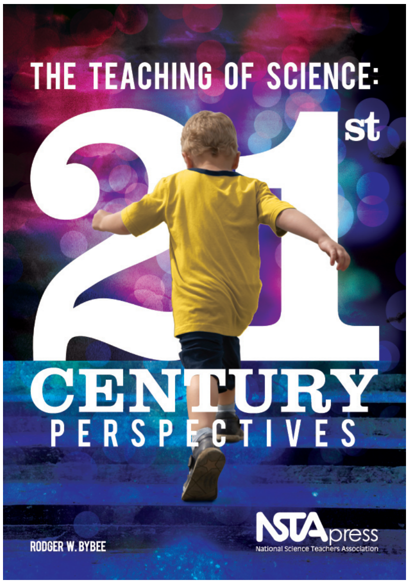
NSTA presents the following excerpt from

The Teaching of Science: 21st Century Perspectives

By Rodger W. Bybee



"What should citizens know, value, and be able to do in preparation for life and work in the 21st century? In *The Teaching of Science: 21st-Century Perspectives*, renowned educator Rodger Bybee provides the perfect opportunity for science teachers, administrators, curriculum developers, and science teacher educators to reflect on this question. He encourages readers to think about *why* they teach science and *what* is important to teach. Only then can they figure out *how* to teach science."

For ordering information, please see the back cover of this insert.

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Teaching Science as Inquiry and Developing 21st-Century Skills

Contemporary national aspirations also include maintaining economic competitiveness. The economic theme is a relatively short-term goal, and for science education it implies preparation of a 21st-century workforce. For the science teacher, this aspiration translates to skills and abilities that can be developed within the theme—teaching science as inquiry.

This chapter directly relates to instruction and the need to reform instructional strategies, particularly those associated with scientific inquiry, so they enhance students' development of 21st-century workforce skills.

National Aspirations for the 21st Century: Maintaining Economic Competitiveness

In recent years, American businesses and industries have released numerous reports calling for major reform of our education system. Based on these calls for reform, for which *Rising Above the Gathering Storm* (National Academies 2005) must be considered the symbol of this national aspiration, one can conclude there is a significant need for education reform.

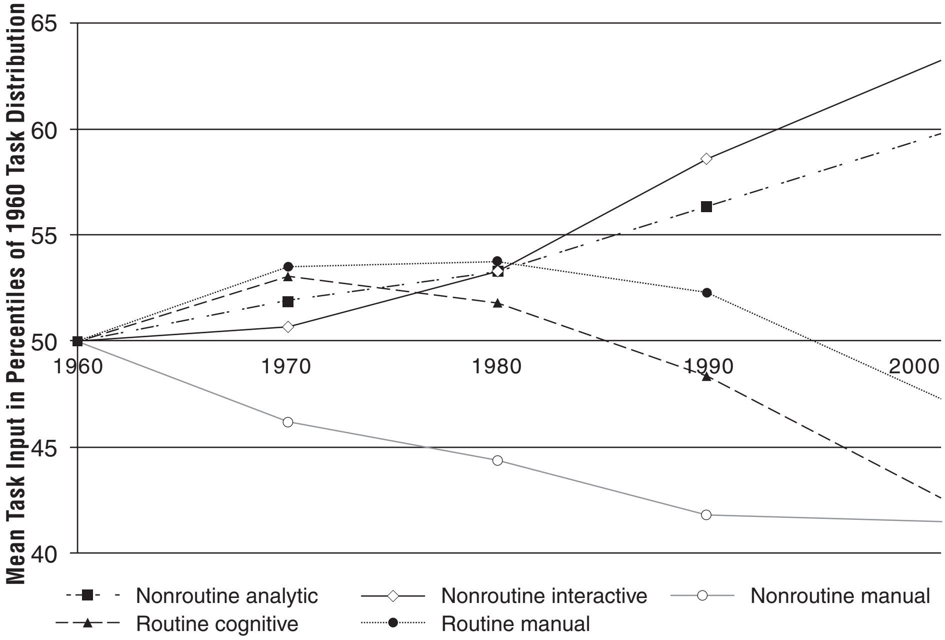
To sustain the U.S. position as a global competitor, our nation needs a first tactical response and eventually a strategic plan that outlines a decade of actions for reforming science and technology education. Although the need to change seems clear, the changes specifically implied for science and technology education for kindergarten through grade 12 are less than clear. This section advances concrete ideas that amount to a first tactical response, an opportunity that is available and generally supported by international, national, and state science education standards—teach science as inquiry.

Trends in Work Skills and Abilities

First, a brief examination of skills needed in the workplace sets the stage for implied changes in the science classroom. Figure 7.1 (p. 128) is a chart from labor economists and a perspective not often presented in science education discussions.

Figure 7.1

Trends in Routine and Nonroutine Task Input in the United States Since 1969



Source: Autor, D., F. Levy, and R. J. Murnane. 2003. The skill content of recent technical change. *Quarterly Journal of Economics* 118 (4): 1279–1333.

Figure 7.1 shows a decline in tasks involving physical work that uses deductive or inductive rules. The figure also shows a decline in skills involving physical tasks that cannot be described as following a set of If-Then-Do rules. The latter has proven extremely difficult for computer programmers. This represents a decline in manual labor.

Much less attention has been devoted to the significant decline in *routine cognitive* task input, involving mental tasks that are well described by logical rules. Because such tasks can be accomplished by following a set of rules, they are prime candidates for computerization, and the figure shows, indeed, that demand for this task category has seen the steepest decline during the recent decade. Furthermore, rules-based tasks also are easier than other kinds of work to send to foreign producers. When a task can be reduced to rules—that is, a standard operating procedure—the process needs to be explained "only once," so the process of communicating with foreign producers is much simpler than the case of non-rules-based tasks where each piece of work is a special case. By the same token, when a process can be reduced to rules, it is much easier to monitor the quality of output. All of this highlights an important issue for school science: If students learn only to memorize and reproduce knowledge and skills, they risk being prepared only for jobs that are, in fact, increasingly disappearing from labor markets. In other words, the kind of learning outcomes that are emphasized in many school science programs and easiest to teach and assess are no longer sufficient to prepare students for the 21st-century.

In contrast, Figure 7.1 displays sharp increases in the demand for abstract tasks *requiring complex* communication, which involves interacting with humans to acquire information, explain it, or persuade others of its implications for action. Examples include a business manager motivating the people, a salesperson assessing a customer's reaction to a piece of equipment, a biology teacher explaining how cells divide, and an engineer describing a new design. Similar increases have occurred in the demand for *expert thinking*, which involves solving problems for which there are no rules-based solutions. Examples include diagnosing the illness of a patient with unique symptoms and repairing an auto that does not run well but for which the computer diagnostics report indicates no problem. These problems require what is referred to as pure pattern recognition—information processing that cannot yet be programmed on a computer. Although computers cannot substitute for humans in these tasks, computers can complement human skills by making information more readily available (Levy and Murnane 2004).

Connecting Science as Inquiry and 21st-Century Workforce Skills

The world economy has changed. Now, new skills will be required for the promising jobs and the 21st-century workforce. Economists have estimated that as much as half of the post–World War II growth in gross domestic product (GDP) in the United States is attributable to technological progress that resulted from research and development. In contrast, labor economists now warn that more than 50% of our children may leave school without the skills they need to enter the middle class. Business organizations produce reports such as *Building a Nation of Learners* and *Tapping America's Potential*, which suggest that many companies are having an increasingly difficult time finding employees with the critical-thinking, problem-solving, and communications skills they need to do their jobs. A rigorous education in science can help prepare students for good jobs, even if they never become scientists or engineers.

Most scientists would argue that science is an important tool for understanding the way the world works, comprehending some of the critical issues of the day, and even improving citizenship. The most compelling rationale for many parents might be to prepare their sons and daughters with skills they will need to prosper in a 21st-century workforce.

This perspective certainly does not mean to imply that everyone in the 21st century will be working as a scientist or engineer. Depending on how strictly we define science, only 3% to 8% of our workforce is employed as scientists, engineers, or other similar technical professionals. When we look at the skills valued by employers, however, it becomes apparent that science teachers have a lot to offer in preparing students to meet these proficiencies. To understand what this means, we will briefly discuss the skills valued by today's employers and examine how well students in the United States are learning these skills.

In the 1970s, students could achieve a middle-class lifestyle with only a high school diploma. Over the past 30 years, however, the skills needed to obtain a job and make a middle-class salary have changed dramatically. During this time, advances in technology, especially in manufacturing industries that had formerly paid high wages, along with the increasing international trade competition for low-skill jobs, have made things more difficult for students with only a high school diploma.

These difficulties are compounded by the fact that the skill set taught in schools has basically remained the same over this time period. The education that was effective in the 1970s has remained in place while the workplace has changed dramatically. In the early years of the 21st century, there is a dramatic gap between the abilities of graduating high school seniors and the skills valued by 21st-century employers.

In *Teaching the New Basic Skills: Principles for Educating Children to Thrive in a Changing Economy* (1996), Richard Murnane and Frank Levy defined a new set of skills important to employee-recruiting and work practices in firms paying high wages. The new basic skills are those abilities needed to obtain a middle-class position. They include

Hard skills

- the ability to read at the ninth-grade level
- the ability to do math at the ninth-grade level
- the ability to solve semistructured problems where hypotheses must be formed and tested

Soft skills

- the ability to work in groups with persons of various backgrounds
- the ability to communicate effectively, both orally and in writing

Other skills

- the ability to use personal computers to carry out simple tasks such as word processing

In today's advanced technological world, many employers are willing to teach knowledge specific to the industry as long as potential employees are proficient in these common abilities. In addition, these skills are needed by all students, regardless of whether they attend college or enter the workforce directly after high school. Recent assessments of 12th-grade students in the United States show that they lack preparation for these basic skills. According to findings from the 2006 National Assessment of Education Progress (NAEP), the number of students performing at a basic level in reading dropped by 7% between 1992 and 2005. In addition, just more than half of students performed at a basic level in mathematics. The Organization for Economic Cooperation and Development's (OECD) Programme for International Student Assessment (PISA) found that in 2003, 58% of students surveyed in the United States scored only as basic problem solvers, the lowest level of problem-solving ability. Furthermore, the United States ranked 29th out of 40 countries surveyed in this study (Lemke et al. 2005).

Inquiry shifts the focus of education to cognitive abilities such as reasoning with data, constructing an argument, and making a logically coherent explanation. On the most basic level, inquiry refers to the process of doing science. Inquiry-based learning engages students in the investigative nature of science. Using inquiry to teach science helps students put materials into context; fosters critical thinking; engages students more fully, resulting in positive attitudes toward science (Kyle et al. 1985; Rakow 1986); and improves communication skills (Rodriguez and Bethel 1983).

Inquiry can contribute to all students' education, not just those planning to attend college and major in science. Whether for a stock broker analyzing investment strategies, an auto mechanic identifying a problem, or an airline agent finding the best combination of seating, price, and schedule for a trip, effective reasoning and communication skills are vital.

Teaching Science as Inquiry in the 21st Century

This section synthesizes insights and ideas from prior sections and presents a contemporary view for the theme of teaching science as inquiry. By now, several points should be clear. First, teaching science as inquiry has a deep and rich intellectual foundation in American education. Second, there is an emerging foundation of research supporting the theme teaching science as inquiry, especially if one expands the idea from lessons to "integrated instructional sequences." Third, there is evidence, disappointing as it is, that teaching science as inquiry has never been fully realized in school science programs. The greatest efforts were during the Sputnik era, but they have not been sustained in contemporary school science programs and practices. In short, we have talked and written more about teaching science as inquiry than we have built and implemented programs that make real our goals and aspirations.

The Contemporary Challenges

To date, most discussions about the need to develop 21st-century workforce abilities and skills have centered on basic literacy and fundamental mathematics. To state the obvious, the potential of science education to be a major contributor to the development of a 21st-century workforce has been overlooked or ignored. Now is the time to remedy that situation.

The challenges we face can be summarized. Science education policies, programs, and practices should contribute to the development of students who have

- basic literacy (e.g., reading, writing, speaking)
- basic math (e.g., arithmetic, algebra, statistics)
- basic science competencies (e.g., identify scientific issues, explain phenomena scientifically, use scientific evidence)
- "hard" skills (e.g., problem solving, ability to apply science and mathematics in new situations)
- "soft" skills (e.g., work with people from other cultures, write and speak well, think in a multidisciplinary way, evaluate information critically, solve problems creatively)
- basic work skills (e.g., personal accountability, time and workload management)

This list may seem unique and unusual for science teachers. Almost immediately, one will note that this list does not emphasize science concepts and processes. However, I would argue they are included in scientific competencies, especially "explain phenomena scientifically."

The unusual nature of this list will engage the question, How can a science teacher possibly help students attain these basics? My response is that we have the opportunity before us if we teach science as inquiry.

Developing 21st-Century Skills in Science Classrooms

In 2007, the National Academies held two workshops that identified five broad skills that accommodated a range of jobs from low-skill, low-wage service to high-wage, high-skills professional work. Individuals can develop these broad skills within science classrooms as well as in other settings (NRC 2008, 2000; Levy and Murnane 2004). The skills identified, based on the National Academies workshops, are displayed in Figure 7.2.

A review of Figure 7.2 reveals a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge, and problem-solving competency. Although diverse, this knowledge and many of these skills and abilities can be developed in inquiry-oriented science classrooms. That said, it should be made clear that science teachers cannot, and probably should not, assume complete responsibility for developing all 21st-century skills. Even so, inquiry-oriented science classrooms have the opportunity to make a substantial contribution.

Figure 7.2

Examples of 21st-Century Skills

Research indicates that individuals learn and apply broad 21st-century skills within the context of specific bodies of knowledge (NRC 2008, 2000; Levy and Murnane 2004). At work, development of these skills is intertwined with development of technical job content knowledge. Similarly, in science education, students may develop cognitive skills while engaged in study of specific science topics and concepts.

1. **Adaptability:** The ability and willingness to cope with uncertain, new, and rapidly changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures. Adaptability also includes handling work stress; adapting to different personalities, communication styles, and cultures; and physical adaptability to various indoor or outdoor work environments (Houston 2007; Pulakos et al. 2000).

2. **Complex communications/social skills:** Skills in processing and interpreting both verbal and nonverbal information from others to respond appropriately. A skilled communicator is able to select key pieces of a complex idea to express in words, sounds, and images to build shared understanding (Levy and Murnane 2004). Skilled communicators negotiate positive outcomes with customers, subordinates, and superiors through social perceptiveness, persuasion, negotiation, instructing, and service orientation (Peterson et al. 1999).

3. **Nonroutine problem solving:** A skilled problem solver uses expert thinking to examine a broad span of information, recognize patterns, and narrow the information to reach a diagnosis of the problem. Moving beyond diagnosis to a solution requires knowledge of how the information is linked conceptually and involves metacognition—the ability to reflect on whether a problem-solving strategy is working and to switch to another strategy if the current strategy isn't working (Levy and Murnane 2004). This ability includes creativity to generate new and innovative solutions, integrate seemingly unrelated information, and entertain possibilities others may miss (Houston 2007).

4. **Self-management/self-development:** Self-management skills include the ability to work remotely, in virtual teams; to work autonomously; and to be self-motivating and self-monitoring. One aspect of self-management is the willingness and ability to acquire new information and skills related to work (Houston 2007).

5. **Systems thinking:** The ability to understand how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system; adopting a "big picture" perspective on work (Houston 2007). Systems thinking includes judgment and decision making; systems analysis; and systems evaluation as well as abstract reasoning about how the different elements of a work process interact (Peterson et al. 1999).

Clearly, statements of 21st-century skills must be adapted for science classrooms. This section describes strategies and contexts for the five skills (see Table 7.1 [pp. 136–137] for specific examples) in the context of school science programs. This discussion also presents connections to the *National Science Education Standards* (NRC 1996), in particular the Standards on inquiry.

Adaptability

Science programs will provide learners with experiences that require coping with new approaches to investigations, analyzing less-than-clear data, using new tools and techniques to make observations, and collecting and analyzing data. Programs will include opportunities to work individually and in groups on science activities, investigations, laboratories, and field studies.

Specific examples include the following:

- Use appropriate tools and equipment to gather, analyze, and interpret data.
- Design and conduct a scientific investigation.

Complex Communications/Social Skills

Programs with varied learning experiences, including laboratories and investigations, will require students to process and interpret information and data from a variety of sources. Learners would have to select appropriate evidence and use it to communicate a scientific explanation. Science programs would include group work that culminates with the use of evidence to formulate a conclusion or recommendation.

Specific examples include the following:

- Design and conduct scientific investigations (with a group).
- Communicate scientific procedures and explanations, as well as defend a scientific argument.
- Use technology and mathematics to improve investigations and communications.

Nonroutine Problem Solving

Science programs will require learners to apply knowledge to scientific questions and technological problems, identify the scientific components of a contemporary issue, and use reasoning to link evidence to an explanation. In the process of scientific investigations, learners will be required to reflect on the adequacy of an answer to a scientific question or a technological solution to a problem. Students may be required to think of another investigation or another way to gather data and connect those data with the extant body of scientific knowledge.

Specific examples include the following:

- Identify questions that can be answered through scientific investigations.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationship between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.

Self-Management/Self-Development

Programs will include opportunities for students to work on scientific investigations alone and as a group. These investigations would include full inquiries and may require learners to acquire new knowledge and develop new skills as they pursue answers to questions or solutions to problems.

Specific examples include the following:

- Design and conduct a scientific investigation.
- Use appropriate tools and techniques to gather, analyze, and interpret data.

Systems Thinking

School science programs would include the introduction and applications of systems thinking in the context of life, Earth, and physical science as well as multidisciplinary problems in personal and social perspectives. Learners would be required to realize the limits to investigations of systems; describe components, flow of resources, and changes in systems and subsystems; and reason about interactions at the interface between systems.

Specific examples include:

- Identify questions that can be answered through scientific investigations.
- Design and conduct a scientific investigation.
- Think critically and logically to make the relationship between evidence and explanation.

Table 7.1 (pp. 136–137) summarizes essential features of the skills and provides examples for school science programs.

Concluding Discussion

Addressing the need to develop 21st-century workforce skills will require students to have experience with activities, investigations, and experiments. In a word, science teaching needs to be inquiry-oriented. This orientation seems obvious, but it must be emphasized. Science education has an opportunity to make a substantial contribution to one of society's pressing problems. Science classrooms provide the setting for helping students learn most, if not all, of the skills described in Table 7.1 (pp. 136–137). To accomplish this goal, science educators must provide opportunities for students to adapt to others' work styles and ideas, solve problems, manage their work, think in terms of systems, and communicate their results.

Table 7.1

Developing 21st-Century Skills in Science Programs

Essential Features of 21st-Century Skills	Examples of Contexts for School Science Programs
Adaptability	
• Cope with changing conditions	• Work on different investigations and experiments
• Learn new techniques and procedures	• Work on investigations or experiments
• Adapt to different personalities and communication styles	• Work cooperatively in groups
• Adapt to different working environments	• Work on investigations in the laboratory and outdoors
Complex Communications/Social Skills	
• Process and interpret verbal/nonverbal information	• Prepare oral and written reports communicating procedures, evidence, and explanations of investigations and experiments
• Select key pieces of complex ideas to communicate	• Use evidence gained in investigations as a basis for a scientific explanation
• Build shared understanding	• Prepare a scientific argument
• Negotiate positive outcomes	• Work with group members to prepare a report
Nonroutine Problem Solving	
• Use expert thinking in problem solving	• Recognize the need to search for expert's knowledge
• Recognize patterns	• Recognize patterns in data
• Link information • Integrate information	• Connect evidence and information from an investigation with scientific knowledge from textbooks, the web, or other sources
• Reflect on adequacy of solutions	• Understand constraints in proposed solutions
• Maintain several possible solutions • Propose new strategies	• Propose several possible solutions and strategies to attain the solutions
• Generate innovative solutions	• Propose creative solutions
Self-Management/Self-Development	
• Work remotely (individually)	• Work individually at home
• Work in virtual teams	• Work with a virtual group
• Self-motivate	• Complete a full/open investigation
• Self-monitor	• Reflect on adequacy of progress, solutions, explanations
• Have willingness and ability to acquire new information and skills	• Acquire new information and skills in the process of problem solving and working on investigation

Table 7.1 ***(continued)***

Developing 21st-Century Skills in Science Programs

Essential Features of 21st-Century Skills	Examples of Contexts for School Science Programs
Systems Thinking	
• Understand the systems concept • Understand how changes in one part of the system affects the system • Adapt a "big picture" perspective • Systems analysis • Judgment and decision making • Abstract reasoning about interactions among components of a system	• Describe components of a system based on a system under investigation • Predict changes in an investigation • Analyze a system under investigation • Make decisions about best proposed solutions • Demonstrate understanding about components and functions of a proposed system

Learning outcomes aligned with inquiry and 21st-century skills can be attained using both full and partial inquiries. Central to these skills are group work and cognitive abilities such as reasoning. Although some may argue for full inquiries, and I agree that these should be part of a student's science experience, there is a place for partial inquiries. After all, the emphasis is on the learning outcomes, and these may be achieved with partial inquiry experiences. The important point is to give emphasis to the skills and abilities described earlier.

One challenge for curriculum, instruction, and assessment is implementing what I have called *integrated instructional sequences*. A National Research Council report, *America's Lab Report: Investigations in High School Science* (Singer, Hilton, and Schweingruber 2006), introduced the idea as "Integrated instructional units connect laboratory experiences with other types of science learning activities, including lectures, reading, and discussion" (p. 4). The BSCS 5E Instructional Model is one example of an integrated instructional unit. In a paper prepared for a National Research Council workshop exploring the intersection of science education and the development of 21st-century skills, I described the research supporting the BSCS 5E model and potential linkages with 21st-century skills (Bybee 2009).

Using the BSCS 5E Instructional Model or another variation on the learning cycle provides connections among curriculum, instruction, and assessment and enhances students' opportunities to attain learning outcomes, including 21st-century skills.

This chapter has provided clarification of 21st-century skills in the context of science education programs and practices. Here are some concrete recommendations that science education leaders can use as they implement changes that will promote 21st-century skills as learning outcomes.

Make sure all students meet the standards for scientific inquiry and technological design. Beginning with the national standards and extending to state and local standards, abilities related to scientific inquiry are included as learning outcomes. Statements of the need to develop the abilities of scientific inquiry and technological design can be the connection between what many will perceive as the abstract vision of 21st-century skills and the concrete context of science teaching.

Build on the opportunities that already exist in school programs and teaching practices. Understandably, many will see the call for development of 21st-century skills as a major change, one beyond their capabilities and interests. Centering the changes on opportunities that already exist in investigations, laboratories, and activities will soften the resistance to change. In many cases, science teachers already contribute to the development of these skills; the change is one of clarity and emphasis. In particular, one of the changes that may be new for science teachers includes placing an emphasis on individual and interpersonal skills.

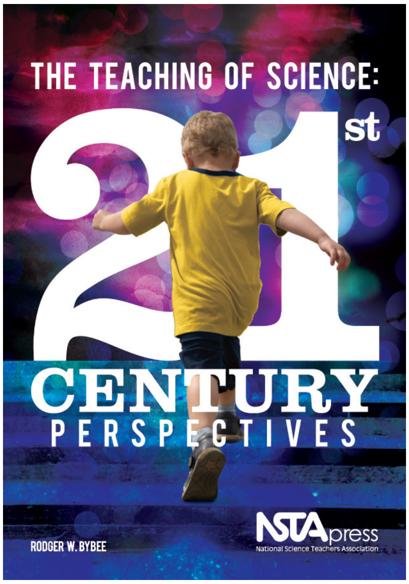
Emphasize cognitive abilities and skills as learning outcomes. Bringing the development of cognitive abilities and interpersonal skills to the foreground in the science classroom may be new to science teachers. Providing teachers with statements they can use, such as "What is the evidence for that explanation?" "What alternative explanations have you heard from the team?" "What goals of the investigation include working together to gather evidence and form an explanation?" will help.

Use the idea of integrated instructional sequences. Helping science teachers connect lessons will provide the time and opportunity needed for the emphasis on 21st-century skills. In addition, using the sequences will enhance the opportunities for other learning outcomes. Of course, I recommend using the BSCS 5E Instructional Model, but the important idea is to use an integrated instructional sequence, not one particular model.

Include basic skills of literacy and mathematics as part of learning outcomes. Because part of the student's work will include the presentation of results, graphs, charts, diagrams, and reports, the inclusion of basic literacy and mathematics should be considered part of a new emphasis on 21st-century skills.

The evidence indicates that teaching science as inquiry is not now, and never has been, in any significant way, implemented. Furthermore, it probably would not matter much what one used as a definition—inquiry as science content or inquiry as teaching strategies. Probably the closest the science education community came to teaching science as inquiry was during the 1960s and 1970s as we implemented the Sputnik-spurred curriculum programs and provided massive professional development experiences for teachers. The evidence does indicate that these programs were effective for the inquiry-oriented objectives that were emphasized in that era. Although science educators continue to state the need for and importance of teaching science as inquiry, our state policies, assessments, textbooks, and classroom practices give little evidence of the realization of this goal.

In this chapter, I have restated and provided details of what we mean by teaching science as inquiry. Appropriately viewed, inquiry as science content and inquiry as teaching strategies are two sides of a single coin. Teaching science as inquiry means providing students with diverse opportunities to develop the abilities and understandings of scientific inquiry while also learning the fundamental subject matter of science. The teaching strategies that provide students those opportunities are found in varied activities, laboratory investigations, internet use, and student-initiated inquiries, all presented in integrated instructional sequence. Science teachers know this simple educational insight. Now we are called to the new challenges of the 21st century. We have the opportunity to show that the science education community will respond to a great national need by teaching science as inquiry.



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Rodger W. Bybee is past executive director of the Biological Sciences Curriculum Study (BSCS), a nonprofit organization that develops curriculum materials, provides professional development, and conducts research and evaluation for the science education community. Dr. Bybee has written widely, publishing in both education and psychology. He is coauthor of a leading textbook titled *Teaching Secondary School Science: Strategies for Developing Scientific Literacy.* His most recent books include *Achieving Scientific Literacy: From Purposes to Practices* (1997) and *Learning Science and the Science of Learning* (NSTA; 2002), and he co-wrote *Teaching Secondary School Science: Strategies for Developing Scientific Literacy* for the past eight editions. Over the years, he has received awards as a leader of American education and an outstanding educator in America, and in 1979 he was Outstanding Science Educator of the Year. In 1989, he was recognized as one of the 100 outstanding alumni in the history of the University of Northern Colorado. Dr. Bybee's biography has been included in the Golden Anniversary 50th Edition of *Who's Who in America.* In April 1998, NSTA presented Dr. Bybee with the NSTA's Distinguished Service to Science Education Award. In 2007, he received the Robert H. Carleton Award, NSTA's highest honor, for national leadership in science education.