The NSTA Reader's Guide to A FRAMEWORK FOR K–12 SCIENCE EDUCATION

Practices, Crosscutting Concepts, and Core Ideas

By Harold Pratt

NSTApress
National Science Teachers Association

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Background

In July 2011, the National Research Council (NRC) released *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* which identifies key scientific ideas and practices all students should learn by the end of high school. The *Framework* serves as the foundation for new K–12 science education standards that will replace those developed in the 1990s, including *National Science Education Standards* (*NSES*) and *Benchmarks for Science Literacy* (*Benchmarks*).

A state-led effort to develop the new science standards—called *Next Generation Science Standards (NGSS)*—is under way. Managed by Achieve Inc., the process involves science experts, science teachers, and other science education partners. The first draft of the *NGSS* will not appear until sometime in 2012, and the final version most likely will not appear until late in the year. In the meantime, NSTA recommends that the science education community fully examine the *Framework* and explore in-depth the concepts and ideas on which the new standards will be built.

Editor's Note: The tables and page numbers referenced in this document refer to the pre-publication copy of the *Framework* released in July 2011. A final print version will be released by the National Academies Press in late 2011 or early 2012 and will most likely have a different page numbering system. NSTA plans to update this *Guide*, including the page numbers, when the final *Framework* is printed. Check the NSTA website at *www.nsta.org/ngss* for updated information.

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Using This Guide

This guide is intended for many audiences—including science teachers, science supervisors, curriculum developers, administrators, and other stakeholders in science education—to help them better understand and effectively implement the new standards when they are released. As the introduction to the *Framework* states, "the framework is intended as a guide to standards developers as well as to curriculum designers, assessment developers, state and district science administrators, professionals responsible for science-teacher education, and science educators working in informal settings" (p. 1-1). Teachers play a key leadership role in each of these functions and will benefit from a deep understanding of the *Framework* as a stand-alone document and as a guide to the use of the forthcoming *NGSS*.

To make the best use of this guide, the reader should have a copy of the *Framework* in hand for reference. The *Framework*, and many other NRC reports noted in this document, can be downloaded free of charge from the National Academies Press at *www.nap.edu*. This guide is designed to facilitate the study of the *Framework*, not replace reading it. For each chapter of the *Framework*, the guide provides

1. an overview;
2. an analysis of what is similar to and what is different from previous standards and benchmarks; and
3. a suggested action for science teachers, science supervisors, and other science educators to support understanding of the *Framework* and anticipate its impact on classrooms, schools, and districts.

Contents of the *Framework*

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The overview is not intended to be an exhaustive summary of the *Framework* chapter, but rather a brief synopsis of the key idea(s). The second section—an analysis of what is new and different—is much more effective if the reader of this guide has a copy of the *NSES* and *Benchmarks* in hand or is reasonably familiar with these documents. Much of our analysis is based on comparisons with these two important documents that were published in the mid-1990s. Other documents also will be referenced to provide additional background and reading. The third section—suggested action—contains recommendations for activities for individuals, small teams, or larger groups to explore and learn about the ideas and concepts in the *Framework*. While some will find the overview and analysis sections most insightful, others will appreciate the suggested actions and use them as guides for possible professional development ideas.

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The Three Dimensions of the *Framework*

1. Scientific and Engineering Practices

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

2. Crosscutting Concepts

- Patterns
- Cause and effect: Mechanism and explanation
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter: Flows, cycles, and conservation
- Structure and function
- 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

Source: NRC 2011, p. ES-3

Executive Summary

The executive summary states the purpose and overarching goal of the *Framework*: 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" (p. ES-1).

The *Framework* recommends that science education be built around three major dimensions, which are provided in the sidebar (Box ES.1, p. ES3)

The intent is that the *NGSS* should integrate these three dimensions. The early sections of the *Framework* do not communicate this intent, but it becomes clear in Chapter 9, "Integrating the Three Dimensions," and in the Chapter 12 recommendations to Achieve Inc. The early chapters are instead designed to provide an understanding of each separate dimension.

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PART I:
A Vision for K–12 Science Education

Chapter 1
Introduction: A New Conceptual *Framework*

Overview

The best description of the general vision of the *Framework* is provided on page 1-2:

> *The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields. The learning experiences provided for students should engage them with fundamental questions about the world and with how scientists have investigated and found answers to those questions. Throughout the K–12 grades, students should have the opportunity to carry out scientific investigations and engineering design projects related to the disciplinary core ideas.*
>
> *By the end of the 12th grade, students should have gained sufficient knowledge of the practices, crosscutting concepts, and core ideas 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 continue to learn about science throughout their lives. They should come to appreciate that science and the current scientific understanding of the world are the result of many hundreds of years of creative human endeavor. It is especially important to note that the above goals are for all students, not just those who pursue careers in science, engineering, or technology or those who continue on to higher education.*

Also from the introduction (p. 1-2),

> *The committee's vision takes into account two major goals for K–12 science education: (1) educating all students in science and engineering and (2) providing the foundational knowledge for those who will become the scientists, engineers, technologists, and technicians of the future. The framework principally concerns itself with the first task—what all students should know in preparation for their individual lives and for their roles as citizens in this technology-rich and scientifically complex world.*

The chapter discusses the rationale for including engineering and technology and for the exclusion of the social, behavioral, and economic sciences. It also includes a brief description of how the *Framework* was developed by the NRC committee.

Analysis

The stated vision reinforces what has been well accepted as the vision for science education for the past two decades and is clearly articulated in the *NSES* and *Benchmarks*.

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A major difference you will notice is that the *Framework* introduces and defines engineering and technology and outlines the reasons for their inclusion in the *NGSS*.

What's also new is that to achieve the goal, the *Framework* moves science education toward a more coherent vision by (1) building on "the notion of learning as a developmental progression"; (2) focusing "on a limited number of core ideas in science and engineering"; and (3) emphasizing "that learning about science and engineering involves integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design" (p. 1-3).

Suggested Action

Compare the *Framework*'s vision and overarching goals for science education to those of your state, school, or district. What differences do you find? A review and possible update by your curriculum committees might be in order because the nature of the vision and goals stated in the *Framework* will undoubtedly appear in the *NGSS*. Note the increased emphasis on how students learn science in the means or goals of how the vision will be achieved. This will be discussed in more detail in the next chapter..

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Chapter 2

Guiding Assumptions and Organization of the *Framework*

Overview

The *Framework* defines several guiding principles about the nature of learning science that underlie the structure and content of the *Framework*. Below is a summary of these principles, adapted from pages 2-1 through 2-4.

Children are born investigators: In the early years of life, children engage in and develop their own ideas about the physical, biological, and social worlds and how they work and, thus, can engage in scientific and engineering practices beginning in the early grades.

Focusing on core ideas and practices: The *Framework* is focused on a limited set of core ideas to allow for deep exploration of important concepts and time for students to develop meaningful understanding of these concepts through practice and reflection. The core ideas are an organizing structure to support acquiring new knowledge over time and to help students build capacity to develop a more flexible and coherent understanding of science.

Understanding develops over time: Student understanding of scientific ideas matures over time—across years rather than in weeks or months—and instructional supports and experiences are needed to sustain students' progress.

Science and engineering require both knowledge and practice: Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential.

Connecting to students' interests and experiences: For students to develop a sustained attraction to science and for them to appreciate the many ways in which it is pertinent to their daily lives, classroom learning experiences in science need to connect with students' own interests and experiences.

Promoting equity: All students should be provided with equitable opportunities to learn science and become engaged in science and engineering practices—with access to quality space, equipment, and teachers to support and motivate that learning and engagement, and with adequate time spent on science.

The balance of the chapter outlines the structure of the *Framework* and its three dimensions—scientific and engineering practices, crosscutting concepts, and disciplinary core ideas—and their progressions across grades K–12.

Analysis

The introduction to this chapter lists the NRC publications *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007), *America's Lab Report* (Singer, Hilton, and Schweingruber 2006), *Learning Science in Informal Environments* (Bell et al. 2009), *Systems for State Science Assessments* (Wilson and Bertenthal 2006), and *Engineering in K–12 Education* (Katehi, Pearson,

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and Feders 2009) that served as background for the writers of the *Framework*. These reports are based on research from the 15 years following the publication of the *NSES* and *Benchmarks* and represents an evolving knowledge of how students learn science and the nature of curriculum and instruction that will facilitate the learning. That increased level of knowledge about how students learn is reflected in the guiding principles outlined above.

Suggested Action

Obtain copies of the publications cited in this chapter and form study or discussion groups to become familiar with the research synthesized in them and their view of how students learn science. Explore how the research and ideas have changed since the publication of the *NSES* and *Benchmarks* and how they are reflected in the *Framework*. One of the best places to begin is with *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, and Cocking 2000). This seminal work is easy to read, contains research on the broad topic of how learning occurs, and has a chapter with examples on how students learn science, mathematics, and history. In addition, a recent report that has had significant influence on the *Framework* is *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007). This report provides the background for the Framework's guiding principles and helps explain the evolution from the language of inquiry to practices.

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PART II:
Dimensions of the *Framework*

Chapter 3
Dimension 1: Scientific and Engineering Practices

Overview

This chapter continues and strengthens one of the principal goals of science education, "to engage in scientific inquiry" and "reason in a scientific context" (p. 3-1). In doing so, it explains the transition or evolution from inquiry to practices and discusses the reasons why practices are considered to be an improvement over the previous approaches.

The change is described as an improvement in three ways:

- "It minimizes the tendency to reduce scientific practice to a single set of procedures" (p. 3-2).
- By emphasizing the plural practices, it avoids the mistaken idea that there is one scientific method.
- It provides a clearer definition of the elements of inquiry than previously offered.

Scientific and Engineering Practices

Asking Questions and Defining Problems

A basic practice of the **scientist** is the ability to formulate empirically answerable questions about phenomena to establish what is already known, and to determine what questions have yet to be satisfactorily answered.	**Engineering** begins with a problem that needs to be solved, such as "How can we reduce the nation's dependence on fossil fuels?" or "What can be done to reduce a particular disease?" or "How can we improve the fuel efficiency of automobiles?"

Developing and Using Models

Science often involves the construction and use of models and simulations to help develop explanations about natural phenomena.	**Engineering** makes use of models and simulations to analyze systems to identify flaws that might occur or to test possible solutions to a new problem.

Planning and Carrying Out Investigations

A major practice of **scientists** is planning and carrying out systematic scientific investigations that require identifying variables and clarifying what counts as data.	**Engineering** investigations are conducted to gain data essential for specifying criteria or parameters and to test proposed designs.

Analyzing and Interpreting Data

Scientific investigations produce data that must be analyzed to derive meaning. Scientists use a range of tools to identify significant features and patterns in the data.	**Engineering** investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria.

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Using Mathematics, Information and Computer Technology, and Computational Thinking	
In **science,** mathematics and computation are fundamental tools for representing physical variables and their relationships.	In **engineering,** mathematical and computational representations of established relationships and principles are an integral part of the design process.
Constructing Explanations and Designing Solutions	
The goal of **science** is the construction of theories that provide explanatory accounts of the material world.	The goal of **engineering** design is a systematic approach to solving engineering problems that is based on scientific knowledge and models of the material world.
Engaging in Argument From Evidence	
In **science,** reasoning and argument are essential for clarifying strengths and weaknesses of a line of evidence and for identifying the best explanation for a natural phenomenon.	In **engineering,** reasoning and argument are essential for finding the best solution to a problem. Engineers collaborate with their peers throughout the design process.
Obtaining, Evaluating, and Communicating Information	
Science cannot advance if scientists are unable to communicate their findings clearly and persuasively or learn about the findings of others.	**Engineering** cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively.

The *Framework* identifies eight practices that are essential elements of a K–12 science and engineering curriculum and describes the competencies for each practice. They are identified and described in "Scientific and Engineering Practices" above.

For each practice, the *Framework* includes a comparison of how the practice is seen in science and engineering, a list of student goals to achieve by grade 12, and a discussion of the progression to reach those goals from the early grades through grade 12. Box 3-2 (p. 3-29), "Distinguishing Practices in Science From Those in Engineering," provides a very useful three-page table.

The *Framework* repeatedly emphasizes that practices are not taught in isolation but are an essential part of content instruction. Consider this quote from page ES-1 (emphasis added): "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."

Analysis

The notion of moving from the language of inquiry to that of practices, and the inclusion of engineering practices, will most likely require an adjustment or paradigm shift for many science educators. For the experienced teacher or science educator who is familiar with the inquiry standards in *NSES* and has helped students meet them through the use of "inquiries," the practices will not seem that foreign. The added details and explanations of the practices will be an advantage to many users.

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The parallel discussion of each practice in both science and engineering does not imply that the two should be taught or learned at the same time, but rather intends to point out the similarities and differences among the practices in both disciplines. In some sense, the science practices have emerged from *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007) and *Ready, Set, Science!* (Michaels, Shouse, and Schweingruber 2008), both of which provide a review of the research on how students learn science and how that can be used in the creation of teaching materials and classroom instruction. The *Framework* builds on this research and has identified engineering practices as a parallel discussion.

In past years, science practices have not received the same emphasis that has been placed on content knowledge, nor has the integration of content and inquiry been achieved to any great extent. The *NGSS* most certainly will include an equal and integrated emphasis. Consider this quote from page 2-3: "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential." The integration of practices with the content will improve students' understanding of the concepts and purposes of science and will avoid the teaching and learning of the competencies of inquiry in isolation.

Suggested Action

The shift for most science educators in this area will be the movement from the language and standards of inquiry in the *NSES* to the language of practices and becoming familiar with the engineering practices. To gain a better understanding of engineering, obtain *Engineering in K–12 Education: Understanding the Status and Improving the Prospects* (Katehi, Pearson, and Feders 2009) and *Standards for K–12 Engineering Education?* (NRC 2010b), two of the many documents referenced at the end of this *Framework* chapter, and use them as resources for study and discussion. Both can be downloaded for free from the National Academies Press at *www.nap.edu*.

Compare the practices of inquiry in your instruction, instructional materials, and assessment to those in the *Framework* to see what may need to be added or spelled out in more detail. Notice the progression of the goals for each practice. Check your grade level for the practices against those in the *Framework*. To what extent are they integrated with the content in your curriculum? Since the *NGSS* will integrate the three dimensions (see Chapter 9), beginning to review how practices of inquiry are integrated in your existing instruction—as well as how they are aligned and progress from level to level—will enhance your ability to use the anticipated new standards.

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Chapter 4

Dimension 2: Crosscutting Concepts

Overview

This chapter outlines the second dimension of the *Framework*, seven crosscutting concepts that have great value across the sciences and in engineering and that are considered fundamental to understanding these disciplines:

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

Analysis

Readers familiar with the *NSES* and *Benchmarks* will recognize that the *Framework*'s crosscutting concepts are similar to those in the Unifying Concepts and Processes in *NSES* and the Common Themes in *Benchmarks*. Although the previous documents call for the integration of these concepts with the content standards, the *Framework* specifically recommends, "Standards should emphasize all three dimensions articulated in the framework." (See Recommendation 4 in Chapter 12, p. 12-3.) This requirement will not only be a challenge to the writers of the *NGSS* but will also call for a major change in instructional materials and assessments.

Suggested Action

Participate in a review to determine if and how the Unifying Concepts and Processes in *NSES* and/or the Common Themes in *Benchmarks* are currently incorporated in your standards, curriculum, and instructional materials.

The list of crosscutting concepts in the *NGSS* will undoubtedly use the list in the *Framework,* making it possible to begin planning professional development to assist teachers in understanding and incorporating the concepts into their current teaching without waiting for the completion of the *NGSS.* The above review could serve as the impetus and needs assessment for the initiation and planning of the professional development. Exemplary instructional materials can serve as models and resources for the professional materials, but any adoption should await the release of the *NGSS*.

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Chapter 5

Dimension 3: Disciplinary Core Ideas: Physical Sciences

Overview

The physical sciences section has been organized under the following four core ideas and 13 component ideas.

Core Idea PS1: Matter and Its Interactions

- PS1.A: Structure and Properties of Matter
- PS1.B: Chemical Reactions
- PS1.C: Nuclear Processes

Core Idea PS2: Motion and Stability: Forces and Interactions

- PS2.A: Forces and Motion
- PS2.B: Types of Interactions
- PS2.C: Stability and Instability in Physical Systems

Core Idea PS3: Energy

- PS3.A: Definitions of Energy
- PS3.B: Conservation of Energy and Energy Transfer
- PS3.C: Relationship Between Energy and Forces
- PS3.D: Energy in Chemical Processes and Everyday Life

Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer

- PS4.A: Wave Properties
- PS4.B: Electromagnetic Radiation
- PS4.C: Information Technologies and Instrumentation

The *Framework* introduces each core and component idea with an essential question that frames the main concept. Each component idea also contains grade band "endpoints" for the end of grades 2, 5, 8, and 12.

Analysis

The *Framework* acknowledges that the content included in the first three physical science core ideas "parallel those identified in previous documents," including the *NSES* and *Benchmarks* (p. 5-1).

The authors introduce a fourth core idea, Waves and Their Applications in Technologies for Information Transfer, which "introduces students to the ways in which advances in the physical sciences during the 20th century underlie all sophisticated technologies today." In

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addition, the *Framework* acknowledges that "organizing science instruction around core disciplinary ideas tends to leave out the applications of those ideas" (p. 5-1). This core idea also provides an opportunity to stress the interplay between science and technology.

The endpoints, though not standards, will undoubtedly provide the disciplinary content that will form one of the three components in the performance standards called for in Recommendations 4 and 5 from Chapter 12.

Suggested Action

Review the *Framework* endpoints for the physical sciences and compare them with the topics or outcomes in your curriculum and assessment. In each of these content areas, we suggest educators keep an eye toward the vertical alignment of the content and check to see that there are no missing core ideas at each grade band. Keep in mind that some local topics/outcomes will not appear in the *Framework* since one of the charges to the writers was to "identify a small set of core ideas in each of the major science disciplines" (p. 1-11). Educators can anticipate finding additional content in their local curriculum, much of which can and should be eliminated as the curriculum is adjusted to meet the upcoming *NGSS*.

The inclusion of the fourth core idea will require some additions to the curriculum of most schools when the *NGSS* are released and adopted by states and schools. Instructional materials for this core idea may not be readily available for some time.

The suggested action section for Chapter 8, p. 24, contains suggestions for thinking about where and how engineering core ideas can be integrated in the science curriculum.

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Chapter 6

Dimension 3: Disciplinary Core Ideas: Life Sciences

Overview

The life sciences section has been organized under the following four core ideas and 14 component ideas.

Core Idea LS1: From Molecules to Organisms: Structures and Processes

- LS1.A: Structure and Function
- LS1.B: Growth and Development of Organisms
- LS1.C: Organization for Matter and Energy Flow in Organisms
- LS1.D: Information Processing

Core Idea LS2: Ecosystems: Interactions, Energy, and Dynamics

- LS2.A: Interdependent Relationships in Ecosystems
- LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
- LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- LS2.D: Social Interactions and Group Behavior

Core Idea LS3: Heredity: Inheritance and Variation of Traits

- LS3.A: Inheritance of Traits
- LS3.B: Variation of Traits

Core Idea LS4: Biological Evolution: Unity and Diversity

- LS4.A: Evidence of Common Ancestry and Diversity
- LS4.B: Natural Selection
- LS4.C: Adaptation
- LS4.D: Biodiversity and Humans

The *Framework* introduces each core and component idea with an essential question that frames the main concept. Each component idea also contains grade band "endpoints" for the end of grades 2, 5, 8, and 12.

Analysis

The *Framework* states that the four core ideas "have a long history and solid foundation based on the research evidence established by many scientists working across multiple fields" (p. 6-2). The ideas draw on those identified in previous documents, including the *NSES* and *Benchmarks*, as well as numerous reports from the National Research Council (NRC), American Association for the Advancement of Science (AAAS), National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Science Study (TIMSS), College Board, and others.

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Suggested Action

Review the *Framework* endpoints for the life sciences and compare them with the topics or outcomes in your school or district's curriculum. Keep in mind that some local topics/outcomes will not appear in the *Framework* since one of the charges to the writers was to "identify a small set of core ideas in each of the major science disciplines" (p. 1-11). Educators can anticipate finding additional content in their local curriculum, much of which can and should be eliminated as the curriculum is adjusted to meet the upcoming *NGSS*.

Be aware of the progression of the endpoints in each grade band. The *Framework* has been very attentive to the progression of ideas for each of the core ideas. The grade band or level may be different from your curriculum or from that of the *NSES* or *Benchmarks*.

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Chapter 7

Dimension 3: Disciplinary Core Ideas: Earth and Space Sciences

Overview

The Earth and space sciences section has been organized under the following three core ideas and 12 component ideas.

Core Idea ESS1: Earth's Place in the Universe

- ESS1.A: The Universe and Its Stars
- ESS1.B: Earth and the Solar System
- ESS1.C: The History of Planet Earth

Core Idea ESS2: Earth's Systems

- ESS2.A: Earth Materials and Systems
- ESS2.B: Plate Tectonics and Large-Scale System Interactions
- ESS2.C: The Roles of Water in Earth's Surface Processes
- ESS2.D: Weather and Climate
- ESS2.E: Biogeology

Core Idea ESS3: Earth and Human Activity

- ESS3.A: Natural Resources
- ESS3.B: Natural Hazards
- ESS3.C: Human Impacts on Earth Systems
- ESS3.D: Global Climate Change

Analysis

The *Framework* authors drew from several recent projects to delineate the Earth and space sciences content, including *Earth Science Literacy Principles: The Big Ideas and Supporting Concepts of Earth Science* (Earth Science Literacy Initiative 2010), *Ocean Literacy: The Essential Principles of Ocean Science K–12* (NGS 2006), *Essential Principles and Fundamental Concepts for Atmospheric Science Literacy* (UCAR 2008), and *Climate Literacy: The Essential Principles of Climate Science* (U.S. Global Change Research Program 2009). The core ideas include a broader range of content than most previous standards documents, but fewer outcomes. The increased breadth is especially evident in the third core idea, Earth and Human Activity, which deals with the increased stress on the planet and its resources due to rapidly increasing population and global industrialization.

Although the core ideas of Earth and space science cover a broader range of ideas, when compared to most Earth and space science instructional materials, the number of topics (components) has been reduced significantly in most areas and the topic of human impact has been more significantly stressed. This shift will ultimately place a burden on teachers and curriculum specialists to modify their curriculum and course syllabi.

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Suggested Action

Begin the process of comparing your local curriculum to the endpoints for Earth and Space Sciences in the *Framework*. You may find that your curriculum or instructional materials have more topics and more detailed information or concepts than those outlined in the *Framework*. The opposite may be true for the third core idea, Earth and Human Activity, which describes how Earth's processes and human activity affect each other. Be aware of the progression of the endpoints in each grade band. The *Framework* has been very attentive to the progression of ideas for each of the core ideas. Local examples and illustrations of Earth science core ideas are excellent teaching resources. Begin to catalog them for use in the current curriculum or the revised curriculum, as it will help implement the *NGSS*.

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Chapter 8
Dimension 3: Disciplinary Core Ideas: Engineering, Technology, and Applications of Science

Overview
The engineering, technology, and applications of sciences section has been organized under the following two core ideas and five component ideas.

Core Idea ETS1: Engineering Design
- ETS1.A: Defining and Delimiting an Engineering Problem
- ETS1.B: Developing Possible Solutions
- ETS1.C: Optimizing the Design Solution

Core Idea ETS2: Links Among Engineering, Technology, Science, and Society
- ETS2.A: Interdependence of Science, Engineering, and Technology
- ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Analysis
While the intent of this chapter is to help students learn how science is used through the engineering design process, the two core ideas have different goals. The goal of the first idea is to help students develop an understanding of engineering design, while the second is to help them make connections among engineering, technology, and science. Although the *language* defining the process of engineering design may be new to science educators, the *ideas* are not new for many of them, particularly those at the elementary level and those using project activities in their teaching. For example, students designing and building a structure in an elementary science unit have followed the three procedures described in the Core Idea ETS1, possibly without the explicit understanding of the engineering design process and use of the terminology.

The early paragraphs in this chapter provide the essential, but limited, direction that learning engineering requires, combining the engineering practices outlined in Chapter 3 with the understanding of engineering design contained in Chapter 8 in the same way that science involves both knowledge and a set of practices.

The second core idea is an excellent complement to the engineering core ideas taught in the science curriculum since it brings together the interdependence of engineering, technology, science, and society. Readers familiar with the standards for Science in Personal and Societal Perspectives in the *NSES* will see some overlap with the core ideas in this section of the *Framework*.

The core ideas in this chapter and those in Chapter 3 dealing with engineering practices may prove to be a significant shift for science educators when the *NGSS* appear. Although many teachers and instructional materials rely on activities that are engineering in nature, the language and specific outcome described in Core Ideas ETS1 and ETS2 are not normally included as part of the activities. A paradigm shift is called for that might be approached with the following professional development activities and curriculum development work.

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Suggested Action

Form study or discussion groups to read and discuss the nature of engineering using resources such as the National Academy of Engineering publication *Standards for K–12 Engineering Education?* (NRC 2010b). This and many other reports can be downloaded for free at *www.nap.edu.*

Study the definitions in Box 8-1, "Definitions of Technology, Engineering, and Applications of Science" (p. 8-11), at the end of the chapter to help gain clarity on the distinction between engineering and technology. Notice the connection between the two definitions. An excellent book on the nature of technology is *The Nature of Technology: What It Is and How It Evolves* (Arthur 2009).

Assemble a team to begin assessing how and where engineering core ideas might be integrated in the science curriculum at each grade band in your school or district. Some courses or units lend themselves to this integration better than others. What are they? Do new activities or units need to be added? Can some of the existing activities be modified or supplemented to provide outcomes in engineering? Where and how can the endpoints from the practices of engineering and the core ideas in this chapter be combined as parallel outcomes of modified or new activities?

Identify or plan professional development activities to immerse teachers in doing engineering design projects and gaining knowledge of the language and endpoints expected of their students. Keep in mind that a thorough modification and revision of instructional material should wait until the new standards are reasonably complete and available.

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PART III: Realizing the Vision

Chapter 9
Integrating the Three Dimensions

Overview

This chapter describes the process of integrating the three dimensions (practices, crosscutting concepts, and core ideas) in the *NGSS* and provides two examples for its writers, as well as for the writers of instructional materials and assessments. The preceding chapters described the dimensions separately to provide a clear understanding of each; this chapter recognizes the need and value of integrating them in standards and instruction. The *Framework* is specific about this task as indicated by the following statement (p. 9-1): "A major task for developers will be to create standards that integrate the three dimensions. The committee suggests that this integration should occur in the standards statements themselves and in performance expectations that link to the standards."

This expectation is based on the assumption that "students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. … At the same time, they cannot learn or show competence in practices except in the context of specific content" (p. 9-1).

Performance expectations are a necessary and essential component of the standard statements. These expectations describe how students will demonstrate an understanding and application of the core ideas. The chapter provides two illustrations in Table 9-1, "Sample Performance Expectations in the Life Sciences" (p. 9-12), and Table 9-2, "Sample Performance Expectations in the Physical Sciences" (p. 9-16), of what the performance expectation could look like for two core ideas.

Although it is not the function of the *Framework* or the *NGSS* to provide detailed descriptions of instruction, this *Framework* chapter offers a fairly extensive example—in narrative form—of what the integration of the three dimensions for a physical science core idea at each grade band (K–2, 3–5, 6–8, and 9–12) would look like. One of the unique features of this example is the inclusion of "boundary statements" that specify ideas that do *not* need to be included. The standard statements are expected to contain boundary statements.

Analysis

Although Tables 9-1 and 9-2 are extensive examples of performance expectation for two core ideas, they are not a model for the format of the standards statements that will appear in the *NGSS*. The practices and crosscutting concepts are only identified and not spelled out in performance language. We will not know the actual format and structure of the standards that integrate the three dimensions until the first draft is released, and we will not know specifics of the final standards until sometime later. The new integrated standards will be a significant

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departure from those in the previous national standards documents, and they will have a huge impact on instruction, instructional materials, and assessments for science educators.

There are few, if any, examples or precedents for this type of standard. Such standards may very well prescribe the instruction and assessment that should be included in the curriculum and instructional materials. Performance expectations indicate the core idea, the practice that should be used or at least emphasized, and the crosscutting concepts that should be included. The performance for each of the dimensions comes close to describing how each should be assessed. The detailed instructional strategies and instructional materials will be left to the instructor, but the outcomes suggested by the practices will be determined by the standard statements and the associated performance expectations.

Suggested Action

The development of instructional materials, their implementation, and the associated assessment from integrated standards will be the second major shift (after the inclusion of engineering) that appears in the *NGSS*. We recommend the following general strategies to accommodate this shift:

- Conduct extensive reading, form study groups, and explore other professional development avenues to become deeply familiar with the scientific and engineering practices, the crosscutting concepts, and the core ideas in the *Framework*. The integration of the dimensions will be most effective if educators have a thorough and clear understanding of each dimension.
- Study Tables 9-1 and 9-2 and the narrative example of instruction from the physical sciences.
- Begin searching for instructional materials that explicitly integrate the three dimensions. Examples may begin to appear in professional literature such as NSTA journals. Examine and evaluate them carefully.
- When the first draft of the *NGSS* appears, study carefully the content of a standard statement at your grade band. As a learning exercise, assemble a small team of colleagues and sketch out a series of lessons or a small unit to facilitate a group of students meeting the performance expectations in the standard. This exercise is only a sample of what will be required to meet the new performance expectations, but it will assist in your planning of longer-range activities and projects when the final version of the *NGSS* is published and adopted by your state or school district.

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Chapter 10

Implementation: Curriculum Instruction, Teacher Development, and Assessment

Overview

Most readers will recall that the *NSES* include standards for the components of teaching, professional development, assessment, educational programs, and educational systems. This chapter acknowledges the value of those standards and the fact that the charge to the *Framework* developers did not include a similar comprehensive assignment to provide standards or even recommendations. This chapter assumes the task of analyzing the overall education system and discusses "what must be in place in order for [each component] to align with the framework's vision" (p. 10-1). In doing so, it depends heavily on a number of recent reports from the NRC that reviewed the research related to each component in the *Framework*. These include *Knowing What Students Know* (Pellegrino, Chudowsky, and Glaser 2001), *Investigating the Influence of Standards* (Weiss et al. 2002), *Systems for State Science Assessments* (Wilson and Bertenthal 2006), *America's Lab Report* (Singer, Hilton, and Schweingruber 2006), *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007), and *Preparing Teachers* (NRC 2010a).

After briefly describing the total education system and calling for coherence within it, the *Framework* addresses the components of curriculum and instruction, teacher development, and assessment.

The section on curriculum and instruction lists a variety of "aspects for curriculum designers to consider that are not addressed in the framework … that the committee considers important but decided would be better treated at the level of curriculum design than at the level of framework and standards" (p. 10-5). These include the historical, cultural, and ethical aspects of science and its applications, and the history of scientific and engineering ideas and the individual practitioners.

Analysis

For many experienced science educators, this section of the *Framework* is the most important despite its limited treatment. The missing ingredient in the first release of the *NSES* and *Benchmarks* was the lack of extensive implementation at the state and local level. Both the *NSES* and the *Benchmarks* received a great deal of attention and some replication in state standards, but the standards for teaching, professional development, assessment, program, and systems did not receive equal emphasis. NSTA believes that for new standards to be implemented successfully, a significant emphasis must be placed on outreach and support for science educators.

The section in the *Framework* on instruction does not go into great depth on the topic and defers to the extensive discussion of the topic and the research behind it in *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007). Teacher development and assessment sections are also light and depend on existing NRC reports previously listed in the overview section.

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Suggested Action

The call to integrate the practices, crosscutting concepts, and the core ideas will require a new and greater emphasis on incorporating change in all components of the system. The *NGSS* are what is to be implemented, not the *Framework*, but the task of implementation needs to start now, long before the *NGSS* are published and adopted in states and school districts. It is not the role of this guide to spell out the multiple steps and decisions that need to be made to implement a new set of standards, but that process needs to begin now! The starting points have been outlined in the previous sections.

To stay informed, follow the NSTA *NGSS* website (*www.nsta.org/ngss*), which provides a continuous flow of information about the draft versions of *NGSS* as they are released.

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Chapter 11
Equity and Diversity in Science and Engineering Education

Overview
This chapter highlights the issues in achieving equity in education opportunities for all students, summarizes the research on the lack of equity in education in general and science education in particular, describes what should be available for all students in broad strokes, and makes a limited number of specific recommendations to the standards developers. The discussion of inequity of education achievement among specific demographic groups is reduced to two key areas: (1) the differences in the opportunity to learn due to inequities in schools and communities; and (2) the lack of inclusiveness in instruction to motivate diverse student populations. The research is clear that all students, with rare exceptions, have the capacity to learn complex subject matter when support is available over an extended period of time.

The *Framework* recommends that the *NGSS* (1) specify that rigorous learning goals (standards) are appropriate for all students and (2) make explicit the need for the instructional time, facilities, and teacher knowledge that can help all students achieve these goals.

On a more general but no less significant level, the *Framework* recommendations address the need to equalize the opportunity to learn. This means providing inclusive science instruction, making diversity visible, and providing multiple modes of expression. To make science instruction more inclusive, the *Framework* suggests several strategies: approaching science learning as a cultural accomplishment, relating youth discourses to scientific discourses, building on prior interest and identity, and leveraging students' cultural funds of knowledge.

The final recommendation in the chapter focuses on creating assessments that use multiple opportunities for students to express their understanding of the content in multiple contexts and avoiding culturally biased assessment instruments.

Analysis
The *Framework* gives the critical issue of equity and diversity modest attention, but it provides a number of well-researched recommendations. Most of the recommendations in the chapter focus on instruction and cultural contexts of education more than the nature of standards. The limited attention to these issues in the *Framework*, due to the charge to the committee of writers, should in no way detract from its extreme importance.

Suggested Action
Schools should reexamine their progress with equity and diversity and reshape their efforts based on the specific recommendations provided in the *Framework*. There is no need to wait to address these issues until the *NGSS* are released; the issues of equity and diversity should be an ongoing agenda for all schools and teachers, and should be addressed aggressively and consistently.

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Chapter 12
Guidance for Standards Developers

Overview
This chapter opens with the recommendation from *Systems for State Science Assessments* (Wilson and Bertenthal 2006) that standards should be "clear, detailed, and complete; reasonable in scope; rigorously and scientifically correct, and based on sound models of student learning … [and] should have a clear conceptual framework, describe performance expectations, and identify proficiency levels" (p. 12-1).

It then lists the following 13 specific recommendations for standard developers with a short discussion following each recommendation. (These recommendations are quoted directly from the *Framework*.)

1. Standards should set rigorous learning goals that represent a common expectation for all students (p. 12-2).
2. Standards should be scientifically accurate yet also clear, concise, and comprehensible to science educators (p. 12-2).
3. Standards should be limited in number (p. 12-3).
4. Standards should emphasize all three dimensions articulated in the framework—not only crosscutting concepts and disciplinary core ideas but also scientific and engineering practices (p. 12-3).
5. Standards should include performance expectations that integrate the scientific and engineering practices with the crosscutting concepts and disciplinary core ideas. These expectations should include criteria for identifying successful performance and require that students demonstrate an ability to use and apply knowledge (p. 12-4).
6. Standards should incorporate boundary statements. That is, for a given core idea at a given grade level, standards developers should include guidance not only about what needs to be taught but also about what does ***not*** need to be taught in order for students to achieve the standard (p. 12-4).
7. Standards should be organized as sequences that support students' learning over multiple grades. They should take into account how students' command of the practices, concepts, and core ideas becomes more sophisticated over time with appropriate instructional experiences (p. 12-5).
8. Whenever possible, the progressions in standards should be informed by existing research on learning and teaching. In cases in which insufficient research is available to inform a progression or in which there is a lack of consensus on the research findings, the progression should be developed on the basis of a reasoned argument about learning and teaching. The sequences described in the framework can be used as guidance (p. 12-5).
9. The committee recommends that the diverse needs of students and of states be met by developing grade band standards as an overarching common set for adoption by multiple

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states. For those states that prefer or require grade-by-grade standards, a suggested elaboration on grade band standards could be provided as an example (p. 12-6).

10. If grade-by-grade standards are written based on the grade band descriptions provided in the framework, these standards should be designed to provide a coherent progression within each grade band (p. 12-7).
11. Any assumptions about the resources, time, and teacher expertise needed for students to achieve particular standards should be made explicit (p. 12-7).
12. The standards for the sciences and engineering should align coherently with those for other K–12 subjects. Alignment with the Common Core Standards in mathematics and English/language arts is especially important (p. 12-7).
13. In designing standards and performance expectations, issues related to diversity and equity need to be taken into account. In particular, performance expectations should provide students with multiple ways of demonstrating competence in science (p. 12-8).

Analysis

Although specifically addressed to Achieve Inc., the group writing the *NGSS*, the recommendations provide a preview of what to expect in the standards document. The reader will notice that the 13 recommendations are closely aligned with the content of the first 11 chapters.

Suggested Action

A few states and districts may be developing their own standards independent of the work being undertaken by Achieve Inc. To those few, the recommendations are germane and highly relevant. To the majority of readers, they are predictors of what to expect in the first and subsequent drafts of the *NGSS*. In most cases, more attention should be paid to the previous sections where the issues that give rise to the recommendations are well articulated.

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Chapter 13

Looking Toward the Future: Research and Development to Inform K–12 Science Education Standards

Overview

Chapter 13 reminds the reader that the *Framework* is based on research and lays out the research agenda for the next near term (five to seven years) and the long term (seven years and beyond). The recommended agenda can be summarized with the following outline, which lists two major areas of research with a number of issues or questions under each.

I. Research to Inform Implementation and Future Revisions of the Framework
- A. Learning and Instruction
  1. What are the typical preconceptions that students hold about the practices, crosscutting concepts, and core ideas at the outset?
  2. What is the expected progression of understanding, and what are the predictable points of difficulty that must be overcome?
  3. What instructional interventions (e.g., curriculum materials, teaching practices, simulations or other technology tools, instructional activities) can move students along a path from their initial understanding to the desired outcome?
  4. What general and discipline-specific norms and instructional practices best engage and support student learning?
  5. How can students of both genders and of all cultural backgrounds, languages, and abilities become engaged in the instructional activities needed to move toward more sophisticated understanding?
  6. How can the individual student's understanding and progress be monitored? (p. 13-2)
- B. Learning Progressions
- C. Scientific and Engineering Practices
- D. Development of Curricular and Instructional Materials
- E. Assessment
- F. Supporting Teachers' Learning

II. Understanding the Impact of the Framework and Related Standards
- A. Curriculum and Instructional Materials
- B. Teacher and Administrator Development
- C. Assessment and Accountability
- D. Organizational Issues

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Analysis

Throughout the *Framework*, the reader is reminded that the document is based on a considerable body of solid education research, which is cited frequently. It should be pointed out that the National Research Council does not do original research; it reviews and evaluates the research already completed by others. The NRC is a part of the National Academies, a private nonprofit institution that provides expert advice on some of the most pressing challenges facing the nation and the world through the publication of reports that have helped shape sound policies; inform public opinion; and advance the pursuit of science, engineering, and medicine. Several new documents are cited in this chapter, including *Learning and Instruction: A SERP (Strategic Education Research Partnership) Research Agenda* (Donovan and Pellegrino 2004), which influenced the agenda and research question on learning and instruction in the *Framework*. The questions in the report could lead to and shape local school district or university cooperative research activities.

Suggested Action

Motivated readers may want to acquire and study the various research reports from the NRC that have been cited in the earlier chapters. As the standards are released and adoption and implementation begin, the question of why many of the changes or shifts from the previous documents and recommendations for classroom practices were made will be asked. The background research can be useful in making local and state decisions for curriculum and assessment and defending them in public and legislative settings.

The suggested action items in the previous chapters provide a host of ideas for science educators and others to gain a deep understanding of the *Framework* as a stand-alone document and as a guide to the use of the forthcoming *NGSS*. We encourage you to pursue these and other opportunities with colleagues to better prepare for the new standards.

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NSTA believes the *Framework* provides valuable guidance and recommendations to encourage the development of standards that allow for the teaching of science in greater depth. We are a committed partner in the process of developing new standards and will stay involved to ensure that the voices of science educators are heard and that the *NGSS* are the best they can be.

NSTA is developing extensive resources to help science educators and other stakeholders address the changes that the *Framework* and the upcoming *Next Generation Science Standards* will bring. All resources will be available online at *www.nsta.org/ngss*. Also look for updates in NSTA's four member journals as well as in *NSTA Express* and *NSTA Reports*.

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"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."

—*From the Executive Summary of* A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

A Framework for K–12 Science Education provides a broad set of learning expectations for students as they study science and engineering throughout the K–12 years. The *Framework* guides the writers of the forthcoming *Next Generation Science Standards (NGSS)*; will influence curriculum, assessment, and teacher professional development decisions for years to come; and ultimately will help inspire new generations of science and engineering professionals and scientifically literate citizens.

This handy *Reader's Guide* unpacks the three key dimensions of the *Framework*—scientific and engineering practices, crosscutting concepts, and core ideas in each specific discipline—allowing teachers, administrators, curriculum developers, university professors, and others to more easily grasp how the soon-to-be-released *Next Generation Science Standards* will differ from the current standards. Harold Pratt, a former NSTA president, a career science coordinator, and a National Research Council senior program officer during the development of the *National Science Education Standards*, offers the following for each chapter of the *Framework*:

- An overview with a brief synopsis of key ideas
- An analysis of what is similar to and what is different from the *NSES*
- A suggested action to help readers understand and start preparing for the *NGSS*

This NSTA *Reader's Guide* is a critical companion to the *Framework* for science educators nationwide as they prepare to incorporate the upcoming standards into their teaching of science and engineering.

The *Reader's Guide* is also available as a free PDF from the National Science Teachers Association. Please visit *www.nsta.org/store* to download your copy. The print edition of *A Framework for K–12 Science Education* is expected in early 2012 from the National Academies and will be available for purchase through NSTA.

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