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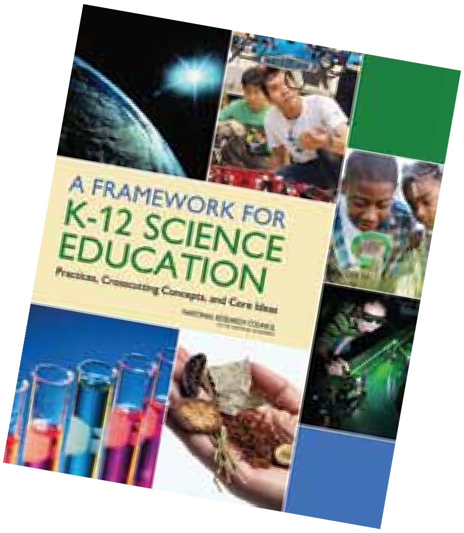
Core Ideas of Engineering and Technology

Understanding *A Framework for K–12 Science Education*



By Cary Sneider

Last month, Rodger Bybee's article, "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* (NRC 2011). 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 article 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 in this article:

- 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 meaning of these terms is 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 2011, pp. 1–3, 4)

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 2011, p. 8–1)

- 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 (R&D) 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.

Core Idea 2A: Interdependence of Science, Engineering, and Technology

The fields of science and engineering are mutually supportive. New technologies expand the reach of science, allowing the study of realms previously inaccessible to investigation; scientists depend on the work of engineers to produce the instruments and computational tools they need to conduct research. Engineers in turn depend on the work of scientists to understand how different technologies work so they can be improved; scientific discoveries are exploited to create new technologies in the first place. Scientists and engineers often work together in teams, especially in new fields, such as nanotechnology or synthetic biology that blur the lines between science and engineering. (NRC 2011, p. 8–2)

- By the end of second grade, students should know that engineers design a great many different types of tools that scientists use to make observations and measurements. Engineers also make observations and measurements to refine solutions to problems.
- By the end of fifth grade, students learn more about the role played by engineers in designing a wide variety of instruments used by scientists (e.g., balances, thermometers, graduated cylinders, telescopes, and microscopes). They also learn that scientific discoveries have led to the development of new and improved technologies.
- By the end of eighth grade, students learn that engineering advances have led to the establishment of new fields of science and entire industries. They also learn that the need to produce new and improved technologies (such as sources of energy that do not rely on fossil fuels and vaccines to prevent disease) have led to advances in science.
- By the time they graduate from high school, students should be aware of how scientists and engineers who have expertise in a number of different fields work together to solve problems to meet society's needs.

Core Idea 2B: Influence of Engineering, Technology, and Science on Society and the Natural World

The applications of science knowledge and practices to engineering, as well as to such areas as medicine and agriculture, have contributed to the technologies and the systems that support them that serve people today. . . . In turn, society influences science and engineering. Societal decisions, which may be shaped by a variety of economic, political, and cultural factors, establish goals and priorities for technologies' improvement or replacement. Such decisions also set limits—in controlling the extraction of raw materials, for example, or in setting allowable emissions of pollution from mining, farming, and industry. (NRC 2011, p. 8–1)

- By the end of second grade, students recognize that their lives depend on various technologies and that life would be very different if those technologies were to disappear. They also understand that all products are made from natural materials and that creating and using technologies have impacts on the environment.
- By the end of fifth grade, students realize that as people's needs and wants change so do their demands for new and improved technologies that drive the work

of engineers. And when those new technologies are developed, they may bring about changes in the ways that people live and interact with each other.

- By the end of eighth grade, students are familiar with cases in which the development of new and improved technologies has had both positive and negative impacts on people and the environment. They understand that the development of new technologies is driven by individual and societal needs as well as by scientific discoveries and that available technologies differ from place to place and over time because of such factors as culture, climate, natural resources, and economic conditions.
- By the time they graduate from high school, students are aware of the major technological systems that support modern civilization; how engineers continually modify these systems to increase benefits while decreasing risks; and how adoption of new technologies depends on such factors as market forces, societal demands, and government support or regulation. By the end of 12th grade, students should be able to analyze costs and benefits so as to inform decisions about the development and use of new technologies.

Why is there increased emphasis on engineering and technology?

The commitment to engineering and technology in the *Framework* is extensive, as references to these terms are found throughout the document. A rationale for this increased emphasis is stated in different ways at a number of places in the *Framework*. One reason is inspirational, as described in the following paragraph:

> *We anticipate that the insights gained and interests provoked from studying and engaging in the practices of science and engineering during their K–12 schooling should help students see how science and engineering are instrumental in addressing major challenges that confront society today, such as generating sufficient energy, preventing and treating diseases, maintaining supplies of clean water and food, and solving the problems of global environmental change. In addition, although not all students will choose to pursue careers in science, engineering, or technology, we hope that a science education based on the* Framework *will motivate and inspire a greater number of people—and a better representation of the broad diversity of the American population—to follow these paths than is the case today.* (NRC 2011, p. 1–2)

A second reason is practical. The value of developing useful knowledge and skills is summed up in the following:

> *First, the committee thinks it is important for students to explore the practical use of science, given that a singular focus on the core ideas of the disciplines would tend to shortchange the importance of applications. Second, at least at the K–8 level, these topics typically do not appear elsewhere in the curriculum and thus are neglected if not included in science instruction. Finally, engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science—and, for many, their interest in science—as they recognize the interplay among science, engineering, and technology. We are convinced that engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science.* (NRC 2011, p. 1–4)

Is it redundant to have engineering practices *and* core ideas?

This is an excellent question, especially because there is no corresponding chapter about core ideas of scientific inquiry. However, a close reading of the document will reveal that although there is some overlap between Chapter 3 and Chapter 8, very little of the content is redundant. Chapter 3 treats engineering design as a set of practices that are similar to scientific inquiry. So students may develop these abilities in the context of asking and answering questions about the world as well as systematically solving problems. Chapter 8 expands on engineering design in ways not mentioned in Chapter 3, addressing such issues as systematically evaluating potential solutions, testing to failure, and the process of optimization.

Also, a major focus of Chapter 8 concerns the interrelationships among science, engineering, technology, society, and the environment, which are essential for all students and are not addressed anywhere else in the document. An important message of this set of core ideas is that it is important for everyone not only to know how to design technological solutions to problems, but also to think broadly about the potential impacts of new and improved technologies and to recognize the role and responsibility that all citizens have to guide the work of scientists and engineers by the decisions they make as workers, consumers, and citizens.

Do we need to have special courses to teach these core ideas?

The *Framework* provides a broad description of the content and sequence of learning expected of all students but does not provide grade-by-grade standards or specify courses at the high school level. There are many ways that these ideas can be combined and presented using a wide variety of media and learning activities. Schools are not asked to offer courses entitled "Engineering" or "Technology" any more than they are asked to offer courses with the title "Scientific Inquiry," although they may certainly do so. And although the *Next Generation Science Standards* (Achieve, Inc., forthcoming) that will be based on the *Framework* will specify learning standards at a finer level of detail, it is not expected to recommend specific courses.

Will teachers need special training?

Many of the ideas about engineering and technology in the *Framework* will be familiar to today's science teachers. Many science curriculum materials include practical applications of science concepts and provide design challenges alongside science inquiry activities. Subjects such as circuit electricity and simple machines, which fall squarely in the realm of technology, have traditionally been a part of the science curriculum.

However, there will be subtle but important differences that teachers will need to become aware of. For example, design challenges are commonly presented without specific instruction in engineering design principles. Although students may have a good time and come up with creative solutions, without specific guidance they are not likely to learn about the value of defining problems in terms of criteria and constraints, how to use the problem definition to systematically evaluate alternative solutions, how to construct and test models, how to use failure analysis, or how to prioritize constraints and use trade-offs to optimize a design. Consequently, it will take some time for curriculum developers and teachers to learn about the new features of the *Framework* and incorporate these ideas into their practices. Undoubtedly the process will be greatly facilitated by inservice professional development as well as modifications of preservice preparation programs for new teachers.

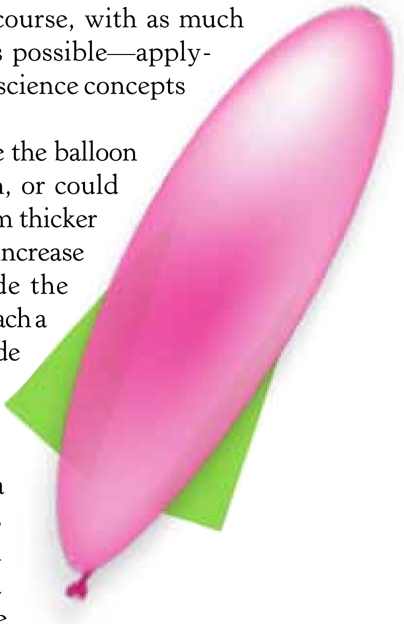
What will it look like in the classroom?

There are innumerable examples in existing curricula that illustrate engineering and technology instruction at all grade levels, many in conjunction with lessons in the natural sciences. An extensive database of materials with expert teacher reviews is available via the web at the National Center for Technological Literacy (2011), hosted by the Museum of Science in Boston. The free website, called the Technology & Engineering Curriculum (TEC) Review, provides a search engine that lets teachers search by grade level, topic, or science standards to find relevant materials.

Because selecting any one of the existing materials as an example would be unfair to all the others, I've chosen to close this article with an invented example, to illustrate how the teaching of science might be enriched with an engineering activity.

Imagine a physical science class in which students are being introduced to Newton's third law, which states that every action has an equal and opposite reaction. The teacher blows up a balloon then lets it go. The balloon flies wildly around the room as air escapes out of the back end. The students are challenged to use Newton's third law to explain why the balloon flew around the room. If the students understand the basic concept the teacher might go on to have students solve numerical problems involving Newton's third law, or introduce a different topic.

Expanding on the lesson with an engineering design challenge is one way to introduce the relationship between science and engineering and to engage students in applying other concepts that they learned earlier in the year. Following the previous lesson, imagine that the teacher now asks the students to modify the balloon so that it flies more like a proper rocket—on a straight, predictable course, with as much speed and distance as possible—applying other appropriate science concepts learned previously.



Do they need to use the balloon the teacher gave them, or could they use one made from thicker rubber so they could increase the air pressure inside the balloon? Could they attach a straw and string to guide its path, or would the rocket need to fly freely? Teams would be urged to generate a number of design ideas and to evaluate them on the basis of the criteria and constraints of the problem. They would be urged to consider trade-offs as part of their planning effort; to test their designs, carefully controlling variables to determine which design works best; and to communicate the solution along with the test results that provide evidence in support of the optimal design.

Adding an engineering design challenge like the one previously described will add time to the lesson. That is not necessarily a bad thing if the science concept being applied is important to teach and challenging for students to understand without concrete examples. There are also many other approaches to introducing engineering and technology into science lessons, such as conducting research on the internet or discussing relevant current events that require less time and may focus on more important issues. And, of course, not all science ideas lend themselves easily to engineering and technology connections.

No matter how carefully new curriculum materials are designed, however, some additional time will be needed for students to apply what they are learning to the real world. Today's science curriculum is so packed that it is difficult to imagine how to add yet another set of ideas on top of what we have now. Consequently, our greatest challenge as a profession will not be whether or how to integrate engineering and technology into the curriculum, because most science educators have long considered these ideas to be an essential part of what they already do. Instead, the challenge will be how to make the difficult choices about what can safely be left out of the curriculum, so that we can do a better job of teaching core ideas and helping our students understand why they are important and how to apply them to real problems. ■

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Editor's Note

The tables and page numbers referenced in this document refer to the "prepublication copy" of the *Framework* released in July 2011. A final published 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.

References

Achieve, Inc. Forthcoming. *Next generation science standards.* Washington, DC: Achieve, Inc.

National Center for Technological Literacy. 2011. Technology & Engineering Resources. Boston: Museum of Science. *www.mos.org/TEC.*

National Research Council (NRC). 2011. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.