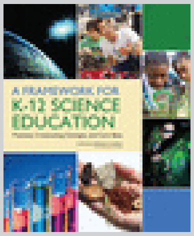

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

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Committee on Conceptual Framework for the New K-12 Science Education Standards; National Research Council

Executive Summary

Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges. Yet too few U.S. workers have strong backgrounds in these fields and many people lack even fundamental knowledge of them. This national trend has created a widespread call for a new approach to K-12 science education in the United States.

The Committee on a Conceptual Framework for New Science Education Standards was charged with developing a framework that articulates a broad set of expectations for students in science. The overarching goal of our framework for K-12 science education is to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology.

Currently, K-12 science education in the United States fails to achieve these outcomes, in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done. The framework is designed to directly address and overcome these weaknesses.

The framework is based on a rich and growing body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K-12 science and engineering. From this work, the committee concludes that K-12 science and engineering education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design.

The committee recommends that science education in grades K-12 be built around three major dimensions (see Box ES.1 for details of each dimension). These dimensions are:

- Scientific and engineering practices;
- Crosscutting concepts that unify the study of science and engineering through their common application across fields; and
- Core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and the applications of science.

To support students' meaningful learning in science and engineering, all three dimensions need to be integrated into standards, curriculum, instruction, and assessment. Engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and earth and space sciences) for two critical reasons: to reflect the importance of understanding the human-built world and to recognize the value of better integrating the teaching and learning of science, engineering, and technology.

The broad set of expectations for students articulated in the framework is intended to guide the development of new standards that in turn guide revisions to science-related curriculum, instruction, assessment, and professional development for educators. A coherent and consistent approach throughout grades K-12 is key to realizing the vision for science and engineering education embodied in the framework: that students, over multiple years of school, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of each fields' disciplinary core ideas.

The framework represents the first step in a process that should inform state-level decisions and provide a research-grounded basis for improving science teaching and learning across the country. It is intended to guide standards developers, curriculum designers, assessment developers, state and district science administrators, professionals responsible for science teacher education, and science educators working in informal settings.

The report also identifies the challenges inherent in aligning the components of K-12 science education with this new vision for science and engineering education, provides recommendations for standards development, and lays out a research agenda that would generate the insights needed to update the framework and generate new standards in the future. The committee emphasizes that greater improvements in K-12 science and engineering education will be made when all components of the system—from standards and assessments, to support for new and established teachers, to providing sufficient time for learning science—are aligned with the framework's vision.

BOX ES.1
The Three Dimensions of the Framework

1. Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2. Crosscutting Concepts

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3. Disciplinary Core Ideas

Physical Sciences
PS 1: Matter and its interactions
PS 2: Motion and stability: Forces and interactions
PS 3: Energy
PS 4: Waves and their applications in technologies for information transfer

Life Sciences
LS 1: From molecules to organisms: Structures and processes
LS 2: Ecosystems: Interactions, energy, and dynamics
LS 3: Heredity: Inheritance and variation of traits
LS 4: Biological evolution: Unity and diversity

Earth and Space Sciences
ESS 1: Earth's place in the universe
ESS 2: Earth's systems
ESS 3: Earth and human activity

Engineering, Technology, and the Applications of Science
ETS 1: Engineering design
ETS 2: Links among engineering, technology, science, and society

Part I
A Vision for K-12 Science Education

A Framework for K-12 Science Education:
Practices, Crosscutting Concepts, and Core Ideas

Committee on a Conceptual Framework for New K-12 Science Education Standards

Board on Science Education

Division of Behavioral and Social Sciences and Education

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FOREWORD

A Framework for K-12 Science Education Standards represents the first step in a process to create new standards in K-12 science education. This project capitalizes on a major opportunity that exists at this moment—a large number of states are adopting common standards in mathematics and English/language arts and thus are poised to consider adoption of common standards in K-12 science education. The impetus for this project grew from the recognition that, although the existing national documents on science content for K-12 (developed in the early to mid 1990s) were an important step in strengthening science education, there is much room for improvement. Not only has science progressed, but also the education community has learned important lessons from 10 years of implementing standards-based education, and there is a new and growing body of research on learning and teaching in science that can now inform a revision of the standards and revitalize science education.

In this context, the Carnegie Corporation, together with the Institute for Advanced Study, established a commission that issued a report *The Opportunity Equation* calling for a common set of standards in science to be developed. The Carnegie Corporation has taken a leadership role to ensure that the development of common science standards proceeds and is of the highest quality by funding a two-step process: first, the development of this framework by the National Research Council (NRC) and, second, the development of a next generation of science standards based on the framework by Achieve, Inc. We are grateful for the financial support of the Carnegie Corporation for this project, and for their vision in establishing the partnership and two-step process for developing the new standards.

This framework builds on the strong foundation of previous studies that have sought to identify and describe the major ideas for K-12 science education. These include *Science for All Americans* and *Benchmarks for Science Literacy* (1993) developed by the American Association for the Advancement of Science (AAAS) and the *National Science Education Standards* (1996) developed by the National Research Council. The framework is also informed by more recent work of two of our partner organizations: the American Association for the Advancement of Science (in Project 2061 especially) and the National Science Teachers Association (particularly the Anchors project 2009). Achieve, Inc., our third partner is this endeavor, will develop next-generation standards for science education based on the framework presented in this report with the aspiration that many states will choose to adopt them. We look forward to working with these organizations in the dissemination and implementation of the vision of science and engineering education that the *Framework* embodies.

The framework highlights the power of integrating understanding the ideas of science with engagement in the practices of science and is designed to build students' proficiency and appreciation for science over multiple years of school. Of particular note is the prominent place given to the ideas and practices of engineering.

As presidents of the National Academy of Sciences and National Academy of Engineering, we are pleased to convey this report to interested readers. We believe that the education of the children of this nation is a vital national concern. The understanding of, and interest in, science and engineering that its citizens bring to bear in their personal and civic decision making is critical to good decisions about the nation's future. The percentage of students who are motivated by their school and out-of-school experiences to pursue careers in these fields is currently too low for the nation's needs. Moreover, an ever-larger number of jobs require skills in these areas, along with those in language arts and mathematics.

We thank the committee and the many consultants and NRC staff members who contributed to this effort, as well as the thousands who took the time to comment on the draft that was made public in July 2010. That input contributed substantially to the quality of this final report.

Ralph J. Cicerone, President, National Academy of Sciences
Charles M. Vest, President, National Academy of Engineering

ACKNOWLEDGMENTS

Together with the rest of the committee, I thank the many individuals and organizations who assisted us in our work, without whom this study could not have been completed. We begin by acknowledging the generous support of the Carnegie Corporation of New York and particularly Andres Henriquez for his attention to and patience with this project.

Next we recognize the importance of the partnership we developed with Achieve, Inc., the American Association for the Advancement of Science, and the National Science Teachers Association, and we are pleased to be continuing this partnership. Each organization brought its unique perspective to our many partner meetings, which led to a stronger report and better communication with the myriad communities with an interest in K-12 science education. Each of these partners has an important role to play as the implementation of ideas in the framework develops.

This report would not have been possible without the work of many individuals, teams, and organizations and we hope we acknowledge them all here. The four design teams (listed in Appendix A) were critical in the development of the framework and providing the committee with insightful and creative models for organizing the core ideas. We are deeply indebted to them and especially to the four team leaders: Rodger Bybee, Joseph Krajcik, Cary Snyder, and Michael Wysession. These team leaders worked closely with the committee until the final stages of the project, tirelessly revising drafts of their work, discussing the research, debating possible approaches, and consistently going above and beyond their initial commitments. The work would have been impossible without them.

The committee also called on many individual experts in a variety of capacities. Some served as presenters, others provided detailed reviews of the draft framework released in July, still others worked closely with groups of committee members to refine portions of the report, and a select few filled all three roles. We acknowledge Valerie Akerson, Indiana University; Charles "Andy" Anderson, Michigan State University; Angela Calabrese Barton, Michigan State University; Anita Bernhardt, Department of Education, Maine; Nancy Brickhouse, University of Delaware; Ravit Golan Duncan, Rutgers University; Daniel Edelson, National Geographic Society; Jacob Foster, Massachusetts Department of Elementary and Secondary Education; Adam Gamoran, University of Wisconsin-Madison; David Hammer, University of Maryland, College Park; David Heil, David Heil & Associates; Leslie Herrenkohl, University of Washington; Frank Keil, Yale University; Rich Lehrer, Vanderbilt University; Kathy Metz, University of California, Berkeley; Jacqueline Miller, Education Development Center; Alberto Rodriguez, San Diego State University; Aaron Rogat, Columbia University; Jo Ellen Roseman, American Association for the Advancement of Science; Leona Schauble, Vanderbilt University; Eugenie Scott, National Center for Science Education; Jean Slattery, Achieve, Inc.; Susan Singer, Carleton College; Carol Smith, University of Massachusetts at Boston, Maria Varelas, University of Illinois at Chicago; Beth Warren, TERC; Iris Weiss, Horizon Research, Inc.; and Marianne Wiser, Clark University.

The committee also benefited from the extensive feedback on the draft released during the public comment period in summer 2010. We thank the large number of individuals who sent thoughtful comments as well as the many stakeholder groups and their leaders who were generous in recording and sending us discussion group feedback (see Appendix A). The committee found this feedback invaluable in revising the report, and we think it has greatly improved the quality of the final document.

We are also deeply grateful to the many individuals at the National Research Council (NRC) who assisted the committee. The success of a large project such as the framework involves the efforts of countless staff members who work behind the scenes. We acknowledge the support and commitment of the project co-directors, Heidi Schweingruber, whose dedication to this work was demonstrated time and again at every stage of the work, and Tom Keller, who likewise played many critical roles in the process. We are grateful for the extensive, thoughtful, and cheerfully supportive work of additional staff of the Board on Science Education who rose to the urgency of the task time and time again—Kelly Duncan, Rebecca Krone, Michael Feder, Natalie Nielsen, Sherrie Forrest, Mengfei Huang (a Mirzyan fellow with BOSE) and Martin Storksdieck. Matthew Von Hendy provided valuable research assistance.

We also thank Kirsten Sampson-Snyder, who shepherded the report through the NRC review process, Christine McShane, who edited the draft report, and Yvonne Wise for processing the report through final production. We were also aided by the editorial skills of Steve Marcus, the work of staff of the National Academies Press, including Steve Mautner, Rachel Marcus, and Virginia Bryant, and Doug Sprunger in the DBASSE communications office. We owe a special debt of thanks to Sara Frueh, who worked closely with project staff on communications and press issues and attended many meetings of the four partners to discuss communication and dissemination strategy.
Prior to the public comment period the draft underwent a condensed version of an NRC internal review. We thank the following individuals for their review of this report: Richard A. Duschl, College of Education, Pennsylvania State University; W.G. Ernst, Department of Geological and Environmental Sciences, Stanford University; Kim A. Kastens, Lamont-Doherty Earth Observatory, Columbia University; and Elizabeth K. Stage, Lawrence Hall of Science, University of California, Berkeley. Lauress (Laurie) L. Wise, Human Resources Research Organization (HumRRO), Monterey, CA and Jerry P. Gollub, Physics Department, Haverford College oversaw the initial review of this report.

This report has been reviewed in draft form by individuals chosen by their diverse perspective and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. 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 study 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: Cristina Amon, Dean, Faculty of Applied Science and Engineering, Alumni Chair Professor of Bioengineering, Department of Mechanical and Industrial Engineering, University of Toronto; William B. Bridges, Carl F. Braun Professor of Engineering, Emeritus, California Institute of Technology; Marye Anne Fox, Chancellor, Office of the Chancellor, University of California, San Diego; Kenji Hakuta, School of

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Although the reviewers listed above have provided constructive comments and suggestions, they are not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. Lorraine McDonnell and Jerry Gollub oversaw the review of this report. 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.

Finally, I would like add my personal thanks, in particular to Heidi Schweingruber, without whose wise advice and support I could not have done my part of the job, and to my colleagues on the committee for their enthusiasm, hard work, and collaborative spirit in writing this report. They attended six meetings of two or more days in length, freely provided their comments, engaged in spirited discussion, read and commented on numerous drafts, and worked at a furious pace.

Helen R. Quinn, *Chair*