority students. In part, these achievement gaps mirror inequities in science education and take on greater significance with the looming mandate of the No Child Left Behind Act that states assess science beginning in the 2006-2007 school year. Thus, science education in the United States has become a subject of grave and pressing concern.

The charge to this committee was to answer three broad questions: (1) How is science learned, and are there critical stages in children's development of scientific concepts? (2) How should science be taught in K-8 classrooms? (3) What research is needed to increase understanding about how students learn science?

Our answers to the first question are embodied in our conclusions. Our answers to the second question are embodied in our recommendations. We also offer recommendations on professional development, a topic that demands attention because of its relationship to the second question: how science is taught ultimately depends on the teachers. Extensive rethinking of how teachers are prepared before they begin teaching and as they continue teaching—and as science changes—is critical to improving K-8 science education in the United States.

PROFICIENCY IN SCIENCE

Underlying all our conclusions and recommendations is a redefinition of and a new framework for what it means to be proficient in science. This framework rests on a view of science as both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge. This framework moves beyond a focus on the dichotomy between either content knowledge or process skills because content and process are inextricably linked in science.

Students who are proficient in science:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

These strands of proficiency represent learning goals for students as well as a broad framework for curriculum design. They address the knowledge and reasoning skills that students must acquire to be proficient in science and, ultimately, able to participate in society as educated citizens. They also incorporate the scientific practices that students need to demonstrate their proficiency. The process of achieving proficiency in science involves all four strands—advances in one strand support and advance those in another.

CONCLUSIONS: WHAT CHILDREN KNOW AND HOW THEY LEARN

Changes in understanding of what children know and how they learn have been profound in the past several decades. This new understanding is central to formulating how science should be taught. In summary:

- Children entering school already have substantial knowledge of the natural world, much of which is implicit.
- What children are capable of at a particular age is the result of a complex interplay among maturation, experience, and instruction. What is developmentally appropriate is not a simple function of age or grade, but rather is largely contingent on their prior opportunities to learn.
- Students' knowledge and experience play a critical role in their science learning, influencing all four strands of science understanding.

- Race and ethnicity, language, culture, gender, and socioeconomic status are among the factors that influence the knowledge and experience children bring to the classroom.
- Students learn science by actively engaging in the practices of science.
- A range of instructional approaches is necessary as part of a full development of science proficiency.

The commonly held view that young children are concrete and simplistic thinkers is outmoded; research shows that children's thinking is surprisingly sophisticated. Yet much current science education is based on the old assumptions and so focuses on what children cannot do rather than what they can do. Children can use a wide range of reasoning processes that form the underpinnings of scientific thinking, even though their experience is variable and they have much more to learn.

Contrary to conceptions of development held 30 or 40 years ago, young children can think both concretely and abstractly. As with most human characteristics, there is variation across children at a given age and even variation within an individual child. Development is not a kind of inevitable unfolding in which one simply waits until a child is cognitively "ready" for abstract or theory-based forms of content. Instead, parents and teachers can assist children's learning, building on their early capacities. Adults play a central role in promoting children's curiosity and persistence by directing their attention, structuring their experiences, supporting their learning attempts, and regulating the complexity and difficulty of levels of information for them. In the sciences, both teachers and peers can and must fill these critical roles.

Children's rich but naïve understandings of the natural world can be built on to develop their understandings of scientific concepts. At the same time, their understandings of the world sometimes contradict scientific explanations and pose obstacles to learning science. It is thus critical that children's prior knowledge is taken into account in designing instruction that capitalizes on the leverage points and adequately addresses potential areas of misunderstanding. To be successful in science, students need carefully structured experiences, instructional support from teachers, and opportunities for sustained engagement with the same set of ideas over weeks, months, and even years.

Children's experience varies with their cultural, linguistic, and economic background. Such differences mean that students arrive in the classroom with varying levels of exposure to science and varying degrees of comfort with the norms of scientific practice. These differences require teachers' sensitivity to cultural and other background differences and their willingness and skill to adjust instruction in light of these differences. Adjusting for variation in students' background and experience does not mean dumbing down the science curriculum or instruction. All children bring basic reasoning skills, personal knowledge of the natural world, and curiosity, which can be built on to achieve proficiency in science.

At present, a variety of factors result in inequities in science education that limit the opportunities for many students to learn science. Classroom-level factors related to instruction, such as teachers' expectations or strategies for grouping students, play a role in producing inequitable learning opportunities for economically disadvantaged and minority children. At the school, district, state, and federal levels, inequities in the quality of instruction and the qualifications of teachers, resources, facilities, and time devoted to science result in widely different learning opportunities for different groups of students. These inequities demand attention from policy makers, education leaders, and school administrators, as well as researchers.

Students' knowledge growth and reasoning are components of a large ensemble of activities that constitute "doing science." These activities include conducting investigations; sharing ideas with peers; specialized ways of talking and writing; mechanical, mathematical, and computer-based modeling; and development of representations of phenomena. To develop proficiency in science, students must have the opportunity to participate in this full range of activities.

Instruction occurs in sequences of designed, strategic encounters between students and science. Any given unit of study may include episodes that are highly teacher-directed as well as structured student-led activities. Across time, quality instruction should promote a sense of science as a process of building and improving knowledge and understanding. Students should have experiences in generating researchable questions, designing methods of answering them, conducting data analysis, and debating interpretations of data.

RECOMMENDATIONS: WHAT, WHEN, AND HOW TO TEACH

Our recommendations for standards, curricula, assessment, and instruction follow from our conclusions. However, in some areas the research base is not robust enough to offer a detailed, step-by-step roadmap for nationwide action. Given the urgent need for improvement in science education, the committee focused on the "best bets" that represent the most promising work. They require additional documentation through continued research and careful evaluation of implementation: by evaluating school, district, and state initiatives, these best bets can be transformed into well-researched alternatives for policy and practice. Our specific recommendations for research are in Chapter 11.

Science standards, curriculum, assessment, and instruction—as well as professional development for teachers—should be conceived of, designed, and implemented as a coordinated system. Standards and curriculum should lay out specific, coherent goals for important scientific ideas and practices that can be realized through sustained instruction over several years of K-8 schooling. Assessment should provide teachers and students with timely feedback about students' knowledge that, in turn, supports teachers' efforts to improve instruction. Teacher preparation and professional development should be focused on developing teachers' knowledge of the science they teach, how students learn science, and specific methods and technologies that support science learning for all students.

Recommendation 1: Developers of standards, curriculum, and assessment should revise their frameworks to reflect new models of children's thinking and take better advantage of children's capabilities.

Currently, standards and many widely used curriculum materials fail to reflect what is now known about children's thinking, particularly the cognitive capabilities of younger children.

Recommendation 2: The next generation of standards and curricula at both the national and state levels should be structured to identify a few core ideas in a discipline and elaborate how those ideas can be cumulatively developed over grades K-8.

Focusing on core ideas requires eliminating ideas that are not central to the development of science understanding. Core ideas should be both foundational in terms of connection to many related scientific concepts and have the potential for sustained exploration at increasingly sophisticated levels across grades K-8. Although existing national and state standards have been a critical first step in narrowing the focus of science in grades K-8, they do not go far enough. Future revisions to the national standards—and the subsequent interpretation of these standards at the state and local levels and by curriculum developers—need to be built around core scientific ideas and clearly identify the knowledge and practices that can be developed in science education over K-8.

Recommendation 3: Developers of curricula and standards should present science as a process of building theories and models using evidence, checking them for internal consistency and coherence, and testing them empirically. Discussions of scientific methodology should be introduced in the context of pur-

suing specific questions and issues rather than as templates or invariant recipes.

The processes and methodology that students encounter in the classroom need to reflect the range of investigatory forms in science. The range of methodology needs to include not only experiments, which have traditionally been the focus of school science, but also examples from scientific work that uses observational methods, historical reconstruction and analysis, and other nonexperimental methods.

Recommendation 4: Science instruction should provide opportunities for students to engage in all four strands of science proficiency.

In order to provide meaningful opportunities for science learning, policy makers, education leaders, and school administrators need to ensure that adequate time and resources are provided for science instruction at all grade levels for all students. They must also ensure that teachers have adequate knowledge of science content and process and are provided with adequate professional development.

Recommendation 5: State and local leaders in science education should provide teachers with models of classroom instruction that provide opportunities for interaction in the classroom, where students carry out investigations and talk and write about their observations of phenomena, their emerging understanding of scientific ideas, and ways to test them.

RECOMMENDATIONS: PROFESSIONAL DEVELOPMENT

Professional development is key to supporting effective science instruction. We call for a dramatic departure from current professional development practice, both in scope and kind. Teachers need opportunities to deepen their knowledge of the science content of the K-8 curriculum. They also need opportunities to learn how students learn science and how to teach it. They need to know how children's understanding of core ideas in science builds across K-8, not just at a given grade or grade band. They need to learn about the conceptual ideas that students have in the earliest grades and their ideas about science itself. They need to learn how to assess children's developing ideas over time and how to interpret and respond (instructionally) to the results of assessment. In sum, teachers need opportunities to learn how to teach science as an integrated body of knowledge and practice—to teach for scientific proficiency. They need to learn how to teach science to diverse student populations, to provide adequate opportunities for all students to learn science. These needs represent a significant change from what virtually all active teachers learned in college and what most colleges teach aspiring teachers today.

Recommendation 6: State and local school systems should ensure that all K-8 teachers experience sustained science-specific professional development in preparation and while in service. Professional development should be rooted in the science that teachers teach and should include opportunities to learn about science, about current research on how children learn science, and about how to teach science.

Recommendation 7: University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in the four strands that constitute science proficiency and giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K-8 curriculum.

Recommendation 8: Federal agencies that support professional development should require that the programs they fund incorporate models of instruction that combine the four strands of science proficiency, focus on core ideas in science, and enhance teachers' science content knowledge, knowledge of how students learn science, and knowledge of how to teach science.

In Chapter 11 the committee offers its recommendations for research—the work that should begin now to inform the future recommendations for science teaching.

To improve science education in the United States, changes are urgently needed throughout the system. Beginning with what is known about how children learn science, changes in teaching and in the education of teachers can and should begin now.

TAKING SCIENCE TO SCHOOL

Learning and Teaching Science in Grades K-8

Committee on Science Learning, Kindergarten Through Eighth Grade

Richard A. Duschl, Heidi A. Schweingruber,
and Andrew W. Shouse, Editors

Board on Science Education
Center for Education
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Foreword

This report brings together research literatures from cognitive and developmental psychology, science education, and the history and philosophy of science to synthesize what is known about how children in grades K through 8 learn the ideas and practice of science. The resulting conclusions challenge the science education community, writ large, to examine some tenacious assumptions about children's potential for learning about science and, as a result, the priority of science in elementary schools. We believe this research synthesis and the implications from it have the potential to change science education in fundamental ways.

For example, the repeated challenge from science educators is that science education should be for "all" the children. This has been a difficult challenge to meet. Although there is general agreement that all children will and must learn to read, historically there has been far less agreement that all children will and must learn science regardless of gender, race, or socioeconomic circumstances.

That issue is addressed in this report. *Taking Science to School* speaks in a clear, evidentiary-based voice. All young children have the intellectual capability to learn science. Even when they enter school, young children have rich knowledge of the natural world, demonstrate causal reasoning, and are able to discriminate between reliable and unreliable sources of knowledge. In other words, children come to school with the cognitive capacity to engage in serious ways with the enterprise of science.

This finding leads to a sobering insight: as educators, we are underestimating what young children are capable of as students of science—the bar is almost always set too low. Moreover, the current organization of science curriculum and instruction does not provide the kind of support for science learning that results in deep understanding of scientific ideas and an ability to engage meaningfully in the practices of science. In sum, science education as currently structured does not leverage the knowledge and capabilities students bring to the classroom. For students from diverse backgrounds, this problem is even more profound.

While sobering, this news also offers hope. At a time when significant resources, thought, and hand-wringing are devoted to the state of science, technology, engineering, and mathematics education in this country, it is welcome news that children come to school far more ready and far more capable to be science learners than previously thought. Indeed, this knowledge should come as a breath of fresh air, a reason for renewed commitment to science education, and most importantly, an invitation to action on the part of researchers, school practitioners, and state and federal policy makers.

In addition to addressing the issue of children's capacity to engage in science, this report provides a redefinition of what it means to be proficient in science. It is a compelling and comprehensive framework. It will stretch us to think beyond the artificial dichotomy between content and process in science. It is comprehensive because it attends to the whole of science learning.

Taking Science to School makes an important contribution to science education. It has been some time since science education has received an infusion of knowledge so central to the intersection of learning and science. The Board on Science Education at the National Academies is pleased to have coordinated this study. We think it exemplifies the central purpose of the National Academies and the National Research Council (NRC), to advise the nation on matters critical to science and policy in science, engineering, and medicine. We are especially grateful to the sponsors of this study—the National Science Foundation (NSF), the National Institute of Child Health and Human Development (NICHD), and the Merck Institute for Science Education (MISE). Through their sponsorship, each demonstrated a deep commitment to the importance of science, science education, and learning.

Consulting scientists for this study—Peter Raven, director, Missouri Botanical Garden; Edward C. Roy, Jr., Department of Geology (emeritus), Trinity University; Maxine Singer, Carnegie Institution of Washington, DC (president emeritus); and Susan R. Singer, Department of Biology, Carleton College—made important contributions to the study process for which they deserve special recognition. They provided the study committee and staff with advice and reflections from the perspective of individuals with significant expertise in science content.

Finally, the intellectual leadership demonstrated by co-study directors Heidi Schweingruber and Andrew Shouse in guiding the work of this study committee and the final report was outstanding. The board is grateful for their significant contributions along with those of every member of the study committee. The importance of this report to the science education community was recognized early in the committee's work. It became a standard to inspire and guide their work throughout the process. We recognize and thank them for their major contributions to the field of science education.

Carl E. Wieman, *Chair*
C. Jean Moon, *Director*
Board on Science Education

Acknowledgments

The consensus report, *Taking Science to School: Learning and Teaching Science in Grades K-8,* would not have been possible without the important contributions from study committee members, NRC leadership and staff, and many other individuals and organizations.

First, we acknowledge the support of NSF, the NICHD, and MISE. We particularly thank NSF senior program officer Janice Earle, whose initial and continuing engagement with the study committee supported and encouraged the development of the report. We are also grateful to Dan Berch from NICHD who encouraged the committee to focus on the basic science of learning (e.g., infant studies, developmental change, and brain mechanisms) as we addressed the goals and agenda for the study committee. Significant recognition and thanks must go to Carlo Parravano, MISE executive director, for his foresight in knowing how central this report would be for science education and for his strong support throughout the process of the study. This report would not have been possible without the collaborative sponsorship provided by NSF, NICHD, and MISE.

Members of the committee benefited from discussions and presentations by the many individuals who participated in our five meetings. In particular, our initial framing of the K-8 science learning domains underwent significant revisions and refinements as a result of the scholarly and thoughtful contributions made by commissioned paper writers, presenters, responders, science consultants, and members of the Practitioner Study Oversight Group. At our first meeting, Clark Chinn, Rutgers University; Christine Massey, University of Pennsylvania; and Ala Samarapungavan, Purdue University, presented their research on young children's science concept learning, reasoning, and argumentation discourse processes. Maureen Callanan, University of California-Santa Cruz, and Greg Kelly, Pennsylvania State University, provided thoughtful responses to the three presentations. The three presentations and two responses guided the committee to a discussion on the need to delineate the kinds of research to consider regarding children's science learning. Jeremy Kilpatrick, chair, NRC study committee for the report *Adding It Up*, helped committee members grasp the magnitude of the enterprise upon which we were about to embark and comforted us with the information that the NRC leadership, study directors, and staff would, as they most certainly did, provide guidance and acumen in the preparation of the report you have before you.

At the second committee meeting, we extended our explorations of research on children's science learning though a commissioned paper presentation by Deanna Kuhn, Teachers College, Columbia University, and a presentation by Corinne Zimmerman, Illinois State University. We next took up the topic of "what is science?" with a presentation and a response on "model-based reasoning practices in science" from philosophers of science Nancy Nersessian, Georgia Institute of Technology, and Richard Grandy, Rice University, respectively, and a presentation on teaching "ideas-about-science" from Jonathan Osborne, King's College, London, England. Also at the second meeting, we had a presentation on assessment practices in science education from Janet Coffey, University of Maryland-College Park, and a response from Dylan William, then at the Educational Testing Service and currently at the Institute of Education, London, England.

For the third committee meeting, we turned our attention to the relationship between instruction and contexts that support science learning. A perspective on early childhood was presented by Rochel Gelman, professor and codirector of the Rutgers University Center for Cognitive Sciences; and the focus on elementary and middle school years was presented by Sister Gertrude Hennessey, (St. Ann's School, Stoughton, WI). Beth Warren and Josiane Hidicourt-Barnes, both from TERC, presented on the instruction and contexts for science learning issue from the perspective of diverse learners. The committee discussions on assessment were further informed by Senta Raizen from West Ed. Her presentation provided the committee with information on using research on science learning to inform large-scale assessments in science. Science learning in out-of-school contexts was a critically important topic for the committee, and Reed Stevens, University of Washington, and Kirsten Ellenbogen, Science Museum of Minnesota, completed a commissioned paper on this topic, which was presented by Dr. Ellenbogen. Another critical topic was sociocultural perspectives on science learning. The commissioned paper on this topic for the third meeting was one by Ellice Forman and Wendy Sink, University of Pittsburgh, and was quite helpful to the committee.

At the next two committee meetings we were occasionally joined by members of the Science Consultants Advisory Board—Peter Raven, Missouri Botanical Garden; Edward C. Roy, Jr., Trinity University (emeritus); Maxine Singer, president emeritus, Carnegie Institution of Washington, DC; and Susan R. Singer, Carleton College. Feedback from our science consultants helped the committee to clarify messages and issues of audience for the report. A special acknowledgment goes to Susan R. Singer, chair of the NRC study committee that produced the report, *America's Lab Report: Investigations in High School Science*, who offered sage advice and feedback to the chair and to our committee on the process and procedures of our deliberations.

At the last several meetings, we were also joined by members of the Practitioner Study Oversight Group for the science learning study practitioner book—Sister Mary Gertrude Hennessey, Stoughton, WI; Deborah C. Smith, Lansing Public School, MI; Sarah Michaels, Clark University; and Janet English, a middle school teacher on leave of absence and who is now with KOCE-TV, PBS. We are grateful to each member of the group for providing excellent feedback to the committee as well as compelling examples of exemplar practices in K-8 science classrooms. This practitioner book, sponsored by MISE, will be released by the NRC approximately six months after the release of this formal report.

We also would like to thank Erin Furtak, Stanford University, who completed a commissioned paper on assessment; Mark Olson, University of Connecticut, and Carla Zembal-Saul, Pennsylvania State University, who provided additional expertise.

Many individuals at the NRC assisted the committee. The study would not have been possible without the efforts and guidance of C. Jean Moon and Patricia Morison. Both were active participants in the deliberations of the study committee, helping us to focus on key messages and conclusions from the study. Additionally, they also made profound contributions to the development of the report through periodic leadership meetings with the committee chair and the NRC study co-directors. We are grateful to Victoria Ward who arranged logistics for our meetings and facilitated the proceeding of the meetings themselves.

Jeremy Kilpatrick also informed us at the first meeting about the critical role study reviews have in bringing the report together. How very right he was!

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 NRC. 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 wish to thank the following individuals for their review of this report: Rolf K. Blank, Education Indicators, Council of Chief State School Officers, Washington, DC; Brian P. Coppola, Department of Chemistry, University of Michigan; Liang-Shih Fan, School of Engineering, Ohio State University; Susan Gelman, Department of Psychology, University of Michigan; Lynda J. Goff, UC Science and Mathematics Initiative, University of California-Davis; Barbara Koslowski, Department of Human Development and Family Studies, Cornell University; Richard Lehrer, Teaching and Learning Department, Vanderbilt University; Douglas L. Medin, Department of Psychology, Northwestern University; Brett D. Moulding, Utah Office of Education, Salt Lake City, UT; Annemarie Sullivan Palincsar, School of Education, University of Michigan; Kathleen Roth, Research Institute, LessonLab, Santa Monica, CA; Norman H. Sleep, Department of Geophysics, Stanford University; Cary Sneider, Educator Programs, Museum of Science, Boston, MA; Nancy Butler Songer, School of Education, University of Michigan.

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 Catherine Snow, Harvard Graduate School of Education, Harvard University, and Johanna Dwyer, Tufts University School of Medicine and Friedman School of Nutrition and Science Policy, Tufts-New England Medical Center. Appointed by the NRC, 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.

Richard A. Duschl, *Chair*
Committee on Science Learning,
Kindergarten Through Eighth Grade

Contents

Appendixes