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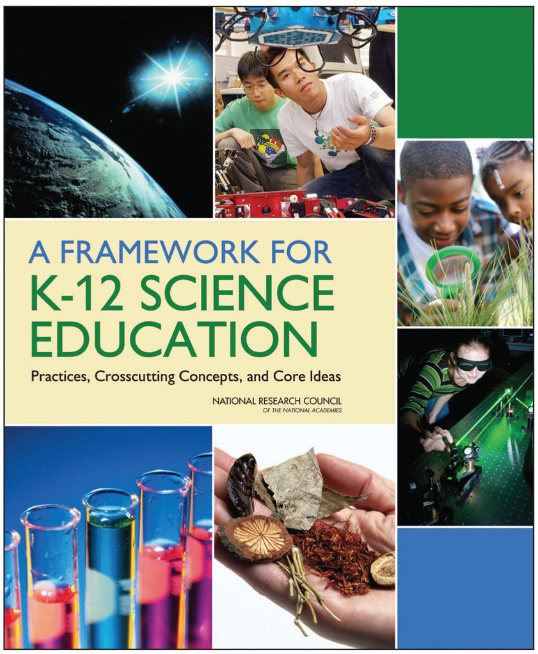
REPORT BRIEF • JULY 2011 • BOARD ON SCIENCE EDUCATION

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



WHY IS A K-12 SCIENCE FRAMEWORK NEEDED?

Science, engineering, and technology permeate every aspect of modern life. Some knowledge of science and engineering is required to understand and participate in many major public policy issues of today, as well as to make informed everyday decisions, such as selecting among alternate medical treatments or determining whether to buy an energy-efficient furnace.

By the end of the 12th grade, students should have sufficient knowledge of science and engineering to engage in public discussions on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to be able to continue to learn about science throughout their lives. They should recognize that our current scientific understanding of the world is the result of hundreds of years of creative human endeavor. And these are goals for *all* of the nation's students, not just those who pursue higher education or careers in science, engineering, or technology.

Today, science education in the United States is not guided by a common vision of what students finishing high school should know and be able to do in science. Too often, standards are long lists of detailed and disconnected facts, reinforcing the criticism that our schools' science curricula tend to be "a mile wide and an inch deep." Not only does this approach alienate young people, it also leaves them with fragments of knowledge and little sense of the inherent logic and consistency of science and of its universality. Moreover, the current fragmented approach neglects the need for students to engage in doing science and engineering, which is a key part of understanding science.

The time is ripe for a new framework for K-12 science education not only because of weaknesses in the current approaches, but also because new knowledge in both the sciences and the teaching and learning of science has accumulated in the past 15 years. In addition, the movement by most of the states to adopt common standards in mathematics and in language arts has prompted the call for comparable standards in science to guide state reforms.

The National Research Council (NRC) of the National Academy of Sciences was asked to develop a framework that would provide unifying guidance for the nation's schools to improve all students' understanding of science. The expert committee that developed the framework used research-based evidence on how students learn, input from a wide array of scientific experts and educators, and past national reform efforts, as well as its members' individual expertise and collective judgment.

HOW WILL THE FRAMEWORK BE USED?

The framework is designed to be the basis for the next generation of science standards. Using the practices, crosscutting concepts, and core ideas that the framework lays out, a group of states, coordinated by Achieve, Inc. (a nonprofit education organization), will develop standards for what students should learn at different grade levels.

The framework is also designed to be useful to others who work in science education, including:

- curriculum developers and assessment designers;
- educators who train teachers and create professional development materials for them;
- state and district science supervisors, who make key decisions about curriculum, instruction, and professional development; and
- science educators who work in informal settings, such as museum exhibit designers or writers and producers of documentary films.

HOW THE FRAMEWORK WAS DEVELOPED

NRC convened a committee of 18 experts in education and scientists from many disciplines to develop the framework drawing on their own expertise, current research , and guidance from small teams of specialists.

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A draft of the framework was released in the summer of 2010 to gather comments from scientists, teachers, and the public. The National Science Teachers Association, the American Association for the Advancement of Science, and other groups aided this effort by collecting feedback from their members.

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The committee revised the draft in response to all the comments received.

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As a final step to ensure high quality, the framework went through the NRC's intensive peer-review process. More than 20 experts in the sciences, engineering, and teaching and learning provided detailed comments.

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The committee revised the framework again in response to the experts' comments.

WHAT IS IN THE FRAMEWORK?

The framework consists of a limited number of elements in three dimensions: (1) scientific and engineering practices, (2) crosscutting concepts, and (3) disciplinary core ideas in science. It describes how they should be developed across grades K-12, and it is designed so that students continually build on and revise their knowledge and abilities throughout their school years. To support learning, all three dimensions need to be integrated into standards, curricula, instruction, and assessment.

DIMENSION 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

This dimension focuses on important practices used by scientists and engineers, such as modeling, developing explanations or solutions, and engaging in argumentation. For example, all of the disciplines of science share a commitment to data and evidence as the foundation for developing claims about the world. As they carry out investigations and revise or extend their explanations, scientists examine, review, and evaluate their own knowledge and ideas and critique those of others through a process of argumentation. These practices have too often been underemphasized in K-12 science education.

Engaging in the full range of scientific practices helps students understand how scientific knowledge develops and gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Similarly, engaging in the practices of engineering helps students understand the work of engineers and the links between engineering and science.

The full report describes these eight practices, articulating the major competencies that students should have by the end of 12th grade and outlining how student competence might progress across the grades.

DIMENSION 2:
CROSSCUTTING CONCEPTS THAT HAVE COMMON APPLICATION ACROSS FIELDS

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

The seven crosscutting concepts are key across science and engineering. They provide students with ways to connect knowledge from the various disciplines into a coherent and scientific view of the world. For example, the concept of "cause and effect: mechanism and explanation" includes the key understandings that events have causes, sometimes simple, sometimes multifaceted; that a major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated; and that such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

Students' understanding of these crosscutting concepts should be reinforced by their repeated use in instruction across the disciplinary core ideas (see Dimension 3). For example, the concept of "cause and effect" could be discussed in the context of plant growth in a biology class and in the context of investigating the motion of objects in a physics class. Throughout their science and engineering education, students should be taught the crosscutting concepts in ways that illustrate their applicability across all the core ideas.

DIMENSION 3: CORE IDEAS IN FOUR DISCIPLINARY AREAS

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

The framework includes core ideas for the physical sciences, life sciences, and earth and space sciences because these are the disciplines typically included in science education in K-12 schools. Engineering and technology are featured alongside these disciplines 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 focus on a limited number of core ideas in science and engineering is designed to allow sufficient time for teachers and students to explore each idea in depth and thus with understanding.

The full report provides detailed descriptions of each core idea, as well as descriptions of what aspects of each idea should be learned by the end of grades 2, 5, 8 and 12. Establishing limits for what is to be learned about each core idea for each grade band clarifies the most important ideas that students should learn.

HOW CAN THE VISION OF THE FRAMEWORK BE REALIZED?

Students will make the greatest strides in learning science and engineering when all components of the system—from professional development for teachers to curricula and assessments to time allocated for these subjects during the school day—are aligned with the vision of the framework. Aligning the existing K-12 system with that vision will involve overcoming many challenges, including teachers' familiarity with new instructional practices and the time allocated to science. The full report identifies such challenges to help educators and policymakers begin to consider how to meet them. It also offers recommendations to guide standards developers and lays out a research agenda to inform updates of the framework and standards in the future.

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National Research Council Staff: **HEIDI A. SCHWEINGRUBER**, Study Co-Director; **THOMAS KELLER**, Study Co-Director; **MICHAEL A. FEDER**, Senior Program Officer (until February 2010); **MARTIN STORKSDIECK**, Board Director; **KELLY A. DUNCAN**, Senior Program Assistant (until October 2010); **REBECCA KRONE**, Program Associate; **STEVEN MARCUS**, Editorial Consultant

For More Information . . .

This brief was prepared by the Board on Science Education www.nationalacademies.org/bose. Copies of the report, *A Framework for K-12 Science Standards: Practices, Crosscutting Concepts, and Core Ideas*, are available from the National Academies Press at (888) 624-8373 or (202) 334-3313 (in the Washington, DC metropolitan area) or via the National Academies Press webpage at www.nap.edu. The study was funded by the Carnegie Corporation. Any opinions, findings, conclusions, or recommendations expressed in the publication are those of the authors and do not necessarily reflect those of the Carnegie Corporation.

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