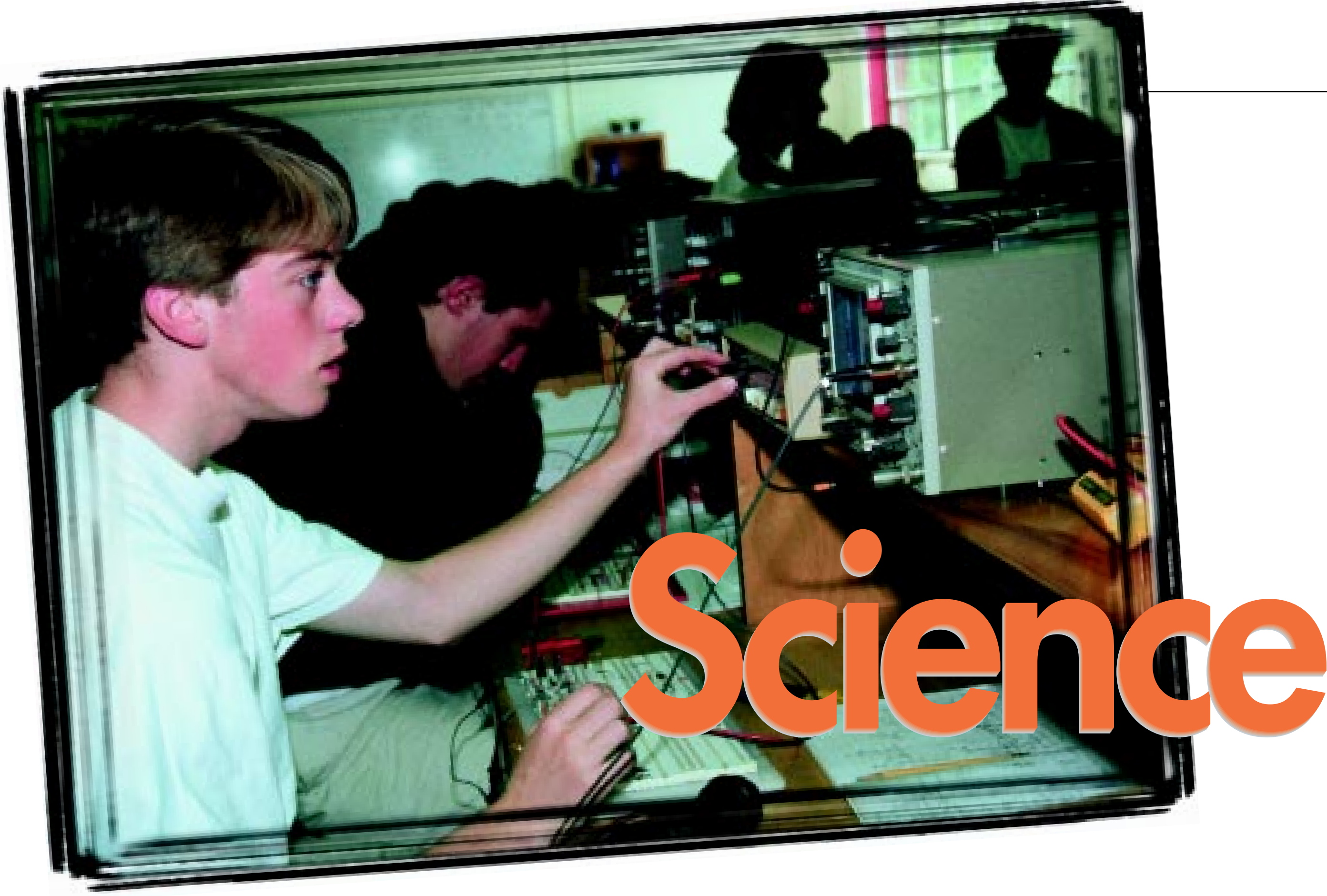


O N A RECENT VISIT TO A SCIENCE CLASSroom, I observed a teacher presenting a challenge to her class. Using simple materials, the students had to design a mechanism that would move 10 metal washers to a designated location on the classroom floor. The students were clearly engaged in the problem and worked very hard to solve it, which they did with varying degrees of success.

This type of exercise is more and more common in today's science classrooms. Is it primarily science or technology? The answer is technology because the exercise emphasizes the process of technological design. Unfortunately, teachers often do not differentiate between science and technology, which may leave students with misconceptions about both disciplines. At a minimum, science teachers should clarify the important differences and complementary features of science and technology. It is time to build bridges that accurately and adequately connect science and technology.

Technology's important links to science should be a part of science classes. Technology has its own distinct knowledge and abilities that students need to understand and develop, and there are opportunities for teachers to address technology within the context of science classes. The *National Science Education Standards* (National Research Council, 1996) provides a basis for discussion on how to connect science and technology.

In this era of reform, the science education community has direction and political support from two documents and prestigious scientific organizations, the *National Science Education Standards*, published by the National Research Council (1996), and *Benchmarks for Science Literacy*, published by the American Association for the Advancement of Science (1993). Both the Standards and Benchmarks refer to the study of technology in the science classroom—the latter has chapters titled "The Nature of Technology" and "The Designed World." In addition, portions of the chapters titled "Historical Perspectives" and "Habits of Mind" present knowledge and skills that apply to the challenge of including technology in school science programs. Developers of the Standards and the Benchmarks were clear and consistent on the fact that technology should be part of school science programs. What follows is some background on science and technology, what the Standards actually says about technology, and some discussion of the implications for science teachers.

RODGER W. BYBEE

DISTINCTIONS BETWEEN SCIENCE AND TECHNOLOGY

Achieving the understandings and abilities described in the Standards and Benchmarks requires teachers and students to distinguish the similarities and differences between science and technology. Figure 1 shows the interrelationships between science and technology.

Science begins with questions and uses evidence to propose explanations for observations about the natural world. Students might ask questions such as: How do earthquakes occur? What causes the difference in seasons in the Northern and Southern Hemispheres? Why do

PHOTO BY MIKE DONALDSON

Bridging & Technology

Teachers can clarify the relationship between these two disciplines

some organisms of the same species show variations? Although these questions may seem elementary, the nature of many questions asked by students and scientists is similar; that is, the questions are about phenomena occurring in the natural world.

As scientists answer questions, they employ recognized, though variable, methods of rational inquiry. For example, scientists propose explanations based on evidence derived from observations. Historically, those observations were direct, now many are made using technology.

The word "propose" suggests that scientific explanations are tentative, which is a fundamental concept in science. Scientific explanations are subject to change and do not purport to be the final truth. The word "propose" also suggests that scientists make their explanations known to others; that is, the explanations are made public through presentations at professional meetings and publication in refereed journals.

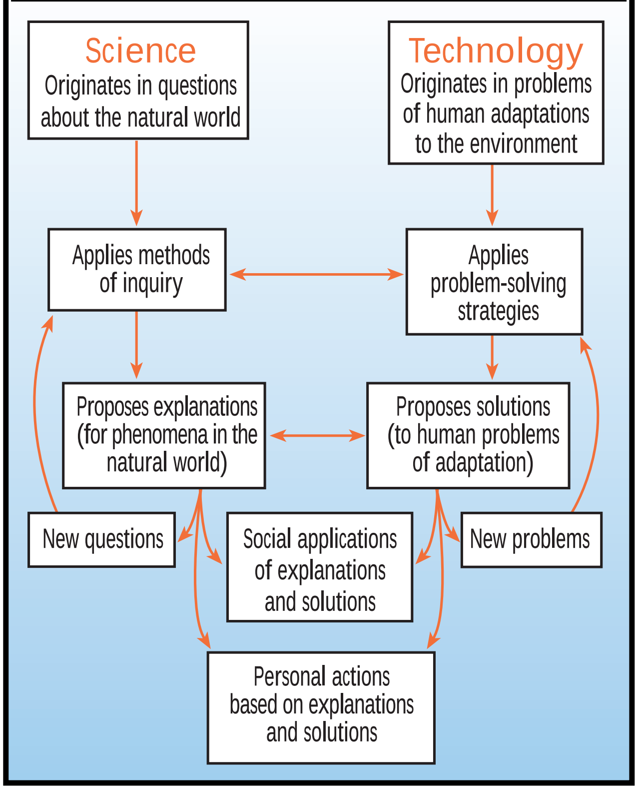
Technology extends the human ability to change the world (Rutherford and Ahlgren, 1989), but the impulse for change originates in the need for humans to adapt to the world. Some technology is an expression of human aspirations; for example, art. This, too, can be thought of as adaptation, though not on a survival level. Technology often originates in problems of human adaptation to the environment (Figure 1). Note that this is nonbiological adaptation. Humans need air, water, food, and safety. They need to move objects and information and need to build shelters and bridge rivers. These and other historical examples of technology, such as the development and use of tools, agriculture, weapons, and compasses, illustrate the origin of technologies in issues of human adaptation.

There are many possible technological solutions to problems of human adaptation, so objectives and requirements must inevitably be considered. Some variables are constraints, such as availability of materials, properties of materials, scientific laws, and cultural requirements. Other variables include cost, benefit, risk, and environmental impact. Engineers often complete several designs for a single project so they can assess trade-offs between constraints and variables before deciding on the best solution. Although the methods of scientific inquiry and technological design have many common elements, technological design is distinguished by this focus on constraints, control, materials, cost-risk-benefit analysis, and decision making.

As the center arrows in Figure 1 indicate, there are interactions between the methods of inquiry and design strategies and between scientific explanations and technological solutions. For example, technology depends on accurate scientific information and cannot contravene scientific laws, and science depends on technology to provide instruments and capabilities that enable new or more refined observations.

Scientific and technological enterprises both result in socially beneficial products. The direct outcome of science is a better understanding of the world, whereas technological solutions are generally more tangible, taking the form of information, products, or services. In any case, individuals and society make decisions and take

FIGURE 1.
Relationships between science and technology.



actions in response to these outcomes, which moves science and technology into the realm of personal use and public policy. Since the early 1980s, science educators have described these connections as the "science-technology-society" theme.

Science and technology also influence our perceptions about the natural and designed world. The shift from a geocentric world view to a heliocentric one is an example of such a change. More recently, as science illuminated our understanding of such processes as photosynthesis and the hydrologic cycles, we had to change our perceptions about the interrelatedness of life on Earth and reconsider the effects of industrial pollution and deforestation. One needs only to think about computers, cell phones, fax machines, and beepers to realize how technology influences our lives.

Scientific and technological outcomes themselves raise new questions and problems. The processes represented in Figure 1 are therefore iterative and interactive. The interactions can result in the need for us to develop new explanations and solutions or amend those already developed. These interactions demonstrate the open-ended nature of science and technology.

The following summarizes several fundamental ideas about technology:

- Technology is an attempt to provide rational solutions to human problems of nonbiological adaptation.
- Technological solutions are incomplete and imperfect.
- Technologies exist within the context of nature. That is, no technology can contravene biological and physical principles.
- All technologies have side effects.
- Because technologies are incomplete and imperfect, all technologies carry some risk.
- The degree to which any society depends on technology corresponds with the degree to which the society must bear the burden of risk (Bybee, et al, 1990).

Science and technology have an increasingly interactive relationship, and it is time for school science programs to accurately and appropriately introduce students to understandings about each of them. The approach recommended by the *National Science Education Standards* is to introduce students to technology in the context of science.

EXAMINING THE CONTENT STANDARDS

Many states, school districts, and science teachers have used the Standards and Benchmarks to identify content for curriculum frameworks. In many cases, however, the curriculum does not include technology or technology is included as "applied science." It is time to change the misconception that technology is only applied science. School science programs should include an introduction to technology because contemporary science is closely related to technology and in many cases depends on technology for advancement.

For science teachers, two obvious questions emerge: What should students know and be able to do? and what should teachers know and be able to do in order to include technology in school science programs? In the Standards, the actual wording of the standard on science and technology answers these questions because it incorporates abilities of technological design and understandings of science and technology. As a result of activities in grades 9–12, students should be able to understand similarities and differences between science and technology and develop abilities identified with the process of technological design.

WHAT SHOULD STUDENTS KNOW?

As a result of science experiences, students should know and understand the fundamental concepts of physical, life, Earth, and space science. These concepts are described in the Standards. In addition, there is ample historical precedent and contemporary support for teaching students about science and technology. It is one thing for students to understand basic science concepts such as the structure and properties of matter, the principle of conservation of energy, biological evolution, energy in Earth systems, and the origin and evolution of the Earth system. It is quite another thing, and just as important, for students to understand the nature of scientific inquiry, the relationship between science and technology, the role and influence of science in personal and social issues, the historical influence of science on society, and the nature of science as distinct from other ways of knowing about the world. Justification for teaching these concepts lies in an understanding of the purposes of education and its contributions to society (Bybee, 1997).

To begin, students should develop an understanding of the ideas expressed in Figure 2. The context for teaching these ideas about technology could simply be the technologies used in classroom-based scientific investigations. In addition, historical scientific events often provide relevant examples of the role of technology.

Although teachers' interest may be in science education, the relationship between science and technology is so close that any accurate portrayal of science must include technology. Much of science in today's world requires a team effort that involves individuals from other disciplines, including engineering and technology.

The common belief that technology is applied science is only partially accurate. As recommended above, the Standards provides science teachers with the opportunity to introduce technology in the context of science. Although technology is applied science in some cases, it also is true that scientific advances often occur only with the introduction of new technologies. For example, Galileo used the telescope to observe the Earth, the Moon, Jupiter's system of moons, and the phases of Venus; to reveal new information about the Moon and planets; and to see stars that had never been seen. Our knowledge of the natural world has advanced because of technology.

WHAT SHOULD STUDENTS BE ABLE TO DO?

From a science teacher's point of view, the emphasis of this standard should be on developing students' cognitive abilities and decision-making skills, which students can develop while designing procedures and using equipment in scientific investigations. In addition, science teachers may present investigations that differentiate the processes and content of technology from those of science.

Science teachers have choices about how to present the learning experiences that will develop students' abilities in technology. Teachers should consider which experiences will best enable students to meet the standard, when to involve students in partial or full design tasks, how to introduce the connections between science and technology, and where in the curriculum to emphasize technology.

In the course of learning science, especially in the context of inquiry-oriented laboratory experiences, personal and social perspectives, and discussions of the history and nature of science, students and teachers can identify problems that require technology. Here, the task for students is to determine what the problem is and how to solve it. As students propose solutions, they should confront issues of scientific knowledge, skill, cost, risk, and benefit, and apply creative and critical-thinking skills. Such experiences will teach students the process of meeting criteria or specifications within constraints.

FIGURE 2.

Abilities of technological design.

- Identify a problem or design an opportunity
- Propose designs and choose between alternative solutions
- Implement a proposed solution
- Evaluate the solution and its consequences
- Communicate the problem, process, and solutions

Implementing a proposed solution may require more or less ingenuity and manipulative skill, depending on the problem. Some problems, such as designing a laboratory investigation, may require simple construction skills using common materials while others may be more complex and require the use of models and mathematical calculations. Regardless of complexity, technological solutions have pragmatic and concrete evaluations—namely, did the students meet the criteria within the constraints, and did the solutions work without detrimental consequences?

Finally, students should prepare and present their problems, the processes they used, and their solutions to other students and the science teacher. Communicating this information could be part of other work in science (for example, completing an inquiry) or as a separate activity included for this standard.

IMPLEMENTING THE STANDARD

Science teachers have an obligation to help students understand the basic concepts and processes of science. Furthermore, they also can provide students with opportunities to learn about technology. Figure 3 provides examples that should help science teachers translate the standards for science and technology into curriculum, instruction, and assessment. This figure highlights a Standards-based approach that begins with an educational outcome and then identifies teaching and assessment strategies to achieve the outcome. This approach is based on the assumption that most science teachers perceive fundamental subject matter as a primary goal of science education and that they use laboratory and investigative experiences in their classroom. Such experiences should not only facilitate the learning of science concepts but also provide experiences upon which to develop abilities and understandings of technology.

Another opportunity to include technology in the science classroom emerges when students are engaged in full inquiry of a scientific question. As students design

FIGURE 3.

Examples of teaching and assessment that support standard-based outcomes of technology.

Educational outcomes	Teaching strategies	Assessment strategies
Understanding subject matter (For example, interactions of energy and matter, biological evolution, geochemical cycles)	Students engage in guided or structured laboratory activities that emphasize conceptual development of science concepts. The laboratories may include use of technology (including computers) and occasional problem solving associated with laboratory techniques, equipment, and methodologies.	Students are given measures that assess their understanding of subject matter. In some cases, the assessments may include use of technology and solving problems of scientific investigation.
Developing abilities necessary for technological design (For example, students propose designs and choose between alternative solutions. The approach gives students opportunities to develop *all* the fundamental abilities of the standard)	Students engage in open laboratory activities that emphasize the design of methods and use of equipment to complete a scientific investigation. They present and defend their design. This approach emphasizes the design standards but includes subject matter.	Students complete a design problem without direction or coaching. The assessment rubric includes the complete list of fundamental abilities from the standard on "science and technology."
Developing understandings about technological design (For example, science often advances with the introduction of new technologies)	Students could reflect on the role and purpose of technology in past laboratories and what problems the technology solved and how it improved the investigation. Students also could read historical case studies of science and identify the role of technology in the discovery.	Students are given a brief account of a scientific discovery and asked to describe the place of technology in the discovery.

the inquiry, they confront problems and have to resolve issues of cost, benefit, and trade-offs. At a minimum, they use technologies in their inquiry; for example, they might use microscopes, telescopes, calculators, or computers as they make observations or prepare summaries of data. The process of designing the experiment requires students to anticipate the problems associated with collection, analysis, and presentation of data; teachers can use this opportunity to develop the abilities of technological design in the context of teaching science as inquiry.

Science teachers can use the Standards to build bridges between science and technology. The science and technology standard establishes links between the natural and designed world and implies that students have opportunities to think critically, make decisions, and understand technology. As a complement to the science as inquiry standard, the standard on science and technology calls for students to identify and state a problem, design a solution—including the costs, risks, benefits, consequences, and trade-offs—implement a solution, and evaluate the solution. These are not standards for technology education but rather originate in the realm of science and highlight the importance of technology to science.

Rodger W. Bybee is executive director of Science, Mathematics, and Engineering Education at the National Research Council, 2101 Constitution Avenue, HA 450, Washington, DC 20418; e-mail: rbybee@nas.edu.

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