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

Practices, Crosscutting Concepts, and Core Ideas

Second Edition

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EDUCATION

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PART I: A Vision for K–12 Science Education

PART II: Dimensions of the *Framework*

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Chapter 1

Introduction: A New Conceptual Framework

Overview

The best description of the general vision of *A Framework for K–12 Science Education* (*Framework*) is provided on pages 8–9:

> *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. 10):

> *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 National Research Council (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 *National Science Education Standards* (*NSES*) and *Benchmarks for Science Literacy* (*Benchmarks*).

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 *Next Generation Science Standards* (*NGSS*).

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. 41). 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. 43).
- 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.

A Framework for K–12 Science Education (*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" below.

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.

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 *Next Generation Science Standards* (*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. *A Framework for K–12 Science Education* (*Framework*) is specific about this task as indicated by the following statement (p. 218): "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. 218).

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. 220), and Table 9-2, "Sample Performance Expectations in the Physical Sciences" (p. 224), 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 appear in the *NGSS*. The practices and crosscutting concepts are only identified and not spelled out in performance language. The new integrated standards are a significant 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

Scientific and Engineering Practices in K–12 Classrooms

By Rodger W. Bybee

This morning I watched *Sesame Street*. During the show, characters "acted like engineers" and designed a boat so a rock could float. In another segment, children asked questions and made predictions about the best design for a simple car. They then built a model car and completed an investigation to determine which design worked best when the cars went down inclined planes. Children also learned that a wider base provided stability for a tower. And, among other segments, the children counted from 1 to 12 and explored the different combinations of numbers that equaled 12. Bert and Ernie had to move a rock and ended up "inventing" a wheel. These segments exemplify the science, technology, engineering, and mathematics (STEM) theme that *Sesame Street* is introducing in the show's 42nd season.

What, you ask, does this have to do with science and engineering practices in K–12 classrooms? The producers of *Sesame Street* decided that STEM practices were important enough that they are using them as substantive themes for the season, if not longer. Children watching *Sesame Street* will have been introduced to practices such as asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics; constructing explanations and designing solutions; engaging in arguments using evidence; and obtaining, evaluating, and communicating information. True, these are sophisticated statements of practices, but many students will be introduced to them when they enter elementary classrooms.

Here, I present the science and engineering practices from the recently released *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (*Framework*; NRC 2012). I recognize the changes implied by the new framework, and eventually a new generation of science education standards will present new perspectives for the science education community. I am especially sensitive to the challenges for those students in teacher preparation programs and classroom teachers of science at all levels. Questions such as "Why practices and why not inquiry?" and "Why science *and* engineering?" are reasonable, and I will discuss them later. But to provide background and context, I first discuss the practices.

Understanding and applying the science and engineering practices

This section further elaborates on the practices and briefly describes what students are to know and be able to do and how they might be taught. Figures 1 through 8 are adapted from the National Research Council (NRC) *Framework*, with changes for clarity and balance. I have maintained the substantive content.

Even before elementary school, children ask questions of each other and of adults about things around them, including the natural and designed world. If students develop the practices of science and engineering, they can ask better questions and improve how they define problems. Students should, for example, learn how to ask questions of each other, to recognize the difference between questions and problems, and to evaluate scientific questions and engineering problems from other types of questions. In upper grades, the practices of asking scientific questions and defining engineering problems advance in subtle ways such as the form and function of data used in answering questions and the criteria and constraints applied to solving problems.

In the lower grades, the idea of scientific and engineering models can be introduced using pictures, diagrams, drawings, and simple physical models such as airplanes or cars. In upper grades, simulations and more sophisticated conceptual, mathematical, and computational models may be used to conduct investigations, explore changes in system components, and generate data that can be used in formulating scientific explanations or in proposing technological solutions.

Planning and carrying out investigations should be standard experiences in K–12 classrooms. Across the grades students develop deeper and richer understandings and abilities as they conduct different types of investigations, use different technologies to collect data, give greater attention to the types of variables, and clarify the scientific and/or engineering contexts for investigations.

Figure 1. Asking questions and defining problems

Science begins with a question about a phenomenon such as "Why is the sky blue?" or "What causes cancer?" 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?" A basic practice of engineers is to ask questions to clarify the problem, determine criteria for a successful solution, and identify constraints.

Figure 2. Developing and using models

Science often involves the construction and use of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and simulate a world not yet seen. Models enable predictions of the form "if…then…therefore" to be made in order to test hypothetical explanations.	**Engineering** makes use of models and simulations to analyze extant systems to identify flaws that might occur, or to test possible solutions to a new problem. Engineers design and use models of various sorts to test proposed systems and to recognize the strengths and limitations of their designs.

Figure 3. Planning and carrying out investigations

Scientific investigations may be conducted in the field or in the laboratory. A major practice of scientists is planning and carrying out systematic investigations that require clarifying what counts as data and in experiments identifying variables.	**Engineering investigations** are conducted to gain data essential for specifying criteria or parameters and to test proposed designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for analysis. Their investigations help them to identify the effectiveness, efficiency, and durability of designs under different conditions.

Core Ideas of Engineering and Technology

By Cary Sneider

Rodger Bybee's chapter, "Scientific and Engineering Practices in K–12 Classrooms," provided an overview of Chapter 3 in *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (*Framework*; NRC 2012). Chapter 3 describes the practices of science and engineering that students are expected to develop during 13 years of schooling and emphasizes the similarities between science and engineering.

This essay addresses Chapter 8 of the *Framework,* which presents core ideas in technology and engineering at the same level as core ideas in the traditional science fields, such as Newton's laws of motion and the theory of biological evolution. Although prior standards documents included references to engineering and technology, they tended to be separate from the "core content" of science, so they were often overlooked.

Giving equal status to engineering and technology raises a number of important issues for curriculum developers and teachers, a few of which I will discuss here:

- How does the *Framework* define *science, engineering,* and *technology?*
- What are the core ideas in Chapter 8?
- Why is there increased emphasis on engineering and technology?
- Is it redundant to have engineering practices *and* core ideas?
- Do we need to have special courses to teach these core ideas?
- Will teachers need special training?
- What will it look like in the classroom?

How does the *Framework* define *science, engineering,* and *technology?*

The meanings of these terms are summarized in the first chapter of the *Framework* as follows:

> *In the K–12 context, science is generally taken to mean the traditional natural sciences: physics, chemistry, biology, and (more recently) Earth, space, and environmental sciences. . . . We use the term engineering in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term technology to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants.* (NRC 2012, pp. 11–12)

Notice that engineering is *not* defined as applied science. Although the practices of engineering have much in common with the practices of science, engineering is a distinct field and has certain core ideas that are different from those of science. Given the need to limit the number of standards so that the task for teachers and students is manageable, just two core ideas are proposed in Chapter 8. The first concerns ideas about engineering design that were not addressed in Chapter 3, and the second concerns the links among engineering, technology, science, and society.

What are the core ideas in Chapter 8?

As with core ideas in the major science disciplines, the two core ideas related to engineering and technology are first stated broadly, followed by grade band endpoints to specify what additional aspects of the core idea students are expected to learn at each succeeding level. Following are brief excerpts from the rich descriptions in the *Framework:*

Core Idea 1: Engineering Design

From a teaching and learning point of view, it is the iterative cycle of design that offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices. The components of this core idea include understanding how engineering problems are defined and delimited, how models can be used to develop and refine possible solutions to a design problem, and what methods can be employed to optimize a design. (NRC 2012, pp. 201–202)

- By the end of second grade, students are expected to understand that engineering problems may have more than one solution and that some solutions are better than others.
- By the end of fifth grade, students are expected to be able to specify problems in terms of criteria for success and constraints, or limits, to understand that when solving a problem it is important to generate several different design solutions by taking relevant science knowledge into account and to improve designs through testing and modification. In some cases it is advisable to push tests to the point of failure to identify weak points.
- By the end of middle school, students should be able to recognize when it makes sense to break complex problems into manageable parts; to systematically evaluate different designs, combining the best features of each; to conduct a series of tests to refine and optimize a design solution; and to conduct simulations to test if–then scenarios.
- By the time they graduate from high school, students should be able to do all of the above and, in addition, formulate a problem with quantitative specifications; apply knowledge of both mathematics and science to develop and evaluate possible solutions; test designs using mathematical, computational, and physical models; and have opportunities to analyze the way technologies evolve through a research and development cycle.

Core Idea 2 (Links Among Engineering, Technology, Science, and Society) has two components that are more distinct than the three components of engineering design, so they are listed separately.