DOCUMENT RESUME

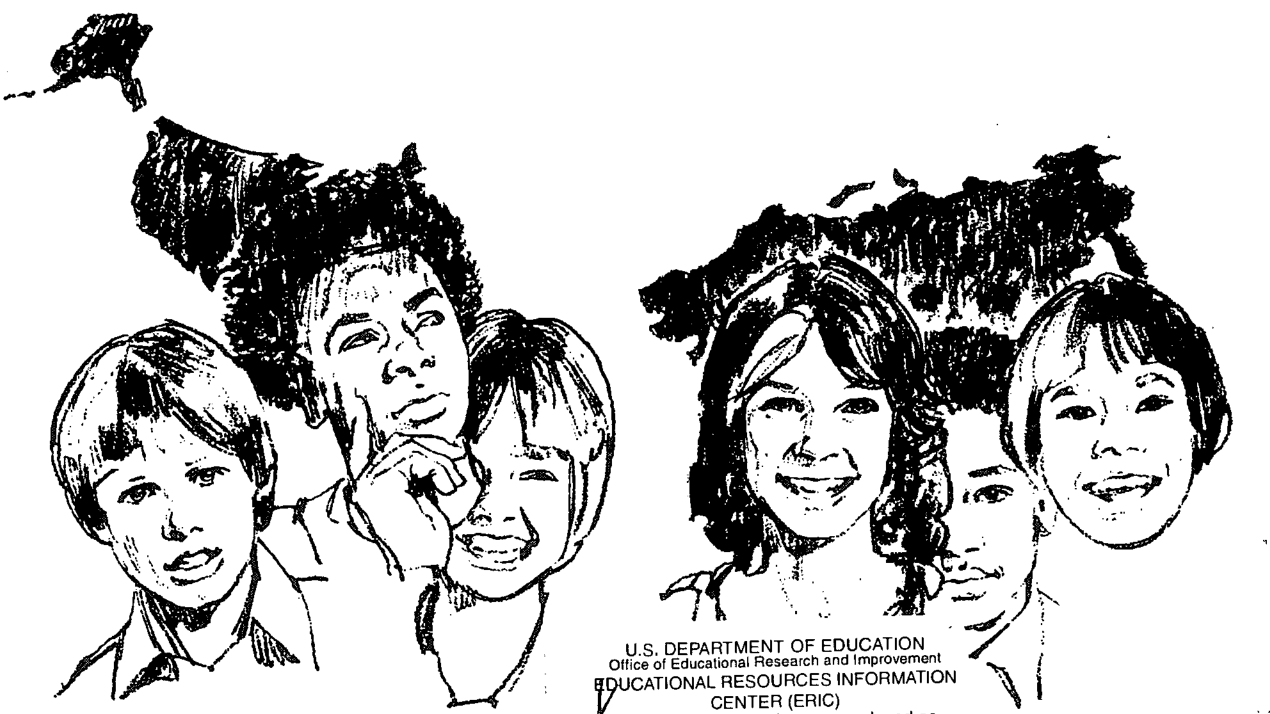
ED 433 179		SE 060 027
AUTHOR	Bybee, Rodger W., Ed.; McInerney, Joseph D., Ed.	
TITLE	Redesigning the Science Curriculum: A Report on the Implications of Standards and Benchmarks for Science Education.	
INSTITUTION	Biological Sciences Curriculum Study, Colorado Springs.	
SPONS AGENCY	National Science Foundation, Arlington, VA.	
PUB DATE	1995-00-00	
NOTE	149p.	
CONTRACT	ESI-9354091	
AVAILABLE FROM	Biological Sciences Curriculum Study, Pikes Peak Research Park, 5415 Mark Dabling Blvd., Colorado Springs, CO 80918-3842.	
PUB TYPE	Collected Works - General (020) -- Reports - Evaluative (142)	
EDRS PRICE	MF01/PC06 Plus Postage.	
DESCRIPTORS	*Academic Standards; Educational Change; Educational Innovation; *Educational Policy; Educational Practices; Elementary Secondary Education; *National Standards; *Science Curriculum; *Science Education; Scientific Literacy	
IDENTIFIERS	*Benchmarks for Science Literacy; *National Science Education Standards	

ABSTRACT

This document presents the results of a project conducted by the Biological Sciences Curriculum Study (BSCS) on the implications of national science education standards documents for the science curriculum. This book features background papers and recommendations directed towards those responsible for curriculum reform, regardless of their roles in local school districts, state agencies, or national organizations. Sections cover the following topics: "Perspectives on Standards-Based Reform"; "Organizational Perspectives"; "Curriculum Perspectives"; and "Concerns and Recommendations." Appendices provide a list of participants in and the agenda for the "Rethinking the Science Curriculum" conference (Colorado Springs, CO, October 20-22, 1993). (Contains 54 references.) (Author/WRM)

REDESIGNING THE SCIENCE CURRICULUM

Report on the Implications of Standards nd Benchmarks for Science Education



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BSCS

REDESIGNING THE SCIENCE CURRICULUM

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This material is based upon work supported by the National Science Foundation under Grant No. ESI-9354091. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Printed in the United States of American
10 9 8 7 6 5 4 3 2 1

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*All contributing authors were asked to express their views on the general topic of national standards and curriculum reform. We have not modified the substance of their essays for this publication.

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ACKNOWLEDGMENTS

In 1993, BSCS celebrated its thirty-fifth anniversary as an organization dedicated to leadership in science education through the design, development, and implementation of curriculum materials. No organization reaches its thirty-fifth anniversary without encountering some difficulties; the struggle has been well worth the effort for those who have been directly associated with the organization and for those who have used curriculum materials developed by BSCS.

We acknowledge here the many people whose names do not appear in this report, but without whom the long and distinguished history of BSCS would have been impossible. We acknowledge our ever-supportive board of directors, who participated in the conference "Rethinking the Science Curriculum," the National Science Foundation, which has supported the majority of BSCS programs, including this project, and our colleagues in the science education community who contributed to the project.

The success of the project on "Rethinking the Science Curriculum" goes to two individuals who deserve special acknowledgment—Yvonne Wise and Dolores Miller. The success of any project requires the skills and dedication of individuals who literally "make it happen" through their administrative abilities to organize and manage the many details of successfully completing a project.

We also express our appreciation to Angela Greenwalt for work on design and production and to Barbara Resch for final review and editing of the manuscript.

Rodger W. Bybee and Joseph D. McInerney
Colorado Springs, 1994

FOREWORD

Publication of the *National Science Education Standards* in 1995 will provide the science education community with clear goals that will have profound implications for curriculum, teaching, and assessment. The *National Science Education Standards* will stimulate further contemporary reform of science education and involve those responsible for curriculum reform regardless of their roles in local school districts or national organizations.

Educators can reasonably assume a need for new science curricula based on the standards. Further, it is likely that several different approaches will be necessary to demonstrate that the standards do not imply one program with a single philosophy and pedagogy, but rather can be interpreted in a variety of ways. The fact that the *National Science Education Standards* will require a variety of models developed both nationally and locally suggests an extension of the traditional role of curriculum-development organizations, with the implied recommendation that funding agencies begin developing requests for proposals (RFPs) as soon as possible. Science education researchers and curriculum developers now realize, however, that sustained curricular change requires more than a new program and that implementation and staff development are integral to the design and development of any new science program. Curriculum developers and school personnel also recognize that publishers and school districts will provide only marginal support for implementing innovative science programs, hence the need for support from funding agencies in the public and private sectors for implementation and staff development.

The contemporary reform implies considerable changes that must originate within local schools and school districts, but many districts do not have the expertise and experience required to design, develop, and implement new science programs. Curriculum-development organizations that heretofore have focused on national programs may therefore find a new role in helping local districts develop programs that are congruent with both the *National Science Education Standards* and local needs.

Curriculum development certainly will adapt to accommodate the goals of the *National Science Education Standards* and the needs of local school districts.

Leaders in curriculum reform can begin by asking a few questions: How will curriculum development change in an era of standards-based science education? What can the nation reasonably expect of science curriculum in achieving American goals for the year 2000? Can curriculum-development groups maintain their integrity and unique approaches to science education and still develop materials that will help science teachers achieve national and local standards? Should those responsible for curriculum development also provide leadership training and technical assistance for school districts developing their own science programs? To what degree can local school districts develop science programs that will achieve local, state, and national standards? What are the actual contributions to, and potential conflicts among, projects such as Project 2061 (AAAS); Scope, Sequence, and Coordination (NSTA); and the *National Science Education Standards* (NRC)? Questions such as these should be answered by those most responsible for translating the policies articulated in standards to the programs implemented in science classrooms.

Redesigning the science curriculum implies a review and reconsideration of priorities by funding agencies, both public and private. How will government agencies such as the Department of Education, National Science Foundation, Department of Energy, Defense Department, NASA, and National Institutes of Health respond to the needs created by the *National Science Education Standards*? Few question the need for a coherent and coordinated effort to improve science education, but how can such a vision be developed and implemented and still maintain the integrity and mission of the funding agency?

The Biological Sciences Curriculum Study (BSCS) proposed a project to address these questions and the broader issue of redesigning the science curriculum in the context of national standards. The National Science Foundation (NSF) funded the project designed to achieve the following goals:

1. Review science curriculum development 1958 to 1993.
2. Review the *National Science Education Standards* from a curriculum-development perspective.
3. Propose designs for science curriculum in the context of standards-based reform.
4. Consider the contributions and conflicts of different curriculum frameworks, benchmarks, and standards in the reform of science education.
5. Address basic questions of curriculum reform from local, regional, and national perspectives.
6. Outline recommendations for public and private funding agencies involved with transforming the *National Science Education Standards* into science programs and practices.

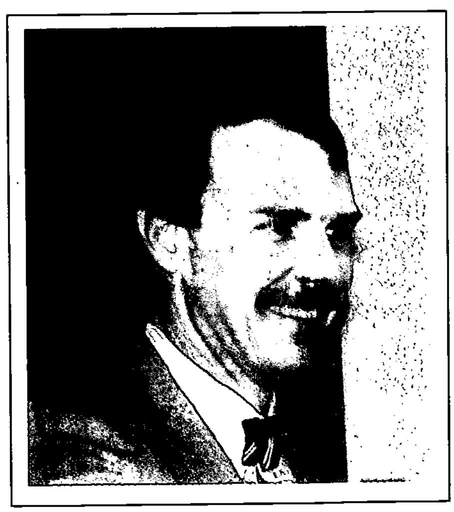
BSCS completed this project in three phases. The first phase involved commissioning articles on the general theme of curriculum development. Several authors developed longer papers on the history, background, and central issues of national standards. Other, shorter, papers considered different questions and provided a provocative and creative, yet scholarly, basis for discussion. In this publication, 20 authors present their ideas in short, editorial-length papers. The papers were distributed prior to a three-day conference and are included in this monograph.

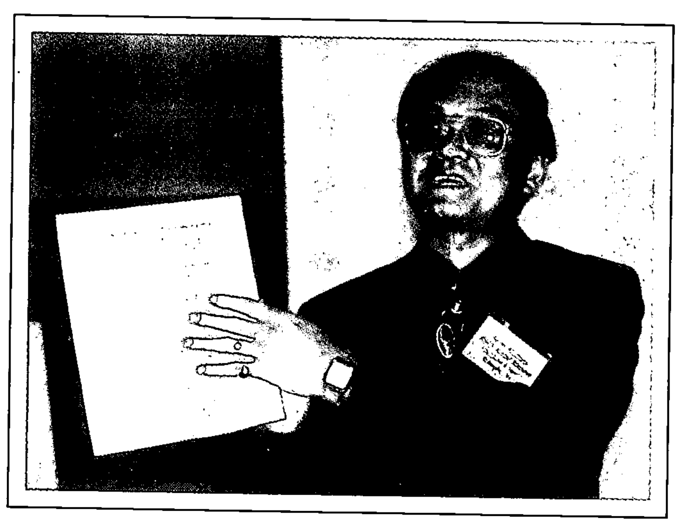
We asked curriculum developers from other organizations that have a history of curriculum development—for example, Education Development Center, Inc. (EDC), Lawrence Hall of Science (LHS), National Science Resources Center (NSRC), and Technical Education Research Centers (TERC)—to prepare statements on their perspectives of standards-based reform. We requested editorials from individuals who are currently developing science materials but are not associated with major organizations. In general, authors addressed their responses to the standards-based reform, the factors that facilitate and inhibit good curriculum development, and the issues and problems they expect to encounter in the next decade.

In the second phase,the project also provided a forum for review of the aforementioned articles and presentations on the *National Science Education Standards* Project (NSES), Project 2061 (AAAS), and Scope, Sequence, and Coordination (NSTA), as well as concerns and recommendations for curriculum reform. The participants and agenda for the conference are displayed in appendices A and B.

The final phase of the project involved the publication and dissemination of the recommendations from the conference. BSCS prepared the document for publication, supervised the publication, and disseminated the document to various organizations, agencies, and individuals interested in curriculum development and standards-based reform of science education.

Rodger W. Bybee and Joseph D. McInerney
Colorado Springs, 1994





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INTRODUCTION

REINVENTING THE SCIENCE CURRICULUM: HISTORICAL REFLECTIONS AND NEW DIRECTIONS

BY PAUL DEHART HURD

This essay describes perspectives for curriculum reform in precollege science. Sources for these perspectives are found in the changes taking place in our social milieu, the nature and ethos of modern science, research on cognition, and public demands for a reform of science education. This mosaic of factors will be explored in both historical and contemporary contexts.

I present an interpretive analysis of the public demands for a reform of education. I emphasize aspects of the movement that have more than a modicum of agreement but rarely a consensus. This research process is not easily described. Nearly two centuries ago, Johann von Goethe came the closest when he wrote

> It is extremely difficult to report on the opinions of others, especially when they agree, border and cross one another. If the reporter goes into detail, he creates impatience and boredom; if he wants to summarize, he risks giving his own point

of view; if he avoids judgments, the reader does not know where to begin, and if he organizes his materials according to principles, the presentation becomes one-sided and arouses opposition, and the history itself creates new histories. [Quoted in *Science* (1991, 259 (5093) 41.]

Science Curriculum Reform for a New Age

Public demands for a reform of science education in the nation's schools are now in their third decade. Historians of education state that this is the longest sustained educational reform movement in the country's history. Efforts to bring about changes in science teaching are on the agenda in 141 countries according to UNESCO. One wonders: What is it that justifies the public's intense concerns about today's schooling, and especially education in the sciences?

In the 1970s, a number of scientists, sociologists, and economists wrote about massive and accelerating transitions in our society. Science and technology were perceived to be at the root of many of these changes. These breaks with the past have been described as a "cultural mutation" (Kenneth Boulding), a "watershed period" (Jonas Salk), a "discontinuity" (Peter Drucker), the birth of a "postindustrial society" (Daniel Bell), a new "information age" (John Naisbitt), a "third wave" and "future shock" (Alvin Toffler), "mankind at the turning point" (Club of Rome). Charles E. Silberman in his 1970 book *Crisis in the Classroom* pointed out these "new times mean new goals" for schooling in America. During the 1970s and early 1980s, hundreds of commission, panel, and committee reports by citizen groups either outlined changes in schooling or maligned current practices.

In 1983, the National Science Foundation (NSF) and a National Commission on Excellence in Education each sought to clarify new directions for science education. The NSF report entitled *Educating Americans for the 21st Century* proposed career preparation in the sciences for all students. The committee also noted that school science curriculums should keep pace with advances in science and technology as well as their impact on practical problems, the economy, social issues, the quality of life, and needs of the workplace. The Committee on Excellence titled their report *A Nation at Risk: The Imperative of Educational Reform*. The committee noted we were entering a new "information age" where knowledge and learning would be the raw materials of commerce, and essential for effective citizenship and success in the workplace. Scientific and technological literacy were viewed as basic in the education of all youth if they were to adapt and to succeed in a learning society. Within a matter of months, 600,000 copies of the report were sold and reprints in journals provided an audience of approximately 6 million readers.

During the 1980s, the plethora of reports demanding a reform of science education continued unabated, and curriculum issues became more and more confused. For sure, there was a lot of action in schools creating an illusion of reform, such as extended school hours, more testing of students as well as of teachers, more computers in schools, longer school years, mandates telling schools what they must do, and more science courses required for high school graduation. Science teaching was presumably made more rigorous by moving faster through the textbook and requiring students to learn more technical terms.

The ferment for a reform of education, and of science education in particular, grew in intensity during the 1980s. The situation reached a crisis in 1989 and led President Bush to convene an Education Summit meeting. Only three times in the entire history of this country has a perceived national emergency led a president to call a summit meeting to help resolve a problem. The governors of all 50 states were selected to serve on a panel to identify strategies for "revolutionary" changes in public education in America. The panel report entitled *America 2000: An Educational Strategy,* recommends a "new generation of schools" to set aside "traditional assumptions about schooling." I would note that accomplishing this task requires "a quantum leap forward" with "far-reaching changes" that are "bold, complex, and long-range." The report identifies a set of national education goals and calls for a reinvention of curriculums to realize these goals; contemporary school curriculums were viewed as out of date, failing to prepare students for an active role as responsible citizens in the years ahead. The call for revolutionary changes implies that any endeavors to revise, reorganize, fix, reorder, restructure, or reshape traditional practices will not likely modernize science education.

In 1993, the U.S. Congress considered two bills, H. R. 1804 and S1150, designed to further define a national framework for the reform of education based on, but not dependent upon the "Goals 2000" report. In 1994, Congress passed legislation on Goals 2000. This legislation makes it clear that the purposes and curriculums of science education must extend beyond the laboratory and classroom doors to include the economy, workplace, and responsibilities of citizenship.

The Case Against Contemporary Science Curriculums

The concerned public perceives the science curriculums in today's schools as graduating students who are "foreigners in their own culture." Though we live in a democracy that is increasingly influenced by achievements in science and technology, students are seen as unprepared for dealing with the personal and social realities of this society. The roots of this problem are buried in the 200-year-old tradition of designing school science curriculums in a vocational context. Students are expected to learn to "think like scientists," to be able to "do science" by becoming skillful in the use of laboratory apparatus. The traditional model for understanding science is a value-free "scientific method," the longest surviving myth in the history of science.

If students are "to be like a scientist," they must first learn the language scientists use when sharing their research findings with other scientists. This means learning the technical terms, symbols, and mathematical expressions characteristic of each discipline studied. As the sciences have progressed over the years, so has the volume of technical terms students must learn; the number runs into the thousands for each science course. Characteristically, there are words students have never seen before today's assignment, have never heard pronounced, and will likely never use in a conversation the rest of their lives. Science textbooks, of necessity, have had to increase in size to accommodate these new terms and today are considered as among our most beautifully illustrated dictionaries.

Laboratory experiments became a part of school science courses in the latter part of the nineteenth century. By performing experiments, it was expected students would gain experience in "doing" science and an appreciation of the objectivity of science, and would understand how scientific facts are established. The requirement that all students get the same answer from an experiment supposedly verified the objectivity of a finding. The student's position in these experiments was that of a detached onlooker or spectator. A criticism of this sort of laboratory work is that students are not intellectually a part of the experiment, they are only the performers of a preprogrammed routine.

The justification for the selection of subject matter for science curriculums is that it contributes to understanding the conceptual structure of a discipline. Broad themes, such as evolution, patterns of change, systems and interactions, models, scale and structure and function, and stability are incorporated into the curriculums to make it possible for students to acquire a unified view of science and make connections between one science and another. By contrast, the traditional framework for the study of science has been summarized as (1) "science as organized and tested knowledge," and (2) "science as a method of obtaining organized and tested knowledge." As science teaching now stands, all goals, objectives, and concepts are internal to specific disciplines. The quest in the reform movement is for goals and curriculums in a societal context. Briefly, this is a movement from the esoteric to the exoteric in science teaching.

Changing the Context of Science Education

Over the past 75 years, there have been many efforts to effect new purposes for an education in the sciences. In 1920, the United States Bureau of Education reported the recommendations of a committee composed of 50 scientists and science teachers. The committee, after seven years of deliberations, proposed a curriculum framework in which the "body of facts and principles taught find their value and significance in the home, school and community and in an intelligent understanding of the conditions, institutions, demands and opportunities of modern life."

A committee on the place of science in education appointed by the American Association for the Advancement of Science reporting in 1928, stressed the practical applications of science and the need to develop "a sense of moral obligation that will prevent the newly acquired knowledge and method of science serving base ends." The committee noted that science courses in schools should **not** be concerned with vocational preparation of science specialists, this was the task of colleges and universities.

The 1930s were marked by the "Great Depression." Advances in science and technology were seen as the root of many of society's ills, such as the development of hybrid corn, the cotton picking machine, inexpensive tractors, and the assembly line in manufacturing. The United States government authorized the Department of Education to survey science instruction in schools and identify what schools were doing. The committee found that science teachers were not concerned about educational goals but perceived their task as one of teaching a textbook. Where purposes were identified, they were in terms of the character of science disciplines. Teachers regarded themselves as science specialists trained to portray science disciplines.

In 1930, the National Society for the Study of Education appointed a committee to examine prevailing practices in science education and to make recommendations for change. The committee saw the primary role of science teaching as "life enrichment through participation in a democratic social order," thus the curriculum should consist of "the principles and generalizations of science that ramify most widely in human affairs," and provide opportunities to utilize science in one's own life experiences.

A third committee appointed by the Progressive Education Association was commissioned to study science education processes and goals relevant to the needs of learners as they interact with situations they confront in the home, school, community, and the wider social scene. After five years of discussions, the committee recommended that the objectives of science teaching be derived from aspects of (1) personal living, (2) immediate personal-social relations, (3) social-civic relationships, and (4) economic relationships.

Following World War II, the demand for scientists and technical workers to assure America's peacetime future, economy, social progress, and military security became a matter of federal concern. A report to President Franklin D. Roosevelt in 1944, written by Vannevar Bush, while president of the Carnegie Institution (1939–1955), recommended the establishment of a National Science Foundation dedicated to increasing "human capital" through education in the sciences and scientific research. The report highlighted a concern that "the general public is still far from true understanding of the nature of basic research and the fundamental difference between science and technology." Bush proposed a more academic approach to science programs in schools.

The National Science Foundation, founded in the early 1950s, began a course content improvement program for the commonly taught school sciences. The task for improving school science was assigned to research scientists. In this way, it would be possible for academic scientists to talk directly to children and adolescents. The scientists chose the curriculum approach they understood best, that of vocational preparation. Not everyone in the scientific community was in agreement with this traditional notion of science education. In 1959, Dwight Eisenhower's Science Advisory Committee recommended a different emphasis. The report entitled *Education for an Age of Science* stresses the importance of an education in science that "produces citizens and leaders who will know how to use the knowledge and tools [of science] to advance social and cultural life." The committee noted that a research specialist "must also be able to deal with problems for which his specialty does not concretely prepare him." These are educational issues we confront on the contemporary reform.

Science Education for a New Age

We are facing a critical period in our history, characterized by radical changes in how we live, learn, and work. We are shifting from an industrial age to a knowledge-intensive society. The traditional purposes of science education and the supporting curriculums are viewed as inadequate for helping young people cope with the life demands of this emerging age. Over the past half century, massive changes have taken place in America altering the character of our society, including our demography, lifestyles, values, family structure, social institutions, economy, patterns of American life, and the nature and ethos of science. Young people today are not living in the same world in which we grew up.

The totality of these changes and their interactions call for a new image of science education. Although there has been a wealth of rhetoric and documents demanding changes in the teaching of science, a studied and coherent rationale has yet to emerge. We need a rationale that reflects the contemporary nature and ethos of science and a social milieu unlike any we have experienced in past history. Our task is to create an education in science that responds to these perspectives.

The first step is to examine the changes that have been taking place in the nature of science and its synthesis with human affairs. As we entered the twentieth century, we noted the traditional boundaries of science disciplines, such as botany, zoology, physics, chemistry, and geology, were starting to break down giving rise to hundreds of specialized fields of research. The major reason for this breakdown was the growth of knowledge in each of these disciplines was such that a lone researcher had little chance of making a major contribution if he or she tried to work across a discipline. Today, we have an unknown number of research specialties, each with its own theoretical framework, research procedures, language, and unique instrumentation. We do know that more than 70,000 journals are required to report research findings with new journals appearing weekly, 29,000 since 1970.

In the 1930s, scientific research was beginning to be housed in industries, such as DuPont, Eastman Kodak, and General Electric. Today, 58 percent of research scientists are employed in industry. Increasingly, science disciplines are being hybridized to form new fields of research, such as astrophysics, biophysics, genetic engineering, laser chemistry, geophysics, biogeochemistry, biotechnology, molecular biology, bioinorganic chemistry, and hundreds more. These interdisciplinary research fields provide a broader context for research and for dealing with complex systems. Chaos theory offers a new way of thinking about nonlinear systems, such as weather, tides, and biological evolution. Today, scientific research is concentrated in biological fields; traditionally it has been in the physical sciences. Of the 10 most widely cited research papers in 1992, nine were in biological sciences and one in chemistry. Ongoing research in biotechnology is viewed as the most likely forerunner of a new industrial revolution in the twenty-first century.

The integration of science and technology provides yet another means for distinguishing postmodern science from traditional notions. The distinction is best seen in the ways computer technology opens new areas of research. Computers extend human capacities for observation, such as the scanning tunnelling microscope that makes it possible to see chemical bonds in living cells. In 1992, a microlaser was developed that can break these bonds one at a time. The headline of the article reporting this achievement was, "For the first time, it is now possible for chemists to see chemistry in action." Another example is the Hubble space telescope. It has already extended the limits of outer space to the degree likely to make the use of light years too small a unit for measuring space distances. The production of new knowledge in the sciences today is as much a matter of technology as human insights. An American Association for the Advancement of Science symposium on research portrayed computers as the "third branch of science."

To identify the science of today from the 400-year-old term "modern science" calls for a new name. Some of the proposed descriptors are "technoscience," "trans-science," and "postmodern science." In this essay, I use "contemporary" to characterize science as it is today. These terms recognize science and technology as an integrated system for the conduct of research. Computers can summarize, in a few minutes, what is known or not known about a problem, prepare models derived from observations, and continuously organize data from other research teams, sometimes scattered throughout the world, as in investigations of AIDS, and they can be used to design new electronic components to advance research.

Nearly all contemporary scientific research is done by teams of researchers working as a unit. The 12 most cited science research papers published in 1991 had an average of 6.6 authors per paper. A recent issue of *Science* carried research reports by author teams of 14, 17, and 27 individuals. The record is 134 authors for a study of world ecological imbalances.

Contemporary science is more holistic in concept than traditional science and operates in broader contexts. Research teams are frequently a collaboration of natural, social, and cognitive scientists in addition to technicians. This collaboration of minds and electronics serves as a cognitive system to increase the fertility of ideas as well as to extend the range of available research skills. We find examples of group research in studies related to biotechnology, human behavior, the neurological basis of human learning attempts to control the AIDS pandemic, and the genetic treatment of human diseases. The trend is toward the unity of the sciences and the unification of the sciences with society.

The National Science Foundation, in December 1992, proposed new standards for the research it will support. These recognize "a greater integration of science and engineering research into society, and the public's increasing expectation for the results of this research." Another standard is "research that crosses traditional boundaries and links science and technology." The current chairman of the House Committee on Science, Space and Technology of the U.S. Congress is George E. Brown, Jr., who recently reported to Congress that there has been a "paradigm shift" in the sciences that "requires us to reconsider the role of science in our society." He recommended support for research be prioritized in terms of its strategic value in social, economic, environmental, or human contexts. It is increasingly evident that scientific research is becoming more socially than theory driven.

In 1993, the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine published a document entitled *Science, Technology and the Federal Government: National Goals for a New Era.* The report is focused on strengthening the covenant between science, technology, and society. The report recognizes that the public support of research in science and technology is justified by its eventual benefits to humanity, improvements in the quality of life, and national well-being. The report notes that the cultural significance of science and technology is reflected in ways that have "changed our ideas about ourselves and our place in the universe, about human history, and the human future." To attain national goals, the committee stresses the need to give greater attention to the use and the "users" of knowledge. President Clinton and Vice President Gore, in their 1993 publication *Technology for America's Economic Growth, A New Direction to Build Strength,* see educational reform as closely tied to the nation's development. They recognize that "new growth industries are knowledge- based," and that learning must be continuous to meet "the demands of a fast-paced economy," and for ensuring the quality of life.

Contemporary research in science is now valued in terms of its sociocultural significance. These attributes interpreted in terms of science teaching call for an integration of the school science curriculum with the needs of society and personal development. School science curriculums today are seen as making no sense in this new era of ours characterized by a knowledge-intensive and contemporary science. Science educators must formulate a new vision of education in the sciences with a coherent statement of its purposes as a basis for the reinvention of science curriculums. The central purpose is to move science education into the framework of society and human affairs. Ironically, this is a view of standards portrayed by Francis Bacon in 1620 when he wrote, "the ideal of human service is the ultimate goal of scientific effort ... providing a better and more perfect use of human reason." To achieve this goal, Bacon recommended a selection of "subject matter which does the most for the welfare of man."

Meeting the demands of living in a knowledge-intensive society adds new dimensions to the teaching of science beyond those previously described. Not all dimensions have as yet been defined and validated in terms of postmodern science, cultural shifts, social change, and recent findings in the cognitive sciences. Following are sketches of some of the issues related to reinventing the science curriculum.

1. In a rapidly changing knowledge-intensive society, what is important to know in a lifetime cannot be learned in 12 to 16 years of schooling. Therefore, "learning to learn" becomes a goal of science education. The skills needed to achieve this goal have not been fully identified, but they include knowing how to find sources of reliable information, how to access new knowledge, and how to use it in relevant and rational ways. Associated with this goal is the recognition that in postmodern science, all facts, laws, and theories are forever tentative, subject to change without notice.
2. In a world of accelerating changes and in a society that is knowledge-intensive, one must become a student for a lifetime. This goal is essential for achieving optimal levels of cultural adaptation, for continual success in the world of work, and for being a productive member of society. It is already evident in our economy that when speaking of a "dead-end" job, it means a person not a position. The details of this goal are described in the U.S. Department of Labor publication entitled *Learning a Living*.
3. The public is demanding the teaching of higher order thinking skills in science courses. In the past, the emphasis has been almost entirely on inquiry and processes representing lower order thinking skills. These are skills having to do with how science information is generated, classified, expressed, and interpreted. These skills are for the most part quantitative in nature and discipline bound.

   The appeal for higher order thinking skills is related to the utilization of science/technology knowledge in human and social affairs. These skills are for the most part qualitative. When science/technology information is brought into contexts where it serves people and society, elements of ethics, values, morals, bias, politics, risks, ideals, opinions, trade-offs, and aspects of uncertainty and probability enter the thinking process.

   These intellectual attributes are essential for understanding the interactions of science and technology as they influence human experience, the quality of life, and social progress. In addition, to deal with science/technology concepts in the context of responsible citizenship requires that the learner be able to distinguish science from pseudoscience or quackery, theory from dogma, fact from myth or folklore, probabilities from certainty, and data from assertions.

4. The desired context for curriculums in the sciences is one that focuses on the future. This is not in the sense of predicting the future but preparing young people to help plan the society and their own lives for living, learning, and working in the world in which they will be spending their lives. Traditionally, school science courses have been historically oriented. This theme is not to be ignored but made richer by pointing out what we once believed, what we believe now, and what we wish we understood. How else can we convey ongoing achievements in science/technology and put stars in the eyes of young people for choosing careers in science or technology?
5. To match the nature of contemporary science with its emphasis on strategic research, which is designed from the onset to benefit human well-being and social progress, curriculum standards must be framed in a sociocultural context. This trend is generally described as relating science to the real life and real world of the student. Historically, this curriculum approach has been recognized as "meeting the needs" of young people. Consequently, our first step in modernizing science curriculums is to identify the personal, social, and behavioral needs of students at various developmental levels to serve as a framework or blueprint for establishing curriculum standards. The educational rationale is a science curriculum that can be lived and can benefit the individual and the common good. A primary purpose of a contemporary science curriculum is to enable students to cope with science/technology-based personal and social problems and to engage in critical argument, in other words, the operationalization of science education in a sociocultural context.
6. Over the past two decades, cognitive scientists have been researching factors related to how people learn, remember, and use knowledge. It has become clear that to achieve these objectives requires a science curriculum a student can experience—a living curriculum. Knowing and understanding arise from our use of information. It also has become evident that what students learn from laboratory activities is limited by what they have been prepared to learn. They learn more when they are the subject of an investigation, not simply a routine "performer" or "observer."
7. To purposely represent the tenets and ethos of contemporary science in school curriculums will require a "core" curriculum representing the unity of various sciences in contrast to isolated disciplines. Conceptual themes will need to be built into the curriculum, rather than left to students. Many scientists find it difficult to relate concepts from one research field to another and more so to society.

Conclusion

What is sought is a broader and richer perspective of science education, one that considers the demands of a changing knowledge-intensive society; the interrelation of science, culture, and social progress; and the adaptive needs of learners. Each of these factors is seen as essential for responsible citizenship in a democratic society characterized by achievements in science and for a rational consideration of human affairs.

SCIENCE CURRICULUM REFORM IN THE UNITED STATES

BY RODGER W. BYBEE

Support for reform is unprecedented in the history of American education. By the early 1990s, more than 300 reports admonished those in the educational system to reform science education. Depending on the group publishing the report, the recommendations for education programs emphasized issues such as updated scientific and technologic knowledge, application of contemporary learning theory and teaching strategies, improved approaches to achieve equity, and better preparation of citizens for the workplace.

In this chapter, I present differences between the contemporary reform of science curriculum and the reform that occurred in the 1950s and 1960s. Then, I describe several important curriculum frameworks that science educators are using for the design of curriculum. Finally, I address a number of important issues in the reform of science curriculum in the United States.

Different Perspectives on the Reform of Science Curriculum

From the perspective of science curriculum, significant differences exist between the reforms of the 1960s and the 1990s (Bybee, 1994). The 1960s reform began at the secondary level and progressed to the elementary level. In the 1990s, reports have generally addressed all levels, K–12, but the specific curriculum reform began at the elementary school level and progressed to middle-level education and continued at the high school level. The impetus for this sequential reform was initiated in the late 1980s by funding from the National Science Foundation (NSF) for new elementary and middle school programs. Policy-level reports also supported the sequence of reform just described (Bybee et al., 1989, 1990; Champagne, Loucks-Horsley, Kuerbis, & Raizen, 1991). School science programs structured from the top down, literally from 12th grade physics to elementary programs, are quite different from school science programs that are structured from the elementary school to high school.

There is a second difference. In the 1980s and 1990s, there are fewer curriculum projects at the national level. Reform efforts are being initiated through state-level frameworks, and many new science curricula are being completed through local development. Such efforts have the advantage of more thorough implementation and the disadvantage of lower levels of real program reform—namely, the incorporation of new perspectives on science and technology, learning theory, and program design. The latter results from a lack of time and money to develop new materials; subsequently, the school districts adopt extant textbooks. In addition, local districts do not implement staff development programs to update teachers in the content of science and technology and in innovative teaching strategies. If this situation is replicated nationally, the result could well be a low level of reform in both quantity and quality.

A final difference between the reforms of the 1960s and the 1990s is the influence of national standards and benchmarks in the current reform. National standards should provide significant impetus for reform as well as goals that should function as coordinators and regulators. I address national standards for science education in some detail later in this chapter, and, along with colleagues, in the next chapter.

Frameworks for Science Curriculum

In the late 1980s and early 1990s, several frameworks for curriculum significantly influenced state and local reform of school science programs. Those frameworks include the American Association for the Advancement of Science (AAAS) 1989 report *Science for All Americans* and the subsequent publication in 1993 of *Benchmarks for Science Literacy;* the National Science Teachers Association (NSTA) 1989 project *Scope, Sequence, and Coordination;* The National Center for Improving Science Education (NCISE) reports on middle-level education (Bybee et al., 1990a, 1990b, 1990c) and secondary education (Champagne, Loucks-Horsley, Kuerbis, & Raizen, 1991); and the *National Science Education Standards* Project.

Science for All Americans. In the 1980s, F. James Rutherford, chief education officer-AAAS, established Project 2061 to take a long-term, large-scale view of education reform in the sciences based on the goal of scientific literacy. The core of *Science for All Americans* consists of recommendations by a distinguished group of scientists and educators about what understandings and habits of mind are essential for all citizens in a scientifically literate society. Scientific literacy, which embraces science, mathematics, and technology, is a central goal of science education; yet, general scientific literacy eludes U.S. society. In preparing its recommendations, Project 2061 staff used the reports of five independent scientific panels. In addition, Project 2061 staff sought the advice of a large and diverse array of consultants and reviewers—scientists, engineers, mathematicians, historians, and educators. The process took more than three years, involved hundreds of individuals, and culminated in the publication of *Science for All Americans* (AAAS, 1989) and the clarification of the definition of scientific literacy. Its recommendations, therefore, are presented in the form of basic learning goals for American students. A premise of Project 2061 is that the schools do not need to teach more content; rather, they should teach less so that content can be taught better.

Recommendations from *Science for All Americans* address the basic dimensions of scientific literacy, which are

- ▼ being familiar with the natural world and recognizing its diversity and its unity;
- ▼ understanding concepts and principles of science;
- ▼ being aware of some of the ways in which science, mathematics, and technology depend upon one another;
- ▼ knowing that science, mathematics, and technology are human enterprises and knowing about their strengths and limitations;
- ▼ developing a capacity for scientific ways of thinking; and
- ▼ using scientific knowledge and ways of thinking for individuals and social purposes.

Science for All Americans covers an array of topics. Many already are common in school curricula (for example, the structure of matter, the basic functions of cells, prevention of disease, communications technology, and different uses of numbers). The treatment of such topics, however, differs from traditional approaches in two ways. One difference is that boundaries between traditional subject-matter categories are softened and connections are emphasized through the use of important conceptual themes such as systems, evolution, cycles, and energy. Transformations of energy, for example, occur in physical, biological, and technological systems, and evolutionary change occurs in stars, population of organisms, and societies. A second difference is that the amount of detail that students are expected to learn is less than in traditional science, mathematics, and technology courses. Key concepts and thinking skills are emphasized instead of specialized vocabulary and memorized procedures. The ideas not only make sense at a simple level, but also provide a lasting foundation for learning more science. Details are treated as a means of enhancing, not guaranteeing, students' understanding of a general idea.

Recommendations in *Science for All Americans* include topics not common in school curricula, among them, the nature of the scientific enterprise and how science, mathematics, and technology relate to one another and to the social system in general. The report also calls for understanding something of the history of science and technology.

Project 2061 also has released the draft document *Benchmarks for Science Literacy* (1993). Based on *Science for All Americans,* the benchmarks consist of specific goals and objectives for science curriculum. Many local school districts and some national organizations began using the benchmarks for different models of science curriculum.

Scope, Sequence, and Coordination. A second approach to the reform of secondary school science has been suggested by Bill Aldridge (1989), executive director of the National Science Teachers Association. In an analysis of school programs, Aldridge found deficiencies related to the scope, sequence, and coordination of programs. The deficiencies were revealed in a comparison with science programs in other countries, specifically the Commonwealth of Independent States and the People's Republic of China.

The project on Scope, Sequence, and Coordination of Secondary School Science is an effort to restructure science teaching primarily at the secondary school level. The project calls for elimination of the tracking of students, recommends that all students study science every year for six years, and advocates the study of science as carefully sequenced, well-coordinated instruction in physics, chemistry, biology, and earth and space science. As opposed to the traditional curriculum where science is taught in year-long and separate disciplines—referred to as the "layer-cake approach"— the NSTA project provides for *spacing* the study of each of the sciences during several years. Research on the *spacing effect* indicates that students can learn and retain new material better if they study it in spaced intervals rather than all at once. In this way, students can revisit a concept at successively higher levels of abstraction (see table 1).

The scope, sequence, and coordination reform effort also uses appropriate *sequencing* of instruction, taking into account how students learn. In science, understanding develops from concrete experiences with a phenomenon before it is given a name or a symbol. Students need experience with a concept in several different contexts before it becomes part of their mental repertoire. With prior hands-on experience, students can come to understand important concepts and processes of science. The practical components of this instruction should begin in the seventh grade with issues and phenomena of concern to students at a personal level and then progress toward a more encompassing scope in the upper grades. As they mature, students are able to generalize from

TABLE 1
Example of a Revised Science Curriculum for Grades 7 through 12.

Subject	Grade Level 7	8	9	10	11	12	Total Time Spent
	Hours Per Week by Subject						
Biology	1	2	2	3	1	1	360
Chemistry	1	1	2	2	3	2	396
Physics	2	2	1	1	2	3	396
Earth/Space Science	3	2	2	1	1	1	360
Total Hours Per Week	7	7	7	7	7	7	
Emphasis	Descriptive		Empirical		Theoretical		

concrete, direct experiences to more abstract and broader theoretical thinking. With a sequenced approach, students should no longer be expected to memorize facts and information. With practical applications, science should make sense and have meaning.

The third component of the scope, sequence, and coordination project is the *coordination* of science concepts and topics. Earth and space science, biology, chemistry, and physics have significant features and processes in common. Coordination among these disciplines leads to awareness of the interdependence of the sciences and how the disciplines form a body of knowledge. Seeing a concept, law, or principle in the context of two or three different subjects helps establish it firmly in the student's mind.

At first, students are introduced more intensively to the descriptive and phenomenological aspects of the sciences; the most abstract and theoretical aspects are emphasized in the later years. Empirical and semiquantitative treatments are emphasized in the middle years. Computers and technology and practical applications are integrated directly into each course. Most important, students would be taught science in a way they would be able to understand and apply—whether as scientists or citizens.

National Center for Improving Science Education. Development of local school science programs can be greatly enhanced by frameworks for curriculum, assessment, and staff development, such as those produced by the National Center for Improving Science Education (NCISE) for the elementary school (Bybee, et al., 1989; Loucks-Horsley, 1989; Raizen, 1989), the middle school (Bybee et al., 1990a, 1990b, 1990c; Loucks-Horsley, 1990; Raizen et al., 1990), and for the secondary level (Champagne, Loucks-Horsley, Kuerbis, & Raizen, 1991).

The curriculum and instruction frameworks for middle school and high school extend the center's proposed framework for the elementary years (Bybee et al., 1989). Treatments of the recommended organizing concepts, however, are more complex. The organizing concepts detailed in the technical report for middle schools include cause and effect, change and conservation, diversity and variation, energy and matter, evolution and equilibrium, models and theories, probability and prediction, structure and function, systems and interaction, and time and scale. The concepts need not be independent units of study; they should, however, link subjects, topics, and disciplines. Curriculum emphases should include scientific habits of mind, such as willingness to modify explanations, cooperation in answering questions and solving problems, respect for reasons, reliance on data, and skepticism. Students also should develop skills for answering questions and solving problems, making decisions, and taking action. Content in the program should relate to the life and world of the student and provide a context for presenting new knowledge, skills, and attitudes. The focus of curriculum and instruction should be on depth of study, not breadth of topics.

National Science Education Standards Project. In this section, I provide a brief overview of the *National Science Education Standards*. The next chapter presents more details of the content, teaching, assessment, program, and system standards.

National Science Education Standards will provide the qualitative criteria and framework for judging science programs (content, teaching, and assessment) and the policies necessary to support them. The standards will

- ▼ define the understanding of science that all students, without regard to background, future aspirations, or prior interest in science, should develop;
- ▼ present criteria for judging science education content and programs at the K–4, 5–8, and 9–12 levels, including learning goals, design features, instructional approaches, and assessment characteristics;
- ▼ include all natural sciences and their interrelationships, as well as the natural science connections with technology, science- and technology-related social challenges, and the history and nature of science;
- ▼ include standards for the preparation and continuing professional development of teachers, including resources needed to enable teachers to meet the learning goals;
- ▼ propose a long-term vision for science education, some elements of which can be incorporated almost immediately in most places, others of which will require substantial changes in the structure, roles, organization, and context of school learning before they can be implemented;
- ▼ provide criteria for judging models, benchmarks, frameworks, curricula, and learning experiences developed under the guidelines of ongoing national projects, or under state frameworks, or local district-, school- or teacher-designed initiatives; and
- ▼ provide criteria for judging teaching, the provision of opportunities to learn valued science (including such resources as instructional materials, educational technologies, and assessment methods) and science education programs at all levels.

Some Issues in the Reform of Science Education

Writing reports about the reform of education and actually reforming education are two very different activities. The former requires that a small group agree on a set of ideas and express those ideas clearly and with adequate justification. The latter requires that millions of school personnel in thousands of autonomous school districts change their school science program, instructional practices, and assessment strategies. Changes in science curriculum in schools represent smaller instances of the latter. For changes to occur in science education, school personnel must change, and the most important factors influencing the possibility of changing school personnel are the programs and practices currently in place and supported by the school system.

Achieving scientific literacy. Scientific and technological literacy is the main purpose of a K–12 science education. This purpose is for *all* students, not just those individuals destined for careers in science and engineering. The curriculum for science education is inadequate to the challenge of achieving scientific and technological literacy by 2000, and publication of national standards will stimulate review of school personnel and science programs.

Increasing the scientific and technological literacy of students requires several fundamental changes in science curricula. First, the amount of information presented must be replaced by key conceptual schemes that students learn in some depth. Second, the rigid disciplinary boundaries of earth science, biology, chemistry, and physics should be softened and greater emphasis placed on connections among the sciences and among disciplines generally thought of as outside school science, for example, technology, mathematics, and ethics (Confrey, 1990; Newmann, 1988).

Achieving the goal of scientific and technological literacy requires more than understanding concepts and processes of science and technology. Indeed, there is some need for citizens to understand science and technology as integral to our society. That is, science and technology are enterprises that shape, and are shaped by, human thought and social actions. As mentioned earlier, aspects of this theme are discussed as STS (Bybee, 1987). The prevailing approach to STS, however, is to focus on science-related social problems such as environmental pollution, resource use, and population growth. My argument expands the STS theme to include some understanding of the nature and history of science and technology. There is recent and substantial support for this recommendation, though few curriculum materials implement it. Including the nature and history of science and technology provides opportunities to focus on topics that soften disciplinary boundaries and establish connections between science and other domains such as social studies (Bybee et al., 1992).

Applying learning theory. The substantial body of research on learning should be the basis for making instruction more effective. This research suggests that students learn by constructing their own meaning from experiences (Driver & Oldham, 1986; Sachse, 1989; Watson & Konicek, 1990). A constructivist approach requires very different science curricula and methods of science instruction.

Not unrelated to the implications of research or learning theory is the age-old theme that science teaching should consist of experiences that exemplify the spirit, character, and nature of science and technology. Students should begin study with questions about the natural world (science) and problems about how human beings adapt to their environments (technology). They should be actively involved in inquiry and problem solving. They should have opportunities to present their explanations for phenomena and solutions to problems and to compare their explanations and solutions to those concepts of science and technology. They should have a chance to apply their understandings in new situations. In short, inquiry-oriented laboratories are infrequent experiences for students, but they should be a central part of their experience in science education. Extensive use of inquiry is consistent with my other recommendations, and it has widespread support (Costenson & Lawson, 1986).

Addressing equity issues. During the 1990s, the issue of equity must be addressed in science programs and by school personnel. For the past several decades, science educators at all levels have discussed the importance of changing science programs to enhance opportunities for historically underrepresented groups. Calls for scientific and technological literacy assume the inclusion of *all* Americans. Other justifications for this position include the supply of future scientists and engineers, changing demographics, and prerequisites for work. Research results, curricula recommendations, and practical suggestions addressing equity issues are available to those developing science curricula (Atwater, 1986, 1989; Gardner, Mason, & Matyas, 1989; Linn & Hyde, 1989; Malcom, 1990; Oakes & The Rand Corporation, 1990).

Including middle schools. The science curriculum in middle schools is a special concern. Numerous reports and commissions address the need for educational reform for elementary and high school science education, but few have specifically recognized the emergence of middle schools in the 1980s. Notable exceptions include the Carnegie Corporation (1989) report *Turning Points: Preparing Youth for the 21st Century,* the California State Department of Education (1987) report *Caught in the Middle,* the Maine Department of Educational and Cultural Services (1988) report *Schools in the Middle,* and the National Association of Secondary School Principals (1985) report *An Agenda for Excellence at the Middle Level.* The movement toward middle schools, and away from junior high schools, is a significant trend in American education. Yet, thus far, the middle school reform has not thoroughly addressed the particular issues of subject-matter disciplines—in this case, science and technology. The contemporary reform must not allow the science education of early adolescents to be overlooked or assumed to be part of either the elementary school or secondary school curriculum.

Integrating assessment. The improvement of curriculum and instruction will be a hollow gesture without concomitant changes in assessment at all levels, from the local classroom to the National Assessment of Educational Progress (NAEP). In general, the changes in assessment practices must reflect the changes described earlier for curriculum and instruction. Incongruities, such as teaching fewer concepts in greater depth but testing for numerous facts in fine detail, will undermine the reform of science education. New forms of assessment are available and being recommended by researchers, policymakers, and practitioners (Frederiksen & Collins, 1989; Murnane & Raizen, 1988; Roueche, Sorensen, & Roueche, 1988; Shavelson, Carey, & Webb, 1990).

Recognizing systemic reform. Reform of science education must be viewed as part of the general reform of education. Approaching the improvement of science education by changing textbooks, buying new computers, or adding a new course simply will not work. Fortunately, widespread educational reform, which includes science education, is under way. Science educators must view reform holistically and systemically as the reconstruction of science education for K–12 and include all courses and students, a staff development program, reform of science teacher preparation, and support from school administrators. This comprehensive or systemic recommendation is based on the research on implementation (Fullan, 1982; Hall, 1989) and research literature on school change and restructuring (Kloosterman, Matkin, & Ault, 1988; Roberts & Chastko, 1990; Tobin & Espinet, 1980; Yeany & Padilla, 1986).

Conclusion

Looking toward the turn of the century leaves science educators viewing a system already in the process of reform. Though distinctly different from earlier reforms, this reform holds great promise of improving the goals of scientific and technological literacy for all citizens.

NATIONAL SCIENCE EDUCATION STANDARDS: A CURRICULUM PERSPECTIVE

BY
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In this chapter, we present an overview of the *National Science Education Standards* (NRC, 1995)*. We describe national standards with an emphasis on curriculum, in particular the important mission of redesigning the science curriculum. Even the emphasis on science curriculum recognizes that the national standards are more than content and subject matter. The *National Science Education Standards* answer several basic and systemic questions: What should students know and be able to do? What do science teachers have to know and be able to do to enhance student learning? How can we appropriately assess student understanding and abilities? How can school programs provide all students the opportunity to learn science? What must the educational system do to support school science programs and practices implied in the national standards? These questions direct attention to the major domains of standards, respectively, teaching, professional development, assessment, content, program, and system (see figure 1–1).

Many issues confront those who wish to use the national standards to improve local, state, or national science education. Perhaps the most important issue, and the one underlying the *National Science Education Standards* is the commitment to **science for all students.** From the earliest published statements, the national standards have maintained an unwavering commitment to the position that any reform of science education must confront directly and address adequately the proposition that school science should be for all students.

Following is a quotation from the National Committee on Science Education Standards and Assessment that elaborates this position.

> We emphatically reject the current situation in science education where members of populations defined by race, ethnicity, economic status, gender, physical disability or intellectual capacity are discouraged from pursuing science and excluded from opportunities to learn science. By adopting the goal of *science for all*, the standards prescribe the inclusion of all students in challenging science learning opportunities and define a level of understanding that all should develop.

*The reader should note that this chapter is based on the first complete draft of the standards and not the final report.

> In particular, the commitment to *science for all* implies inclusion not only of those who traditionally have received encouragement and opportunity to pursue science, but of women and girls, all racial and ethnic groups, students with disabilities, and those with limited English proficiency. Further, it implies attention to various styles of learning and differing sources of motivation. Every person must be brought into and given access to the ongoing conversation of science.

Thus, the commitment to *science for all* requires content, teaching, and assessment standards that take into account student diversity vis-á-vis interests, motivation, experience, and ways of coming to understand science. The standards must define criteria for high-quality science experiences that include the engagement of all students in the full range of science content. These experiences must teach the nature and process of science as well as the subject matter and must support the notion that men and women of diverse backgrounds engage and participate in science and that all have a claim on this common human heritage.

Clearly, the commitment to *science for all* has implications for redesigning the science curriculum, school science programs, and building capacity for systemic response to science education reform. The very difficult task of realizing this

FIGURE 1–1
National Science Education Standards.

- **Teaching Standards:** Specify criteria to be used in making judgments about the quality of classroom science teaching.
- **Professional Development Standards:** Specify criteria to be used in making judgments about the quality of professional development opportunities for teachers of science.
- **Assessment Standards:** Specify criteria to judge the quality of the assessment practices used by teachers and state and federal agencies to measure student achievement and the opportunity provided students to leam science.
- **Content Standards:** Specify what students should know, understand, and be able to do in natural science.
- **Program Standards:** Specify criteria for judging the quality of and conditions for school science programs.
- **System Standards:** Specify criteria for judging the performance of the components of the science education system responsible for providing schools with the financial and intellectual resources necessary to achieve the vision present in the *National Science Education Standards*.

FIGURE 1–2
Guiding Principles for the National Science Education Standards.

- All students, regardless of gender, cultural or ethnic background, physical or learning disabilities, aspirations, or interest and motivation in science, should have the opportunity to attain higher levels of scientific literacy than they do currently. This is a principle of equity.
- All students will learn all science in the content standards.
- All students will develop science knowledge as defined in the content standards and an understanding of science that enables them to use their knowledge as it relates to scientific, personal, social, and historical perspectives.
- Learning science is an active process.
- For all students to understand more science, less emphasis must be given to some science content and more resources, such as time, personnel, and materials must be devoted to science education.
- School science must reflect the intellectual tradition that characterizes the practice of contemporary science.
- Improving science education is part of systemic education reform.

proposition of *science for all* must be addressed by those who develop curricula, set policy, and implement programs and practices. Figure 1–2 describes this proposition and others that guided work on the national standards. These principles also present a framework that can guide the design and development of science curriculum.

Content Standards

Science Content Standards describe what all students should know and be able to do in science as a result of their school science studies. Although we recognize that the intellectual character of the science curriculum is largely derived from the knowledge base of the natural sciences, we also believe "science content" in schools should include more than the concepts, principles, facts, laws, and theories that represent the body of scientific knowledge.

Eight general categories of *school science content* serve to define the breadth of science content and to provide organizers for the standards (see figure 1–3).

Readers should recognize what these categories represent and—equally important—what they do not represent. They serve to organize and group eight overlapping and mutually dependent "clusters" of student learning in science. We expect that effective science curricula will routinely interweave these important aspects of what students should know and do in a variety of creative and constructive ways.

By contrast, categories of the Content Standards do not imply that separate science teaching units or courses should support each topic in isolation. The concepts, skills, and understandings organized under these headings are intended attainments of students, not the instructional experiences through which students develop such understandings. In other words, the organization of standards for science content is not necessarily congruent with the organization of a particular program of study or science curriculum.

Figures 1–4 through 1–11 provide an overview of the eight Content Standards and the fundamental organizers for grade levels K–4, 5–8, and 9–12.

FIGURE 1–3
Science Content Standards.

- ▽ Science as Inquiry
- ▼ Physical Science
- ▼ Life Science
- ▼ Earth and Space Science
- ▼ Science and Technology
- ▼ Science in Personal and Social Perspectives
- ▼ History and Nature of Science
- ▼ Unifying Concepts and Processes

FIGURE 1–4
Science as Inquiry.

Grades K–4

- ▼ Ask a question about objects, organisms, and events in the environment.
- ▼ Plan and conduct a simple investigation.
- ▼ Employ simple equipment and experiences to gather data and extend the senses.
- ▼ Use data and experiences to construct a reasonable explanation.
- ▼ Communicate about investigations and explanations.

Grades 5–8

- ▼ Identify questions that can be answered through scientific investigations.
- ▼ Design and conduct a scientific investigation.
- ▼ Use appropriate tools and technologies to gather, analyze, and interpret data.
- ▼ Develop descriptions, explanations, predictions, and models using evidence.
- ▼ Think critically and logically to make the relationships between evidence and explanations.
- ▼ Recognize and analyze alternative explanations and predictions.
- ▼ Communicate scientific procedures and explanations.

Grades 9–12

- ▼ Identify the questions and concepts that guide scientific investigations.
- ▼ Design and conduct a full scientific investigation.
- ▼ Use technology to improve investigations and communications.
- ▼ Formulate and revise scientific explanations and models using logic and evidence.
- ▼ Recognize and analyze alternative explanations and models.
- ▼ Communicate and defend a scientific argument.

FIGURE 1–5
Physical Science.

Grades K–4

- ▼ Properties of Objects and Materials
- ▼ Position and Motion of Objects
- ▼ Light, Heat, Electricity, and Magnetism

Grades 5–8

- ▼ Properties and Changes of Properties in Matter
- ▼ Motions and Forces
- ▼ Transformations of Energy

Grades 9–12

- ▼ The Structure of Atoms
- ▼ Structure and Properties of Matter
- ▼ Chemical Reactions
- ▼ Forces and Motion
- ▼ Conservation of Energy and the Increase in Disorder
- ▼ Interactions of Energy and Matter

FIGURE 1–6
Life Science.

Grades K–4

- ▼ The Characteristics of Organisms
- ▼ Life Cycles of Organisms
- ▼ Organisms and Environments

Grades 5–8

- ▼ Structure and Function in Living Systems
- ▼ Reproduction and Heredity
- ▼ Regulation and Behavior
- ▼ Populations and Ecosystems
- ▼ Diversity and Adaptations of Organisms

Grades 9–12

- ▼ The Cell
- ▼ The Molecular Basis of Heredity
- ▼ Biological Evolution
- ▼ The Interdependence of Organisms
- ▼ Matter, Energy, and Organization in Living Systems
- ▼ The Nervous System and the Behavior of Organisms

FIGURE 1–7
Earth and Space Science.

Grades K–4

- ▼ Properties of Earth Materials
- ▼ Objects in the Sky

Grades 5–8

- ▼ Structure of the Earth System
- ▼ Earth's History
- ▼ Earth in the Solar System

Grades 9–12

- ▼ Energy in the Earth System
- ▼ Geochemical Cycles
- ▼ The Origin and Evolution of the Earth System
- ▼ The Origin and Evolution of the Universe

FIGURE 1–8
Science and Technology.

Grades K–4

- ▼ Abilities to Distinguish between Natural Objects and Objects Made by Humans
- ▼ Abilities of Technological Design
- ▼ Understanding about Science and Technology

Grades 5–8

- ▼ Abilities of Technological Design
- ▼ Understanding about Science and Technology

Grades 9–12

- ▼ Abilities of Technological Design
- ▼ Understanding about Science and Technology

FIGURE 1–9
Science in Personal and Social Perspectives.

Grades K–4

- ▼ Personal Health
- ▼ Characteristics and Changes in Populations
- ▼ Types of Resources
- ▼ Changes in Environments
- ▼ Science and Technology in Local Challenges

Grades 5–8

- ▼ Personal Health
- ▼ Populations, Resources, and Environments
- ▼ Natural Hazards
- ▼ Risks and Benefits
- ▼ Science and Technology in Society

Grades 9–12

- ▼ Personal and Community Health
- ▼ Population Growth
- ▼ Natural Resources
- ▼ Environmental Quality
- ▼ Natural and Human–Induced Hazards
- ▼ Science and Technology in Local, National, and Global Changes

FIGURE 1–10
History and Nature of Science.

Grades K–4

- ▼ Science as a Human Endeavor

Grades 5–8

- ▼ Science as a Human Endeavor
- ▼ Nature of Science
- ▼ History of Science

Grades 9–12

- ▼ Science as a Human Endeavor
- ▼ Nature of Scientific Knowledge
- ▼ Historical Perspectives

FIGURE 1–11
Unifying Concepts and Processes.

Grades K–12

- ▼ Order and Organization
- ▼ Evidence, Models, and Explanation
- ▼ Constancy, Changes, and Measurement
- ▼ Evolution and Equilibrium
- ▼ Form and Function

Teaching Standards

The Teaching Standards consider three major areas: the structure of science teaching, the skills and knowledge science teachers must have, and the professional development program that must be in place for teachers to gain and maintain their skill and knowledge base.

Throughout the Teaching Standards, the term "students" means "all students," regardless of background, future aspirations, or interest in science. In some cases, accommodations in instruction must be made to realize this goal, but in all cases, the conviction that every student can learn is a critical component of effective science teaching.

Any division of the complex process of teaching oversimplifies the situation. For purposes of describing what teachers do to provide meaningful science learning experiences, we are currently using six categories, acknowledging that they overlap considerably. The statements of Teaching Standards are broad and, in many instances, reflect good teaching practice in any domain. The Teaching Standards are summarized in figure 1–12 and elaborated in the following paragraphs.

1. Planning the science program. This category includes the work that teachers do as they select and organize the content for science teaching. Science teachers work individually, and with others, to plan and design, evaluate, and select science curriculum for their students that reflects the Content Standards and the range of ways that diverse students learn science. Two important considerations in the planning process are appropriateness to students' levels of development and connection to and sensitivity to students' experiences, family, culture, community, and prior understanding. Curriculum also must be based in rich and challenging inquiry and accommodate the contributions of students.

Science teachers select and design teaching strategies that reflect both the nature of science and the ways their students learn. Some characteristics of these strategies are that they are flexible and open to the ideas, strengths, and needs of students and that they engage students in inquiry, providing sufficient time for extended investigations. Strategies also must enable students to construct their

FIGURE 1–12
Teaching Standards.

▼ **Science teachers will plan an inquiry-based science program for their students.** In doing this, they develop a framework of long- and short-term goals for their students; select science content and adapt and design curriculum to meet the particular interests, knowledge, skills and experiences of their students; determine teaching strategies that support the development of student understanding and nurture a community of science learners; and work with colleagues within and across disciplines and levels.

▼ **Science teachers will guide and facilitate science learning.** In doing this, they interact with their students to focus and support their inquiries; orchestrate discourse among students about scientific ideas; challenge students to take responsibility for their own work and also to work collaboratively; recognize and respond to student diversity and encourage all students to participate fully in science learning; encourage and model the skills of scientific inquiry as well as the curiosity, openness to new ideas, and skepticism that characterizes science.

▼ **Science teachers will engage in ongoing assessment of their teaching and of student learning.** In doing this, they systematically gather data on their students and their development; analyze assessment data to guide teaching; guide students in self–assessment; and use student data, observations of teaching, and interactions with colleagues to reflect on and improve practice.

▼ **Science teachers will design and manage a learning environment that provides students with the time, space, and resources needed for learning science.** In doing this, they structure the time available so that students are able to engage in extended investigations; create a setting for student work that is flexible and supportive of science inquiry; ensure a safe working environment; make the available science tools, materials, and print and technological resources accessible to students; identify and use resources outside the school; and engage students in designing the environment.

▼ **Science teachers will develop communities of science learners that reflect the intellectual rigor of scientific inquiry, the attitudes, and the social values conducive to science learning.** In doing this, they display and demand a respect for and valuing of the ideas, skills, and experiences of all students; give students a significant voice in decisions about the content and context of their work, and require students to take significant responsibility for the learning of all members of the community; nurture collaboration; structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse; and model and emphasize the skills, attitudes, and values of scientific inquiry.

▼ **Science teachers will be active participants in the ongoing planning and development of the school science program.** In doing this, they plan and develop the school science program; have a voice in decisions concerning the allocation of time and other resources to the science program; and plan and implement professional growth and development strategies for themselves and their colleagues.

knowledge in a social environment and communicate their ideas in many forms. Teaching strategies support students in using and making connections to other disciplines.

2. Guiding and facilitating student learning. This category includes the daily work that teachers do with students to support science learning. Science teachers recognize the diversity of students within the classroom, reflect sensitivity to diversity in words and actions, and support the full participation of all students. They create opportunities for students to take responsibility for their own learning and work collaboratively by encouraging students to pursue their own ideas individually and in groups, guiding students in the skills and uses of self-assessment, providing for collaborative group work, and requiring presentations of work accomplished.

3. Assessing, learning and teaching. This category concerns the work that teachers do to assess students' understanding for a variety of purposes, formally and informally, individually, and in groups. Science teachers engage in ongoing assessments of learning and teaching for the purposes of guiding their planning and instruction, understanding, monitoring, and challenging student development, and communicating science learning to students, parents, and administrators.

Science teachers employ a variety of assessment strategies including observing and listening to students as they work; discussing students' ideas and conceptions; asking students questions; examining students' work; analyzing responses to an array of formal assessment tasks; engaging students in self-assessment; maintaining portfolios with students; talking with colleagues; and talking with parents.

Science teachers develop a set of criteria to use in the analysis of students' work, including whether students are able to use a variety of ways to illustrate knowledge and understanding; explain science concepts and apply them in new contexts; formulate questions and develop hypotheses; plan and carry out observations, explorations, and investigations; identify patterns and synthesize data; and formulate generalizations from experience.

4. Designing and managing the physical environment. Science teachers and their students use the resources available to design the physical environment to support learning. The learning environment includes space and areas for individuals and groups to work and space for students to keep and display completed and ongoing work. It is a safe environment with space for storage of chemicals, equipment, and other materials, and rules of safety for all to follow. This environment allows students maximum access to equipment such as safety equipment, generic science tools, technological tools, and content-specific tools, as well as content-specific reference materials and secondary sources (books, videodiscs, databases, etc.). The environment for science extends beyond the classroom and school walls to include environments and resources, such as the natural setting, informal science centers, museums, regional science resource centers, industry, and higher education.

5. Building learning communities. This category includes the work that teachers do to develop and maintain learning environments that function as communities of learners. Science teachers work with their students to create a social and intellectual community of learners that encourages science learning, promotes the appreciation of scientific exploration and discoveries, and provides an intellectually open, stimulating, and exciting environment. It is a culture that recognizes, values, and shares contributions from all and takes advantage of the richness of all students' backgrounds, experiences, and ways of thinking. It promotes individual and group responsibility for learning. It stimulates students to initiate and explore questions, problems, and ideas meaningful to them and applicable to their daily lives and interests. The culture exemplifies and promotes students' use of scientific habits of mind and scientific attitudes (such as curiosity, questioning, skepticism, and debate), and extends beyond the classroom into the community.

6. School planning. This category includes the work that teachers do as they interact with colleagues and the larger community. Teachers approach their own work with a spirit of inquiry, continuously seeking to understand which actions are effective in helping students learn and which are not. To these ends, science teachers engage in self-reflection and collaboration with colleagues.

Science teachers do not do their work alone, but work actively with other members of the school and larger community to assure sufficient material and human resources for effective science teaching; plan the use of local resources; plan school and district guidelines for science education to ensure integration of content across the sciences and disciplines and articulation across grades. Teachers also engage in the planning and implementation of professional development. They work with others in ongoing assessment, reflection, and research about their work in order to revise individual practice, influence school practice, and contribute to the knowledge base of science teaching and learning.

Standards for Professional Development

We acknowledge Professional Development Standards as being very important for the ultimate success of the Teaching Standards and of the *National Science Education Standards* overall. These standards provide the basis for the extensive skills and knowledge that are required for successful science teaching and the professional development sequence that supports teachers in becoming increasingly effective science teachers.

The Teaching Standards, by implication, define the knowledge, skills, attitudes, and experiences teachers must have if they are to engage in science teaching as described in the NRC standards. The Professional Development Standards make this knowledge explicit and describe the criteria for the preparation and ongoing opportunities that teachers must have to gain and maintain the knowledge base and skills and to provide the learning opportunities for students that the Teaching Standards define. Figure 1–13 summarizes the Professional Development Standards.

FIGURE 1–13
Professional Development Standards.

- **The professional development of science teachers requires learning science content through the perspectives and methods of inquiry.** Science learning experiences for teachers involve teachers in actively investigating scientific phenomena, interpreting their results, and making personal sense of their findings consistent with currently accepted scientific understanding; address issues, events, problems, or topics significant in science and of interest to participants; introduce teachers to scientific literature, media and technological resources that expand their science knowledge and their ability to access further knowledge; build on the teacher's existing science knowledge, skills, and attitudes; incorporate ongoing reflection on the process and outcomes of understanding science through inquiry; and encourage and support teachers to work together.
- **The professional development of science teachers requires the integration of a knowledge of science, learning, pedagogy, and students, and the application of this understanding to science teaching.** Learning experiences for teachers of science connect and integrate all aspects of science and science education; use actual classroom experience to illustrate and model effective science teaching; address teachers' developmental needs and build on their existing knowledge of science content, teaching, and learning; and use strategies of inquiry, reflection, interpretation of research papers, modeling, and guided practice to build understanding and skill in science teaching.
- **The professional development of science teachers should enable teachers to build the knowledge, skills, and attitudes needed to engage in lifelong learning.** Science learning experiences for teachers provide regular, frequent opportunities for individual and collegial examination and reflection on classroom and institutional practice; provide opportunities for teachers to receive feedback about their teaching and to understand, analyze, and apply that feedback to improve their practice; provide opportunities for teachers to learn and use various tools and techniques for self- and collegial reflection, such as peer coaching, portfolios, and journals; support the sharing of teacher expertise by preparing and using mentors, teacher advisors, coaches, lead teachers, and resource teachers to provide professional development opportunities; provide opportunities to know and have access to existing research and experiential knowledge; and provide opportunities to learn and use the skills of research to generate new knowledge.

FIGURE 1–13
Continued

▼ **Preservice and inservice professional development programs for science teachers are coherent and integrated.** Quality programs are characterized by clear and shared goals that are based on a vision of science learning, teaching, and teacher development congruent with the *National Science Education Standards;* integration and coordination of the components so that understanding and skills can be built over time, reinforced continuously, and practiced in a variety of situations; options that recognize the developmental nature of teacher professional growth and individual and group interests, as well as the needs of teachers who have varying degrees of experience, professional expertise, and proficiency; collaboration among the people involved in the programs, including teachers, teacher educators, scientists, administrators, policymakers, and business people and respect for the unique perspectives and expertise of each; recognition of the history, culture, and organization of the school environment; and continuous program assessment that captures the perspectives of all those involved, uses a variety of strategies, both formal and informal, focuses on both the process and impact of the program, and feeds directly into the program improvement and evaluation.

Assessment Standards

The Science Assessment Standards define the principles for the assessment and analysis of student attainment, the opportunity afforded students to learn science, the methods for achieving appropriate correspondence between the assessment information collected and the purposes that information will serve, the characteristics of valid and reliable science assessment information, the variety of methods for collecting it, and the appropriate concerns for reporting and interpreting the information. Just as the Content Standards have broadened the definition of content, so too, the Assessment Standards have broadened the view of assessment.

In many minds, the word "assessment" conjures up the image of Friday afternoon tests whose primary purpose is to provide scores to be averaged and used to assign a grade—or the standardized achievement tests, administered each spring, whose scores are used to rate the quality of teachers, schools, and districts. In our view, assessment is not synonymous with tests. Rather, assessment is a process whose purpose is to provide information to individuals in the science education system on which to base decisions about student attainment and the opportunities students have to learn science.

In contrast to the view of assessment as a test, we view assessment as a multistep process. Included among the steps are definition of the use to which the information collected will be applied, decisions about what information will be collected, determination of the method to be used to collect the information, interpretation of the information collected, and taking action.

Fundamental Principles Underlying Assessment Practices

Assessment Standards assume several principles that underlie exemplary assessment practices. These principles include the following:

1. At every level of science education, as much attention is given to the assessment of opportunity to learn as to the assessment of student attainment. It is socially and intellectually reprehensible to assess and hold students responsible for what they should have learned without comparable attention to the students' opportunity to learn science. Thus, a measure of the quality of science assessment across the educational system is the extent to which it includes indicators of opportunity to learn. At the classroom level, such indicators include the extent to which students are engaged in learning all aspects of content defined by the Content Standards; the quality of teaching, as defined by the Teaching Standards; and the availability and quality of the resources for teaching (for example, laboratory facilities and equipment, educational technologies, other instructional materials, and supplies). In the same way that the Teaching Standards recognize that accommodations may need to be made to ensure that all students have the opportunity to learn, Assessment Standards recognize that accommodations may need to be made to ensure that all students have the opportunity to show what they have learned.
2. The form of science assessment follows its function. Decisions based on assessment information can only be made with confidence when assessment strategies are well matched to the intended uses of the information. For instance, a classroom teacher's requirements for information about students' understanding are quite different from those of a policy analyst. To select teaching strategies that are appropriate to the learning requirements of individual students, teachers need detailed information about individual student's understanding of particular content. In contrast, to measure the effects of a policy initiative intended to improve science achievement overall, policymakers need more general information from a representative sample of the population of students who were supposed to benefit from the initiative.
3. Users of assessment information are aware of the limitations of the information and the interpretations that can be made from it. Many of the current abuses of assessment information are a result of overinterpretation and overgeneralization. This means that teachers, administrators, parents, and policymakers need to be skilled in interpretation and application of assessment information to the functions for which they are responsible.

4. Assessment data are well matched to the goals of science education. The goals of science education are rich and varied, encompassing knowledge acquisition and the capacity to use that knowledge, to reason scientifically, to inquire into the nature of the natural world, and to address personal and societal concerns. However, psychometric theory and practice are well developed primarily for the assessment of student knowledge. Thus, educators and policy analysts are more confident in instruments that claim to measure what students know about science than those that measure what students can do with the knowledge. Consequently, science assessment at all levels should attempt to measure the full range of goals of science education, not simply those that have traditionally been measured.

   In fact, none of the goals of science education is easily measured. Even knowledge presents measurement challenges. An oft-heard criticism of science achievement tests is that they measure what Alfred North Whitehead called "inert" knowledge rather than "active" knowledge. This focuses attention on the fact that knowledge is active only when it is well structured, not stored in memory as discrete bits. Thus, a standard of quality for instruments that claim to measure knowledge is the degree to which the instruments produce data about the structure, as well as the extent, of the student's information base.
5. The primary responsibility for the assessment of student attainment resides with teachers. Teachers are strategically placed to make the most valid assessments of students' science attainment and to use information gained from it to improve science learning. The public's trust must be restored in the teacher's ability to make such judgments while, at the same time, the teacher's ability to conduct high-quality assessments is enhanced.
6. Assessment practices are fair. Assessment tasks should be set in a variety of contexts, engage students with different interests, and not unfairly assume the perspective or experience of a particular gender, racial, or ethnic group.
7. Performance standards are public. Students, parents, and the general public know what is expected of students. To prevent shortfalls in student attainment, schools and the community must set demanding expectations. For assessment to be a fair and effective lever of change, students must know the standards by which their performance will be judged.
8. Assessment practices throughout the system are internally consistent. The strength of science education depends on assessment practices that consistently reinforce its priority goals while serving learning, teaching, policy, accountability, and certification. Figure 1–14 summarizes the Assessment Standards.

FIGURE 1–14
Assessment Standards.

- ▿ **Assessments are consistent with the decisions that they are designed to inform.** Assessments are deliberately designed. Assessments have explicitly stated purposes. The relationship between decisions and data is clearly stated. Assessment procedures are internally consistent.
- ▾ **The achievement data collected focuses on the science content that is most important for students to learn.** Data collected reflect the complexity of the Content Standards and measure student achievement of each and all of the dimensions described in those standards. Opportunity-to-learn data collected focuses on the most powerful indicators of students' opportunity to learn. Data collected reflect the essential indicators of opportunity to learn as they are described in the Teaching, Program, and System Standards.
- ▾ **The technical quality of data collected is well-matched to the consequences of the decisions and actions taken on the basis of the interpretation of those data.** The feature of student attainment or opportunity to learn that is claimed to have been measured was actually measured. Assessment tasks are authentic. Time intervals for data collection reflect the time dimension implied in what is being measured. An individual student's performance is the same on two or more tasks that claim to measure the same aspect of student attainment. Students have adequate opportunity to demonstrate their achievements. Tasks and methods provide data that are sufficiently stable to lead to the same decisions if utilized at different times.
- ▾ **Assessment practices are fair.** Large-scale assessments use statistical techniques to identify differential performance among sub-groups of the population assessed that signal potential bias. Males and females of different racial and ethnic backgrounds have been included in the development of large-scale assessments. Assessment tasks have been reviewed for the use of stereotypes, for assumptions that reflect the perspectives or experiences of a particular group, for language that may be offensive to a particular group, and for other features that may distract students from the intended task. Assessment tasks are modified appropriately to accommodate the needs of students with physical disabilities or limited English proficiency. Assessment tasks are set in a variety of contexts and are engaging to students with different interests and experiences. Assessment tasks do not assume the perspective or experience of a particular gender, racial, or ethnic group.

Program Standards

Development of Content, Teaching, and Assessment Standards always recognized their interdependence. The way that they work together in immediate learning environments, such as the classroom, school, and community provides the opportunity for students to learn. The way that they are supported by policies beyond the immediate learning environment, for instance in the district, state, and the nation, provides the opportunity for teachers to teach. Thus, the *National Science*

Education Standards include Program and System Standards. The overarching goals of Program and System Standards are the coordination of content, teaching, and assessment with resources and the alignment of teaching and assessment with the goals of science education.

Program Standards will describe how content, teaching, and assessment are coordinated in classroom practice to provide all students the opportunity to learn science. They focus on the immediate learning environment of the classroom, school, and community. Program Standards are summarized in figure 1–15.

FIGURE 1–15
Program Standards.

- **All elements of the K–12 science program are consistent with the standards and with one another and are articulated within and across grade levels to meet a clearly stated set of goals.** An effective science program encompasses a set of clear goals and expectations for students to guide the design, implementation, and assessment of all elements of the science program. A curriculum framework is used to guide the selection and development of units and courses of study. Teaching practice is consistent with the goals and curriculum framework. Assessment policies and practices are aligned with the goals, student expectations, and curriculum frameworks. Support systems and formal and informal expectations of teachers are aligned with the goals, expectations of students, and curriculum frameworks. Responsibility is clearly defined for determining, supporting, and maintaining all elements of the science program.
- **The curriculum in science for all students in grades K–12 should contain the following aspects.** All the content standards are included and embedded in a variety of curriculum patterns that are developmentally appropriate, interesting, and relevant to students' lives; inquiry is emphasized as a tool for learning science; and the curriculum connects to other school subjects.
- **The science program should be coordinated with the mathematics program to enhance student use and understanding of mathematics in the study of science and to improve student understanding of mathematics overall.**
- **The science program gives students access to appropriate and sufficient resources including time, materials and equipment, space, teachers, and community.** Time is a major resource in a science program; conducting scientific inquiry requires that students have easy and frequent opportunities to use a wide range of equipment, materials, supplies, and other resources for experimentation and direct investigation of phenomena; collaborative inquiry requires space as well as time; the most important resource is personnel; and good science programs require access to the world beyond the classroom.
- **The science program provides equitable access to opportunities to achieve the National Science Education Standards.** All students, regardless of sex, cultural or ethnic background, physical or learning disabilities, future aspirations, or interest in science,

FIGURE 1–15
Continued

should have the opportunity to attain high levels of science literacy. By adopting this principle, standards prescribe the inclusion of all students in challenging science learning opportunities and define a level of understanding that all students should achieve; not only is science education for all students, but all of the understandings and abilities described in the content standards should be achieved by all students. This is the principle of excellence. The standards describe expectations of achievement.

- **Schools are communities that encourage, support, and sustain teachers as they implement an effective science program.** Schools demonstrate colleagueship, openness, and trust, as well as explicitly support reform efforts. Regular time is provided for, and teachers are encouraged to, discuss, reflect, and conduct research around science education reform. Teachers are supported in creating and participating in networks of reform. An effective leadership structure is in place that includes teachers.

System Standards

Science education is one part of a larger education system which interacts with economic, social, and political systems. Science classrooms are affected by economic, social, and political conditions in the communities in which they are located. The nation's scientific enterprise is a unique part of science education, at the same time as science education is an important contributor to the scientific enterprise. All of these systems depend on rational allocation of resources and coordination.

System Standards describe how components of the educational system outside the immediate learning environment support high-quality science education programs. Optimal functioning of the educational system requires consistency among the components; thus, standards address alignment of assessment, teaching, and content, teacher preparation and certification, communities, and resources. Figure 1–16 describes the System Standards.

Conclusion

This chapter presents an introduction of the *National Science Education Standards*. We presented the overview with a goal of developing a general understanding of the national standards and a specific objective of clarifying the role of standards in the design and development of science curriculum. In this conclusion, we will attempt to answer several questions concerning the national standards and science curriculum.

First, what standards are and what they are not. The *National Science Education Standards*, like *Science for All Americans*, the *Benchmarks for Science Literacy* from AAAS, and *The Content Core* from NSTA, are frameworks that describe content from various domains such as earth and physical sciences. For

FIGURE 1–16
System Standards.

- **System Standards include a common vision.** Policies that influence the practice of science education must be consistent with the program, teaching, assessment, and content standards while allowing for adaptation to local circumstances.
- **System Standards include coordination across the system.** Policies should be coordinated within and across agencies, institutions, and organizations.
- **System Standards include continuity.** Policies need to be sustained over sufficient time to provide the continuity necessary to bring about changes required by the standards.
- **System Standards include resources.** Policies must be supported with resources.
- **System Standards include equity.** Science education policies must be equitable.
- **System Standards include unanticipated effects.** All policy instruments must be reviewed for possible unintended effects on the classroom practice of science education.
- **System Standards include individual responsibility.** Responsible individuals take the opportunity afforded by the standards-based reform movement to achieve the new vision of science education portrayed in the standards.

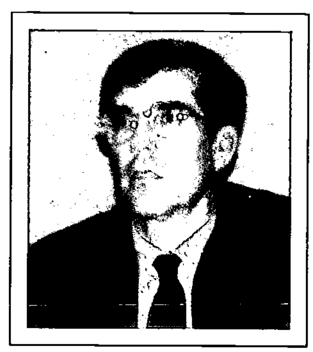
the *National Science Education Standards* and the *Benchmarks,* content also includes areas such as inquiry, technology, and the history and nature of science. In the case of the *National Science Education Standards,* the framework also includes teaching, assessment, program, and system. Although distinct differences exist, there is considerable overlap among the various frameworks. The *National Science Education Standards* give a general plan and guide to science curriculum but they do not define a curriculum. The latter would establish a national curriculum for science which is an inappropriate endeavor.

Second, what can the standards do and what can they not do? The standards provide the policies to coordinate various aspects of science curriculum at local, state, and national levels. They provide developmentally appropriate emphasis at elementary, middle, and high school levels, and they suggest some topics and teaching approaches that should be included, for example, evolution in the life sciences, and student inquiries, as well as some topics and approaches that should not be included, such as creationism and the memorization of facts. The standards should not diminish the responsibility of local and state agencies to design, select, and implement curriculum materials, instructional practices, and assessment strategies. State and local school districts have a tremendous responsibility to improve the science curriculum as it should be.

Third, what do we need and what do we not need? Probably the greatest need is for a coordinated effort among scientists, science educators, and science teachers to redesign the science curriculum. As any one of these groups exceeds its respective expertise, there presents the potential of giving over- or underemphasis to a particular aspect of the science curriculum. We base recommendations on the observation that all components of the science education system are vital to its effective and efficient functioning.

Finally, we often hear the question, "Haven't we done this before?" The answer is both yes and no. We have often redefined the content of the science curriculum. In the 1950s and 1960s, for example, we made a major attempt to update the science curriculum. In fact, the nature of science itself suggests the continual need to update and clarify the science curriculum. But, because we answer this question with a yes, it does not necessarily follow that the entire experience is useless or that we should return to an earlier framework. It is always helpful to ask a second question, "If we did it before, did it work?" And here we find that the answer is less clear, and in fact, it may be that the answer is no. This suggests that the issue of improving science education in general, and the science curriculum in particular, may consist of doing more than updating the science content. Because of this insight, the *National Science Education Standards* have placed significant emphasis on teaching, assessment, program, and system, with the hope that this wider perspective will contribute to both a substantive and substantial improvement of science education. We have not done this before.

The *National Science Education Standards* provide a tremendous opportunity to improve science education. But, the responsibility for improvement exceeds the standards, and extends to the wider community, who assume responsibility for policy, curriculum development, supervision, teacher education, and most importantly, science teaching.



2

PERSPECTIVES ON STANDARDS-BASED REFORM

ESSAY

Necessary But Not Sufficient: Reflections on the Role of Standards in Science Education Reform

BY DOUGLAS LAPP

Science education reform has always been susceptible to panaceas and simplistic solutions. Each successive wave of reform—the massive science curriculum reform projects of the 1960s, the teacher education institutes of the late 1960s and early 1970s, and the science alliance movement of the 1980s—only focused on a part of the problem. The fragmentary nature of these previous reform efforts prevented them from achieving the goals of science education reform. Yet, much was learned from these past efforts that can inform our work now and in the future.

CURRICULUM REFORM EFFORTS

In the 1960s, the universal prescription for the nation's science education ills was curriculum reform. The nation supported large-scale projects to create innovative science course materials that offered a radical change from the textbooks used in schools for years. The best of these science curriculum reform projects—such as the Physical Science Study Committee (PSSC) and Project Physics courses, the Biological Sciences Curriculum Study (BSCS) programs, the CHEM Study program, the Earth Science Curriculum Project (ESCP), and the Elementary Science Study (ESS) and Science Curriculum Improvement Study (SCIS) elementary science projects—provided a rethinking of the science curriculum and an infusion of hands-on, inquiry-centered pedagogy.

Unlike commercial textbooks, these new materials were developed through a rigorous research and development process involving the active collaboration of academic scientists with expert teachers. The first drafts produced by the curriculum projects were subjected to repeated cycles of trial-teaching, rethinking, and revision. This enabled the curriculum projects to create a new standard of excellence for precollege science education and attracted allegiance from large numbers of science teachers, particularly in high schools.

From any viewpoint, the high school curriculum projects funded in the 1960s by the National Science Foundation were successful. For example, in 1970, approximately 40 percent of U.S. students studying biology were using one of the BSCS versions. In the early 1970s, the use of PSSC physics peaked at about 35 percent, and the three Chem Study adaptations reached a total maximum use rate of approximately 30 percent.

FACTORS THAT IMPEDED ADOPTION

However, the continued adoption of these curriculum materials suffered because most of the projects gave insufficient attention to implementation activities. In addition, leaders of the curriculum projects made little effort to cultivate the educational establishment, or to develop a shared vision among people in the schools that the innovative learning techniques that characterized the new courses—the inquiry approach, hands-on student experimentation, and student-centered discussion—were desirable.

Moreover, most of the projects were not funded for the preparation of teachers to use the new materials. This situation was exacerbated by the National Science Foundation, which for years actively discouraged the integration of its curriculum projects and teacher institutes for political and legal reasons. As a result, after an initial peak of usage in the early 1970s of the innovative science course materials developed with NSF support, implementation and use declined.

The adoption and implementation of some of the science course materials produced in the 1960s also were hampered by a concern that they were designed primarily for highly capable students, and did not meet the needs of all students. Where this criticism was justified, it came about when projects limited the testing of their trial materials to schools serving highly motivated, privileged students, and neglected to solicit the input of teachers who were familiar with the practical realities of more typical public school classrooms.

The lesson here is clear: The development of high-quality science course materials is necessary, but it is not sufficient. Only marginal results can be expected if curriculum development is done in isolation, without attention to the dissemination and implementation of the new materials, the development of a shared vision supporting change among school personnel, and sustained programs of professional development to prepare science teachers.

PROFESSIONAL DEVELOPMENT PROGRAMS FOR TEACHERS

The first wave of NSF summer and academic-year institutes for science teachers that were initiated in the 1960s appeared to have a significant initial impact. Several studies demonstrated that the institutes held prior to 1970 were generally successful, and that teachers who attended the institutes were more likely than other teachers to use curriculum materials developed with NSF support, to emphasize laboratory activities, and to stress a pupil-centered approach.

However, in the early 1970s, funding for NSF teacher institutes was sharply curtailed, and in 1975 all funding for NSF teacher education programs was suspended. Later, when a small amount of funding was restored, it was restricted to institutes that were purely disciplinary in nature, and not integrated with course development efforts.

Constraints of funding and disciplinary focus continued to limit severely the effectiveness of professional development programs for science teachers during the 1980s. Although some of the content-centered programs helped to improve teachers' knowledge of science, most were not designed to prepare teachers to become experts in the use of any specific curriculum materials, nor did they attempt to deal with the conditions which teachers usually faced when they returned to their classrooms—didactic curriculum materials, a lack of science apparatus, and an unsympathetic school administration. As a result, the impact of professional development programs during the 1970s and 1980s on science teaching was marginal.

Again, experience would suggest that if we wish to bring about significant and widespread change in science education, professional development programs for science teachers are certainly necessary, but in isolation they are not sufficient. Unless professional development programs are carefully designed to focus on more than science content so that they prepare teachers to become proficient in using innovative curriculum materials that are more effective than their present materials, little will change when they return to their classrooms.

In addition, professional development programs need to be closely linked to efforts to build a shared vision of improvements desired in science education within the school district administration and in the community. This is essential to assure that teachers who are seeking to adopt new approaches will be supported in their efforts.

SCIENCE ALLIANCES AND PARTNERSHIPS

During the 1980s, a number of communities launched a movement to encourage "science-rich" institutions like universities, corporate laboratories, and national laboratories to share their resources with the public schools. Some of these cooperative relationships—usually called partnerships, collaboratives, or alliances—were successful in attracting broad participation from a spectrum of community leaders, and in generating a spirit of enthusiasm and empowerment among teachers that schools have not had, particularly in urban areas. However, as the alliance movement matured, a concern grew that science alliances were not always focusing their energies on the most promising targets, or in some cases, had not even considered a specific focus for their programs. A study prepared for the Carnegie Corporation of New York identified this lack of focus in many science alliances, noting that often "a guiding vision of good science teaching is missing: Many communities are all dressed up, with no place to go."

This provides another example that working on only one part of the problem in isolation—in this case, building community support for science education through the development of local science alliances—is necessary but not sufficient. In order for local alliance building to bear real fruit, it is essential that these efforts take place in concert with other activities, such as the development of a shared national vision for science education, the creation of high-quality science course materials that embody this vision, and professional development programs to help teachers become proficient in using the new materials.

NATIONAL STANDARDS FOR SCIENCE EDUCATION

This brings me to the issue of national standards, and the questions of how they fit into the above matrix. In assessing the potential impact of the national standards movement on science education in the schools, experience tells me that the emerging new standards are necessary, but they will not be sufficient. Certainly, there can be no question that science education needs a shared vision supporting improvements among teachers, parents, state and local school district officials, and the general public. Although most teachers are dedicated, and most parents want better schools, there is a need to raise expectations, and the national standards movement offers opportunities and incentives to do this. But much more needs to be done if we are to produce significant and lasting improvements in science education in the schools.

The experience of the past 30 years demonstrates that school districts need several kinds of assistance to translate the science education standards into effective practice. First, the schools need a variety of new, high-quality science curriculum materials that incorporate the vision of science education described in the science education standards. To ensure that a sufficient variety of such course materials are produced, and to encourage the development of new approaches to science education that are creative and innovative, it is essential that the new science education standards hold to the maxim that "less is more" and not be overly restrictive as to content.

Because so few high-quality course materials have been produced during the past decade, particularly at the secondary school level, a considerable expansion of activity is needed in this area. It is unlikely that much will change in science education in the schools until new course materials are developed and effectively implemented. The National Science Resources Center (NSRC) is taking an active role in the development and dissemination of these curriculum materials, with projects such as *Science and Technology for Children.*

Although new science course materials are necessary to translate the science standards into significant changes in science instruction, the new course materials will have minimal impact unless their development is closely coupled to programs to prepare teachers to use them effectively. Some of this can be done through teacher institutes organized at the national level, but many inservice education programs also need to be organized at the local level. Also essential are support systems to provide teachers with science materials and apparatus, opportunities for dialogue with other teachers, and specialized technical assistance. These programs are most effectively organized by local science alliances involving teachers, scientists, and representatives from business and industry.

Moreover, new kinds of leadership are now called for at the local level to help science alliances and school districts create the professional development programs and teacher support systems described above. Leadership development and technical assistance programs are urgently needed at the national level to help train and support these local leaders, who can be drawn from both school district personnel and scientists from the local community. The NSRC has developed considerable expertise and experience in this area during the past eight years by operating programs such as the National Science Education Leadership Initiative, which can provide a model for future efforts of this type.

In conclusion, national standards for science education thus need to be viewed as one necessary, but not sufficient, element in systemic reform. If the science standards being developed are viewed in this context, and adequate attention is paid to other essential factors such as course materials development, the professional development of teachers, the creation of teacher support systems, and the development of leadership at the local level, then a new age of quality science education will dawn. But, we must guard against premature declarations of victory once the national standards are published, so that we don't abandon the field of action before the real work begins.

ESSAY

The National Science Education Standards from a Curriculum Developer's Perspective

BY HAROLD PRATT

"It was the best of times, it was the worst of times .... It was a time of innovation, it was a time of conformity." A play on the opening line of Charles Dickens' *Tale of Two Cities* has metaphorical value as curriculum developers examine the *National Science Education Standards* published by the National Research Council (NRC). In the name of improved quality, will the new standards encourage innovation, creativity, and diversity of curriculum materials, or will their interpretation lead curriculum developers to a narrow road of conformity and compliance? Such a question must be in the minds of those developing the standards as well as of those anticipating their use in the near future. As a district science coordinator, curriculum developer—both at the local and national levels—I have implemented and pilot tested a wide range of elementary and secondary curriculum for 30 years. Now, I am contributing to the development of the *National Science Education Standards.* Based on these perspectives, the aforementioned questions loom large in my mind.

The National Committee on Science Education Standards and Assessment, the oversight committee from the NRC, provided the following charge to the working groups on curriculum, teaching, and assessment standards.

> The standards will provide a vision of excellence to guide the science education system in productive and socially responsible ways. Standards for curriculum, teaching, and assessment will be integrated in a single document. The standards will specify criteria to judge the quality of school science and to guide the future development of the science education enterprise.

Can standards be both a vision and criteria for judging quality? Can standards guide and inspire without restricting? Soon grants for funding, textbook advertisements, teacher's guides, and a flurry of articles and speeches will contain the phrases "conforms to *National Science Education Standards,*" "supports *National Science Education Standards*" or "meets criteria in *National Science Education Standards.*" Would a curriculum developer dare produce materials without being able to make one of those claims? If that assumption is correct, is there a price we will all pay?

The National Research Council is currently developing standards whose purpose is to provide criteria for judging the:

- science content that students should have the opportunity to learn during their K–12 educational experience;
- instruction and other characteristics such as facilities, learning

culture of the school, and the availability of computers designed to support students' opportunity to learn;

- ▼ assessment program that must serve the individual student's learning, instruction, and the policies that direct the collection and dissemination of a variety of student and program assessment data from the classroom to the state or national level; and
- ▼ development and administration of policy and other decisions that support the opportunity of all students to learn science.

The good news about science education standards is that they will provide local and national curriculum developers with a powerful rationale for the broad direction of reform to guide their work. Although contained in the literature for many years, these ideas of reform now take on greater significance as they become part of the quasi-national policy for science education. The systemic nature of the *National Science Education Standards* imply that curriculum development can no longer be considered an isolated activity apart from the professional development of teachers, the assessment of students, modes of instruction, or the overall culture of the school. There is a sense in some of the literature that if American schools—or more specifically, teachers and curriculum developers—would be more innovative, the problem of reform would be solved. Such innovations often take the form of eliminating the layer-cake curriculum and replacing it so that the strands of subject matter now run vertically through at least the secondary grade levels. Other proposals suggest that curriculum should be built on themes and interdisciplinary topics, or that the curriculum should take on a strong science-technology-society dimension by placing student-identified social and personal issues at the heart of the curriculum.

Many, if not all, of these innovations have merit, but by themselves they will not provide the reform so widely called for. Improvement can come only if those in all parts of the system find the will, the skill, and the resources to walk together in the same direction. The *National Science Education Standards* can provide that direction.

What is the possible down side of national standards? Are the standards a vision or are they criteria? If they are criteria, they need to be specific and well-defined. But if they become so well-defined that they reduce or eliminate various interpretations, translations, and local visions, the standards have crossed the line and have begun to dictate curriculum. If they do not articulate the criteria with enough detail, then thousands of interpretations will result. As an example, the directors of Project 2061 and Scope, Sequence, and Coordination often find themselves wondering how so many different products claim to have been derived from the parent project. Criteria should be clear and unambiguous, but some people claim that without ambiguity, creativity is not possible.

Do the *National Science Education Standards* from NRC, the 2061 Benchmarks from AAAS, and *The Core Content* from NSTA really mean for all students to learn all the content listed? Is there any evidence, direct or indirect, that this is likely to occur in any significant percentage of the nation's students? My experience with lists, whether they be tables of contents, syllabuses, objectives, or teacher's goals for the year suggest they are rarely met. The most frequent reason science teachers give for not "covering" everything is that when the learning experience of students gets richer and deeper, the list of topics covered gets shorter. To illustrate this point, what would happen if a teacher or an entire department decided to reduce drastically the content they presented in favor of a series of extended investigations by the students? Assume for a moment that the resources, laboratory space, guidance, coaching, and student motivation were all in place for students to conduct several multiweek experimental investigations. Would the standards be met if teachers eliminated much of the content in favor of this rich investigative approach?

The standards for elementary school curricula have their own problems. When all the standards being currently developed by the various groups are stacked up side by side, the elementary teacher's academic and instructional load may have been doubled. The independent, unrelated efforts of the six or seven national groups developing standards for elementary school curriculum may find their work falling on deaf ears because of the lack of integration among the standards, and lack of attention to the realities of how much teachers accomplished in the elementary school classroom. Although elementary students have the most to gain from the implementation of the *National Science Education Standards*, the results in the typical elementary school likely will be less than revolutionary. With the pressure to meet standards in language arts, social studies, geography, math, art, music and dance, and others, science will be taught in its traditional place near the end of the day.

Will the *National Science Education Standards*—with their somewhat traditional-looking organization of science subject matter and separate description of inquiry, connections, and science in human affairs—foster and promote creative and innovative ways of meeting the standards? Or will curriculum developers at the local and national levels take the easy way out and begin to organize their curriculum so that it can be laid very conveniently on top of the *National Science Education Standards* and pronouncements made about the match?

The creative ways of meeting the standards, where content is organized in interdisciplinary ways or based on inquiry or on issues involving social problem solving, will force the developer into another level of activity. The interpretation and translation of the material so that it is obvious to the consumer that the standards have been supported will become a major responsibility of developers. But will the consumer understand and agree, and how often will the curriculum developer stretch a point as textbook publishers often do today with end-of-chapter illustrations, separate problem-solving workbooks, and a whole variety of techniques to lay features on the table but not to put them in the mainstream of the science curriculum?

Think back 30 years. If something comparable to the *National Science Education Standards* had existed in the early 1960s, would the richness of elementary curriculum projects with the diversity of activities and goals such as those produced by Science: A Process Approach, Elementary Science Study, and

Science Curriculum Improvement Study have been produced? Look at the contemporary elementary curricula. Will it be possible in a year to judge whether FOSS (Lawrence Hall of Science), *Science for Life and Living* (Biological Sciences Curriculum Study), *Science and Technology for Children* (National Science Resources Center), Insights (Education Development Center), and Life Lab meet the standards? If the answer is "no" or only partially "yes" for any or all of the projects, will this make them any less valuable? And the question most important of all: Will the receptivity on the part of the American elementary schools to science education be increased or decreased?

ESSAY

Science Education Standards: The Good News and the Bad News

BY CAROLEE S. MATSUMOTO

There is good, and potentially bad, news associated with the science education standards. The good news is that the efforts to produce standards should generate a flurry of activity among teachers; educational leaders at the school, district, regional, and state levels; community members; curriculum developers; and publishers. One needs only to look at the remarkable reform stimulated by the National Council of Teachers of Mathematics (NCTM) Standards to understand the potential power of science education standards. As with the NCTM Standards, the science education standards must be integrated into the current systemic reform efforts and will most likely stimulate new initiatives for science education reform.

With clear vision provided by standards, teachers, principals, parents, and other educational leaders can direct their reform efforts in a way not possible without standards. We will be able to see clarification of the ambiguities usually associated with science curriculum definition and development, teacher preservice and inservice development, and assessment and evaluation. The standards will help answer questions such as:

- ▼ What science concepts and skills should students learn?
- ▼ How will we know if students have learned the concepts and developed the skills?
- ▼ What knowledge and skills do teachers need—and how can they best develop them?

The bad news concerning the science education standards is that few people know what to make of three different sets of standards being developed independently. I know how they came to be; but in the end, teachers and other school district personnel either need one set of standards or need to know how the three do or do not make sense together.

As they are currently conceived, the standards do not offer much help in how they can be used, individually or together. Naturally, people will need time to learn what the standards are, to make sense of them for their students and themselves as teachers, principals, parents, central office administrators, or regional and state leaders, and to figure out how they will be used in their efforts to reform science education. Again, we can learn from the events that followed publication of the NCTM Standards. A great deal of confusion arose about what the NCTM Standards are and how they are to be used. Some believed the standards were a curriculum or components for student evaluation. Others believed the standards were to be "implemented" wholesale and did not understand the "how-to's" of using the standards or their own roles and responsibilities. Science education will suffer the same confusion about the standards unless their formats build in a user's guide or some bridges between the documents themselves and their consumers.

Curriculum developers and other science educators are likely resources to serve as the bridges between the standards and teachers, schools, districts, and states. This role for science education will only be possible if there is sufficient funding. If resources are available, developers and other science educators can focus their time and efforts on:

- ▼ orienting teachers, schools, districts, and states to the vision described by the standards and helping them develop a road map for their reform efforts;
- ▼ helping teachers, schools, districts, regions, and states develop and implement models, strategies, and plans to effectively and appropriately make use of the standards in their reform efforts; and
- ▼ involving teachers and other educational leaders in the development of multiple curriculums that exemplify the standards to educators, parents, and publishers.

Three important purposes will be served if curriculum developers and other science educators can work to achieve the goals. Teachers, schools, districts, and states will have both appropriate curriculum and direct technical assistance to their reform efforts. These efforts also can help to shape an educated market for instructional materials and can help to influence publishers to reconceptualize instructional materials as advised by the cacophony of textbook critics. If teachers, principals, districts, and parents understand the standards and demand different kinds of instructional materials, publishers will need to respond with new and different products.

I desperately hope everyone will understand and use the standards as they are intended. The standards can be an effective vehicle for reform if they are used appropriately and if they are adequately supported with policy and funds. I truly hope our national and state legislators and departments of education, the National Science Foundation, and other public and private institutions will develop policies and resources to support the standards as a powerful part of our overall science education reform. From my colleagues in the science education community, I expect leadership in using the standards to accelerate the reforms they have already initiated, to redirect those that need new direction, or to initiate reform where none exists.

In my optimistic world, every story should have a happy ending. The one I am hoping for is that the science education standards will synthesize our reform efforts to ensure all American students are given the opportunity to learn science in the best ways possible. Although some may try, there is no excuse for using the standards for one's personal, political, or financial gain. If everyone assumes some responsibility for the success of the science education standards and if everyone can put aside their personal and political agendas, I think it may be possible.

ESSAY

Rethinking the Science Curriculum

BY PEGGY CARNAHAN

To rethink the science curriculum, one should be prepared to reconsider the complete universe of education—and education reform—in America today. There is no question that myriad content practitioners, pedagogical specialists, curriculum developers, and assessment professionals have launched independent and narrowly focused efforts across the nation. Although some benefit from the very intensity of their close scrutiny, many unfortunately reveal a conceptual myopia that has restricted visualization of true progress toward change. The educational system must revitalize and restructure the initial educational system so that all students will become life-long learners, informed decision makers, and confident problem solvers.

To rethink school curriculum today, one must be prepared to undertake a three-step process. First, all the elements of teaching and learning must be identified. Up to this point, such attempts have been both incomplete and somewhat wrong headed. The result has been that a spotlight has been placed on a few obvious elements, such as a teacher, a student, or a set of scores. Too often, national attention on standards has been entirely disconnected from national support of education.

Second, a more expansive vision begins with a view of all students as the center and core of the educational process. Students are essentially surrounded and impacted by the crucial and interacting forces of teachers, curriculum, and standards. Although each of these three has some independent validity and force, only through combined and complementary initiatives can they approach unified goals. Within such a widened perspective, minor individual differences among specializations recede in importance and significant common objectives and values emerge.

What has not been sufficiently acknowledged up to this point, now becomes most apparent. All facets of the educational process co-exist in a complex and dynamic system. Surrounding this system of discrete educational entities, exists the greater elements of the noneducational community. Opportunity, support, and delivery now assume unique and somewhat unacknowledged consequence.

The process of reexamination and redefinition that has become so widespread by school specialists at this time must be undertaken by the community in all its guises—parents, business, media, and policymakers.

On the basis of this expanded view of education as a complex and interacting system, serious reform initiatives hold greater promise. Within this view, all students, all teachers, all disciplines share common dependence on external support and resources.

Finally and the most critical, the standards establishment, which has too often been considered a painful and unrealistic imposition, must now be prepared to assume an expanded role with all concerned individuals. Standards should be a driving force in bringing together all the elements that have been considered in isolation.

To make these goals a reality, the following procedures must be undertaken:

- Systemic restructuring of the educational system, including curriculum. Rethinking the science curriculum must be part of a systemic reform. For years, the sciences have tried to improve student learning by rethinking curriculum, standards (outcomes), and teaching. This internal structure has had little collaboration with each other and even less connection with external structures—preservice education, business and industry, educational policy, education finance, and parents and community. Both the internal and external structures must work together, not in isolation, to develop a systemic change.
- Develop science literacy standards for all students. With the United States changing from an industrial to an information era, it is imperative that all students be scientifically literate. No longer can our country only educate a select few to understand basic science principles. This is too restricting and omits too many people from job opportunities. Few students know what they want to be when they begin to attend school, nor do they know what careers will be available. Literacy standards must be developed to encourage student learning by promoting "a need to know" perspective. Then, and only then, will our country have citizens who are lifelong learners, informed decision makers, and confident problem solvers.
- Create literacy standards that connect the sciences—science, mathematics, social sciences, and technology. Teaching each discipline independently has been prolonged enough—educators have not been modeling real-world tasks or experiences that connect the sciences to other disciplines. If the standards are to establish the "need to know" for students, they must use experiences that students can relate to their world. Since it is impossible to anticipate future challenges that our students will face, we must prepare all students to comprehend the relationships between our natural world and the human-made world.

  Because we are in an information era, students cannot possibly learn everything; therefore, careful selection of "need to know" requirements is necessary. Quality and in-depth understanding of concepts must replace quantity—"less is more."
- Design standards that address more than just content. If standards do drive the curriculum and teaching, they must address content, process skills, the nature of, and habits of mind for, science, mathematics, social sciences, and

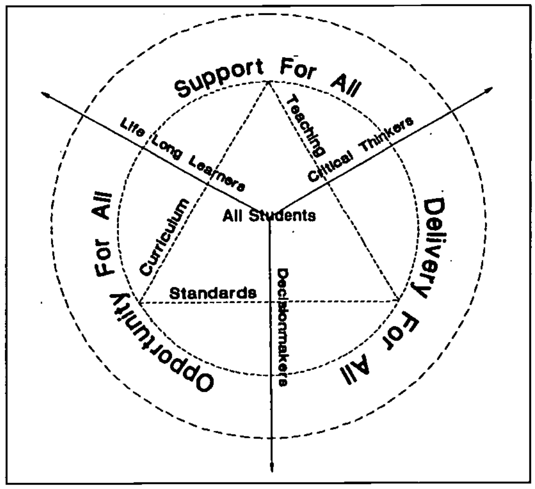
technology. To ensure critical thinking, the habits of the mind attributes of curiosity, openmindedness, skepticism, imagination, integrity, diligence, and fairness must be an integral part of a student's education. The world does not exist in isolation and neither can curriculum. In order for students to become decision makers and problem solvers, they must be exposed to meaningful curriculum that teaches more than just isolated facts and content.

- Include a spiral (PreK-Exit) set of standards that directs cognitive and age-appropriate curriculum development and instructional teaching. For students to achieve standards, there must be benchmarks or checkpoints to monitor the progress of the student that leads to the understanding of concepts. Too often, the underpinnings that are necessary to understand a more complex concept are taken for granted. Therefore, the student never truly understands the concept. These benchmarks must be built on one another to create spiral learning which allows for a time to revisit and extend previous experiences. Significant developmental and social reasons exist for distinguishing between the primary and intermediate elementary grades. For example, if you want a student to begin to understand the pendulum, you must introduce the concept in primary grade levels with simple everyday materials like string and a paper cup. As the student progresses in school, more mathematics and sophisticated equipment will be added.

  Spiraling standards must be guidelines for all students. Checkpoints must be included to determine student progress. To ensure that the basic process skills—observing, classifying, predicting, for example—are taught when children are young, they must be assessed in primary grades. If the first checkpoint is not until the intermediate level, the students could be five years behind before intervention. Educators and parents should be evaluating a student's progress continuously; a national or state assessment would be necessary every three to five years.

- Include professional development. To be professional, educators and especially teachers need quality time and staff development. It is impossible to generate long-range planning when five to seven hours per day are spent with students. Each student has individual needs and learning styles. Most school resources are for students; schools generally have few resources for professional development of teachers. It is unfortunate that in education most professional development is optional or after hours. The airlines in America do not tell their pilots that in order to stay updated, they must train after an eight-hour day, weekends, or vacations. Training also is not an option.

No, they all train on company time with the latest research and technology. Real allocation of time and resources are essential if educators are to keep pace with the changing expectations of what schools must do to prepare students for the future. Professional development must be more closely aligned to that of other professions.



Restructuring Curriculum

In conclusion, there are few initiatives that connect the internal and the external players and address the sciences, including mathematics. However, two documents currently addressing the systemic changes necessary to aid the rethinking of science curriculum are *Benchmarks for Science Literacy* (AAAS Project 2061, 1993) and the *Secretary's Commission on Achieving Necessary Skills* (SCANS Report, U.S. Department of Labor, 1991).

ESSAY

Science Curriculum by Outside Experts: A Help for Teachers and Students in Pursuit of Learning?

BY ROBERT E. YAGER

Indeed, we are in an era of standards-based reform. In science, major funding has been provided to the National Research Council to develop standards for school science. The leadership has chosen 89 individuals to serve on three committees—the largest "lead" group being the curriculum committee (later called content). The idea is that the curriculum defines programs, that teaching and assessment follow. The staff for the NRC Standards distributes drafts of the work of the experts to professionals in the field for reaction and advice—there have been three editions to date. The standards are meant to provide guidelines for all 50 states and the 16,000 school districts in the U.S. as they work to reform and restructure their science programs.

The problem is that all we know about learning suggests that real learners are engaged in problem-solving activities. It is the doing and the construction of meaning that is a prerequisite for learning to occur. Constructing a curriculum needs to involve those who want and need such a framework. Perhaps the major work of our standards workers should be an honest look at desirable outcomes of the educational experiences that would have meaning and use in a scientific and technological world. These goals could then be used by local groups for structuring their own curricula.

To date, the curriculum group working on the science standards has debated what concepts should characterize the outcomes of school programs and how they should be the goals for the improvement of teaching and the development of improved assessment practices. For the first published work of the curriculum group, the emphasis was on a new (and presumably better) outline of science concepts for school science. This last effort—not even circulated to all serving on the curriculum committee—narrowed its focus to a consideration of science concepts. It remains, however, an attempt of the national committee to set content standards.

Nearly all curriculum development efforts have failed when outside groups develop a plan—even the materials development efforts (or content improvement projects) that occurred during the 1960s and early 1970s with significant federal funding. Every state with prescriptive standards, curriculum frameworks, and/or course structures has experienced resistance, much complacency, and few positive results with the prescriptions. One occurrence has been textbook companies trying to include everything from every state framework, especially those from textbook adoption states. The result is that all textbooks include too much material, especially in terms of coverage, and most textbooks at given grade levels and science disciplines look much like all other textbooks. State frameworks establish a national curriculum as they strain to include all that is recommended by state standards.

Meaning comes from experience, reflection, trial and error, and engagement. Developing a curriculum that will affect learning positively must involve teachers and students in the same way. The science curriculum cannot be restrictive; it cannot be provided from the outside.

Outside curriculum developers must provide what most people want or the material will not be used or purchased. Outside curriculum developers are, therefore, in a difficult position. They cannot use research about learning and teaching to develop a superior plan; it would not be used in the U.S. unless we change one of our basic premises: (1) the advantages of diversity among schools, (2) local control for the school operation and education program, and (3) the research which indicates the importance of "buy-in" on the part of professionals.

Do we want Big Brother to provide the structure? Are the guidelines developed externally really research-based? What are the questions? Can all real professionals be involved—and not just those chosen by persons given public funds and the charge to develop standards? Of course, we want consensus! But, isn't that just a clever way of suggesting no debate and acceptance that the experts do know best?

Science arises from questions—and different possible answers to them. It comes from devising tests of nature that can provide evidence for others to see concerning the validity of the ideas and proposed answers. Can school science be structured in ways that deny questions, variety, the collection of evidence to see if the structures work, the emergence of new questions as we seek continued change in a search for continual improvement?

Curriculum by expert groups, state committees, textbook publishers, or government agencies should be suspect. It should be alien to the American Way. It is certainly contradictory to what we now know about human learning.

Of course, NRC has engaged some of the best minds—many thoroughly aware of the research on learning. But, it also has involved curriculum developers, directors of national projects, scientists, supervisors, and a few chosen teachers. Apparently, it is tough to get consensus from such a diverse group. It should be even tougher to get consensus on the part of people not directly involved.

Science teaches us to question—to not conform—to propose new and varied ways. Curriculum as developed by outside experts—even when following general guidelines provided by the science or professional groups—provides an imposed structure for the "believers." Curriculum becomes something that people believe in; they use it because experts have given it to them. This is one of our problems in education. It indicates our failure to establish education as a meaningful profession.

Curriculum developers must assume more humility. Those developing standards must strive even harder to be nonprescriptive. History suggests, however, that few will question further once consensus is reached or once that it is declared to have occurred. Most funding groups already suggest the importance of using the emerging standards if one wants funding. It sounds like imposed structure and conformity in spite of the rhetoric of those involved.

It should be a troubled time for curriculum developers. However, living in a standards-based era should make the work easier. But, the impact of current curriculum efforts—even those based on national standards—must await some years for the wisdom that history provides.

3

ORGANIZATIONAL PERSPECTIVES

ESSAY

The Role of the Lawrence Hall of Science in an Era of Standards–Based Reform

BY HERBERT D. THIER

In its twenty-fifth year as an integral part of the University of California at Berkeley, the Lawrence Hall of Science (LHS) is and always will be committed to the three major goals of the University, which are research, teaching, and public service. As a primarily self-funded organized research unit, LHS is responsible for defining what research, teaching, and public service are related to its mission. The mission of LHS is to improve the quality of science and mathematics education for all students and to demonstrate how such understanding can contribute toward a productive life as a citizen in a democratic society.

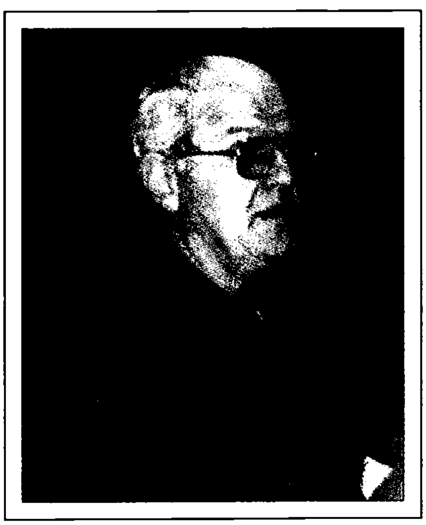
Research, as operationally defined by LHS, is the process of designing, developing, field testing, and having produced for distribution innovative materials and approaches for teaching and learning science and mathematics. This research, primarily supported by independent peer-reviewed proposals to the National Science Foundation, has resulted in instructional materials such as CHEM Study, SCIS, OBIS, SAVI-SELPH, GEMS, POPS, FOSS, and SEPUP. These materials have changed, and are continuing to change, what is learned and how it is taught in schools, community groups, and science centers nationwide. The common ingredient in all instructional development projects at LHS is the commitment to changing how the individual learns science. Rather than emphasizing the "read about, hear about" science of the typical textbook, LHS programs for all ages have emphasized the learners' actual involvement in the collection and processing of evidence as the basis for the teacher-learner interaction that leads to an understanding of science and the role it plays in our lives. This emphasis on experience by the individual as the basis for his or her learning about science has contributed significantly to the ability of LHS to produce materials that have helped to make science available to all Americans, irrespective of their socioeconomic status and/or personal limitations.

National standards for science education in America will help to guide the direction and emphasis of research on instructional development at LHS in the future. Based on the degree of their acceptance by the profession and the public, national standards will provide part of the all-important needs assessment that is a part of any carefully designed instructional development project. Combined with experience from the classroom or other learning environment [our laboratory] and the input of teachers [our consultants] the national standards will help define the planned content and approach of any new project. It is hoped that peer reviewers and others responsible for contributing to funding decisions will utilize the standards as guidelines rather than proscriptions, so that promising new ideas that deviate from current standards will be supported to encourage evolutionary development both of the field of science education and the standards themselves.

Teaching, as operationally defined by the Lawrence Hall of Science, involves the many events, programs, and projects carried out to develop knowledge, understanding, and leadership in teachers and other science educators regarding how to improve science education in their own locality, region, state, or country. Prior emphasis in these programs has been on individuals and groups interested in implementing specific LHS programs, and, to a lesser extent, on individuals and groups interested generally in techniques, materials, and approaches for improving science education generally using resources developed at the Lawrence Hall of Science and other centers. The availability and general acceptance of national standards will be very helpful in planning and carrying out such programs in the future. Individuals, school systems, or other entities interested in the continuous growth and improvement of their science program will have the national standards as a frame of reference to which they can compare where they are and where they want to be in the future. As our colleagues in the field better understand and are able to more easily articulate where they are and where they want to be, LHS will be able to design more effectively its teacher and other leadership education efforts to help them accomplish their locally identified goals and expectations. Since these local goals and expectations will be "standards driven," it will be easier to analyze these field-based concerns as one basis for identifying new national efforts in the development of science materials and how to teach them. This will help to inform the future progress of the research efforts in instructional development at LHS.

Public Service, as operationally defined by the LHS, is the myriad of programs, activities, and exhibits that take place at the LHS (and increasingly at other locations) to introduce to or enhance for the public (individuals from age 2 to 102) the role science can play in their own lives. Ranging from preschool programs and short courses to increase the knowledge and skills of hobbyists and professionals in fields as diverse as astronomy and the latest developments in biotechnology, these programs have the common ingredient that most participants choose to take part in them (the exceptions are at lower ages). Since virtually all such programs and events are supported by the participants, these extensive activities (over 200,000 participants a year) act as a continuous informal survey of what interests the public about science, technology, and related fields. As LHS offers exhibits, programs, and events related to the goals and expectations for public understanding of science embedded in the *National Science Education Standards*, the extent of public interest in and uptake of those programs will be an informal measure of public understanding and acceptance of those goals and expectations. Such public understanding and acceptance of the standards is necessary if the resources—financial and otherwise—to accomplish the goals and expectations of the standards are to be made available. This provides a new emphasis for and importance to the funding from the private and public sector of efforts to develop more effective nonformal science experiences and activities for the general public.

In conclusion, the opportunity to have available generally accepted *National Science Education Standards* as a guideline for the continuous efforts of the Lawrence Hall of Science will be very helpful. They will be used in decision making regarding directions to go in new materials development, teacher, and other leadership development, and public understanding of science efforts. They also will help LHS in designing more effective ways to accomplish the ongoing internal assessment of the value and effectiveness of its programs.



ESSAY

BSCS and National Standards: An Affirmation and A Challenge

BY JOSEPH D. MCINERNEY

Those who have been involved in American science education for more than a decade know first-hand that reform is almost as recurrent as the cycles of nature whose dimensions we try to impress upon our students. It is not surprising, therefore, that some respond to the current reform movement with something less than enthusiasm and optimism. There is, after all, more than enough evidence to demonstrate that previous reforms often have not found receptive audiences, or have languished for lack of proper support.

Something is different this time, however: Two major scientific organizations—the National Research Council (NRC) and the American Association for the Advancement of Science (AAAS)—have raised the stakes. Unlike previous iterations of reform in science education that involved only relatively small numbers of scientists in the direct development of new curricula, or the education of science teachers, NRC and AAAS are making strong statements on behalf of the entire scientific community about the appropriate nature of content, teaching, and assessment for precollege science. Notwithstanding the lack of formal sanctioning authority from either NRC or AAAS, many expect these standards to have a substantial impact on the what and how of science education in America, and I applaud both organizations for recognizing that the scientific community must provide leadership in setting standards for precollege science.

In brief, the recommendations from NRC and AAAS propose conceptually based content, inquiry-oriented instruction, and assessment that measures students' ability to synthesize and apply new knowledge to solve real problems. None of these broad recommendations represents a departure for groups such as BSCS that have been developing curriculum for more than three decades. The view of science education promoted by the standards instead constitutes an affirmation of the philosophy that brought BSCS into existence and that historically has sustained groups such as the Lawrence Hall of Science, Technical Education Research Center (TERC), and Education Development Center (EDC), as well as newly organized groups such as the National Science Resources Center (NSRC) and Life Lab.

Although the national standards provide general support for the long-standing activities of groups such as BSCS, they are by no means an invitation for us to declare victory and go home. On the contrary, they provide a challenge to us to provide leadership that converts policy recommendations into workable programs and that promotes the philosophy behind the standards in such a compelling manner that its validity is self-evident to teachers, parents, students, publishers, undergraduate schools that train teachers, and a host of other players in the complex enterprise of precollege education.

How will we do this? It is unlikely that the programs of BSCS will change in any dramatic way because of the standards; we already are doing many of the things the standards propose, and we have been doing them for 35 years. The standards will, however, serve as a constant source of guidance, and as a reminder:

- to make our conceptual base more clear and to make more clear to students the relationships between major concepts in biology and across the sciences;
- to choose content wisely so that it reinforces major concepts and illustrates the nature and methods of science;
- to make inquiry more evident and legitimate, especially in laboratory-based lessons; and
- to make our assessment instruments more consistent with our content and pedagogy.

We must be certain that we communicate our rationale for these approaches clearly to our publishers and suppliers—our close partners in the development process—and, with them, to teachers, administrators, and adoption committees.

Equally as important, the standards will compel us to increase our attention to the implementation of our programs. We must expand our efforts to educate teachers and administrators about the central assumptions of the standards and about the ways in which our programs manifest those assumptions. BSCS programs always have asked teachers to embrace more innovations than have more traditional programs, and the literature is clear that the introduction of innovations requires sustained support. Our implementation efforts now must apprise teachers and administrators of the innovations inherent in the standards, of the ways our materials incorporate those innovations, and of the ways we can provide continued support for those innovations in cooperation with our publishers and suppliers.

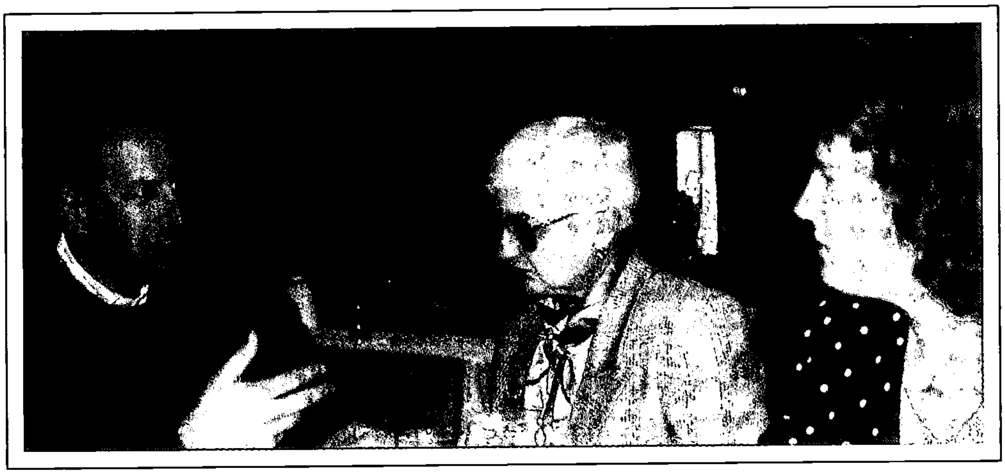
Do we feel constrained or threatened by the standards? No, for two reasons. First, the standards do not call into question the substance of our work during these three-and-one-half decades. Second, review of the early products related to the standards indicates that they provide considerable latitude for interpretation in curriculum development. In fact, the NRC standards project is silent on curriculum, and Project 2061 proposes several different curriculum models. As always, curriculum developers at the local and national levels will bring diverse and creative approaches to their articulation of the standards in materials for the classroom. These different approaches will attend to the diverse circumstances and priorities of diverse communities.

Although such local control of curricular approaches always has been the case in the United States, one expects that all communities now will feel obliged at least to reflect upon the recommendations in the standards and to reject them, if they so choose, with full knowledge that they are discounting considerable consensus in the scientific community. Perhaps this consensus will have most impact in those areas—such as evolution—where school boards and administrators have avoided controversy by avoiding certain content.

Although it is naive to expect, for example, that the strong support for evolution evident in both the Project 2061 benchmarks and in the NRC standards will by themselves carry the day in communities that still oppose the teaching of evolution, these statements by two major scientific organizations may provide additional ammunition for those confronting assaults on the integrity of the curriculum.

A final challenge inherent for experienced curriculum-development groups is the obligation to help those who wish to embrace the standards, but do not know how. National groups such as BSCS, TERC, Lawrence Hall of Science, and EDC harbor enormous expertise that can help the standards take hold. We must be willing to make this expertise available—within the limits of our resources—to those who wish to develop local curricula based on national standards and to those who wish to implement nationally developed curricula that have the same focus. We must do this even if our own programs do not benefit directly from our assistance.

The national standards lend support to the philosophic approach that BSCS and other groups have promoted for decades, and we now are being provided a vote of confidence for a view of science that has been honored more often in the breach than in the observance. It is incumbent upon us to turn this affirmation of our work to our advantage and to the advantage of students and teachers throughout the country. If we fail to provide leadership against a background of such strong support, we will have much to answer for when the inevitable assessment of the effectiveness of standards is complete some years hence.




Hands-On Experiences
that Develop
Positive Attitudes
and
Excitement towards Lear

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CURRICULUM PERSPECTIVES

ESSAY

The Goals of Science Curriculum

BY GEORGE E. DEBOER AND RODGER W. BYBEE

At any one time, individuals express a variety of opinions about the goals of science teaching. The history of science teaching reveals, however, a relatively small number of common goals that science educators have had for our students and that historical changes are primarily shifts in emphasis among the goals rather than the creation of entirely new goals. Thus, studying the history of science education, in particular the changing structure and function of goals, provides insights for curriculum developers today. For an extended historical review of the goals of science teaching, the reader is referred to *A History of Ideas in Science Education* (DeBoer, 1991), *Reforming Science Education* (Bybee, 1993), and "Goals and the Science Curriculum" in *A Handbook of Research on Science Teaching* (Bybee & DeBoer, 1994).

Throughout the history of science education, three major goals for students have been (1) to acquire scientific knowledge, (2) to learn the procedures or methodologies of science, and (3) to understand the applications of science, especially the relationship between science and society. The terms used to express these goals have changed throughout history. Scientific knowledge, for example, has been referred to as facts, principles, conceptual schemes, and major themes. Scientific procedures have been referred to as the scientific method, problem solving, scientific inquiry, and the nature of science. We also should note here that there has long been confusion between an emphasis on knowing about the procedures of science and doing scientific investigations. The applications of science have found expression as life adjustment (circa 1940s), science manpower shortage (circa 1960s), and the contemporary science-technology-society (S-T-S) movement. In the following discussion, we use the terms "scientific method," "knowledge," and "applications" broadly and generically to encompass the variety of terms used by science educators.

Sometimes the goals of scientific knowledge, method, and applications are accompanied by clearly articulated justifications, but other times they are advanced and accepted less critically, either because of the bandwagon effect or because of historical momentum. Science educators should periodically examine our curricular emphasis—the structure and function of goals—and decide why we hold the views that we do and if we can justify the particular emphasis in light of contemporary societal demands. This examination enables us to justify our focus and determine what, specifically, we mean by each of these major goals in curriculum design.

Three reasons for teaching science knowledge, methods, and applications have included the following: (1) enhancing personal development, which includes aesthetic appreciation, intellectual development, and career awareness, (2) maintaining and improving society, which includes the maintenance of a stable social order, economic productivity, and the preparation of citizens who feel comfortable in a scientific and technological world, and (3) sustaining and developing the scientific enterprise itself, which involves the transmission of scientific knowledge from one generation to the next so that each subsequent generation has a knowledge base from which new scientific discoveries can be made and the formation of a scientifically enlightened citizenry sympathetic to the importance of science as a field of inquiry.

AN EXAMPLE OF CHANGING GOALS

In the middle and late nineteenth century, scientific method, especially inductive reasoning, was taught as a means of disciplining the mind. The curriculum emphasis during the period was on scientific methods as a route to personal development. Toward the end of the nineteenth and the beginning of the twentieth century, the United States became more industrialized and urbanized, and science educators looked to the goal of scientific method as a model of problem solving that could be applied to social problems. In the late 1940s and 1950s, during the Cold War, the national focus turned to security, space, and the subsequent need for scientists and engineers. The curriculum emphasized a rigorous study of the structure of scientific knowledge to ensure the well-being of the nation and scientific inquiry was incorporated as the means to achieve higher levels of understanding. More recently, such social concerns as the economy, environment, infectious disease, and technological advantage have supported the S-T-S theme and greater emphasis on the societal applications of science. Through these examples, we can see the interconnections among the goals of science teaching and the societal and personal needs that direct those goals.

The challenge for science educators now, as in the past, is establishing an appropriate balance among competing goals given today's social needs. Recently, more than ever before, we are beginning to recognize the potential interrelatedness of the three major goal areas and this recognition allows us to balance our curriculum focus on scientific knowledge, method, and applications without viewing the goals as mutually exclusive and thus diminishing our support for any one of them.

THE INTERRELATEDNESS OF KNOWLEDGE, METHOD, AND APPLICATION

In elementary and secondary schools, the primary reason for teaching science knowledge today is the same as it has been in the past—to give students an understanding of the natural world and the abilities to reason and think critically as they explain their world. Students should begin early observing and describing the world around them and move toward progressively more elaborated explanations of phenomena. By the end of high school, students should be able to provide comprehensive explanations for the most obvious and compelling events that they experience, for example, the seasons, day and night, disease, heredity and species variation, and dangers of hazardous substances. The curriculum should emphasize science as inquiry leading to understanding which assesses the students' explanations. Memory of facts, concepts, and principles for their own sakes, unconnected to the kinds of events and phenomena mentioned here, have little importance either for personal and social development or advancing the science enterprise.

With respect to the methods of science, students should learn a disciplined way of asking questions, making investigations, and constructing explanations of a scientific and technologic nature. The latter can certainly be developed in a personal/societal context. Students should learn that scientific inquiry is a powerful, but not the only, route to progress in our world. Inquiry should not be taught in isolation but as a tool for finding answers to questions about the world in which students live. In addition, science teachers should very clearly and consistently emphasize students' conceptual development of scientific explanations, as opposed to step-by-step methods that too often characterize nature of scientific inquiry.

Concerning the applications of science, students should confront examples of how scientific knowledge is related to social advances and how society influences scientific advances. Once again, the focus should not be on learning about science and society for their own sakes, but to bring students to an appreciation of the complexity of the scientific/technological enterprise and to provide contexts and explanations for important scientific- and technology-related societal challenges they confront.

Neither scientific knowledge, method, nor applications should be taught in isolation. Each needs to be taught in connection with the other, having one outcome in mind, and that is to enlarge our students' understanding of their world in meaningful ways.

THE GOALS OF SCIENCE EDUCATION AND NATIONAL STANDARDS

In the contemporary reform, the phrase "scientific literacy" expresses the configuration of goals for science education and thus any review of national standards should assess the degree to which the standards incorporate the acquisition of scientific knowledge, development of inquiry abilities, and understanding of the applications of science. Further, those implementing the standards, benchmarks, and frameworks should review the priorities and emphases suggested for the different goals. To what degree and in what form are the goals expressed? Do the standards suggest one orientation for the structuring of the goals or do they suggest variations in the structuring of goals? Are there guidelines or suggestions for the use of goals in the design of curriculum materials, teaching strategies, and assessment practices? Do the standards allow for a variety of curriculum materials and instructional approaches in order to achieve the goals? If the standards were achieved, would we have individuals who could continue into careers associated with science, engineering, and related work?

It now appears that the standards present a fairly balanced approach to the goals of science education. Although this assessment may be good, it is not enough only to express the goals in standards. The goals also must be manifest in curriculum materials, instructional practices, and assessment strategies. The next step in the contemporary reform includes developing programs that can be used to improve school science.

In conclusion, science curriculum developers should continue to work toward an integration of the three major goals of acquiring scientific knowledge, developing the abilities of scientific inquiry, and applying the understandings and abilities of science to personal decisions and societal challenges. If they do, students' lives will be enriched, the levels of scientific literacy heightened, and the sympathy toward science as a way of knowing will be enlarged. More students will pursue careers in science and engineering, and we should continue to develop the understanding and skills required to solve our most vexing problems.

ESSAY

Scientific Literacy: The Importance of Multiple "Curriculum Emphases" in Science Education Standards

BY DOUGLAS A. ROBERTS

This commentary has three purposes. First, I discuss the goals expressed by the current *National Science Education Standards,* with special reference to the significance of the phrase "science for all" [students]. Second, because the NRC standards proposed developing some degree of scientific literacy as the appropriate outcome of science for all students, I briefly review the history of science education in North America to provide a sense of what science programs the curriculum has emphasized about science since the turn of the century. One finds that seven distinguishable "curriculum emphases" in science education have appeared and reappeared, in the name of providing school science programs that are defensible for various populations of students. These have coalesced gradually into a composite definition of scientific literacy which now enjoys considerable currency in the discourse of science education. Finally, I offer some remarks about the related processes of curriculum development, assessment, and research in science education which inevitably are affected by the production of prestigious nationwide standards for science education. The NRC report provides significant opportunities for renewal and fresh approaches to perennial problems in science education, and the thrust of my comments are directed to those who will have to do something, such as develop curriculum, with the standards.

"SCIENCE FOR *ALL*" [STUDENTS]

In the NRC report (all references of this sort are to the NCSESA Progress Report of July 1993), the committee takes a firm stand on behalf of science for all, delineating five major principles which, admittedly, are contentious. Many teachers and professors of science, and many members of the general public as well, are convinced from their own experience that "real" science cannot be taught to a significant proportion of the population. The conceptual load, the requirement for mathematical fluency, and general intellectual demands are cited as factors that simply put science out of reach for many students.

Against that sentiment, people responsible for school science education have to face the fact that the public pays for the schools, and therefore all segments of the public are entitled to the best the school can offer. As well, no one would seriously contest the point that as much understanding of science and technology as possible is a reasonable goal for all citizens of the United States, indeed the world, for all kinds of reasons. Perhaps the most visible at this time is the need for the citizenry to understand and make decisions about an almost overwhelming scientific/technological "machinery" that increasingly characterizes our lives.

The goal of "science for all" presents a healthy, viable image for a set of national curriculum standards precisely because it allows for some differentiation in the kind of school science program which different segments of the population will experience. This approach to curriculum is common fare for school personnel. They have been doing it for years. Increasingly, though, public awareness of and advocacy for segments of the population which heretofore were institutionalized, otherwise seen as out of the mainstream of public education, has expanded the variety of subpopulations which school personnel have to consider in their planning. As well, the sensitivity of educators to such matters as the subtle exclusiveness of gender bias has been heightened by research developments in areas like critical pedagogy and feminist psychology. The need is more pressing than ever to avoid setting standards based on monolithic, single-purpose visions of science education programs. Equal access to scientific literacy does not have to mean that every student studies the same program.

There is no backing away from the goal, though, even if there is some disagreement about the means. *Science for All Americans* (AAAS, 1989) is the familiar title of the 1989 report of Project 2061. Similarly, *Science for Every Student* (SCC, 1984) is the title of the final report of a nationwide study of science education in Canada, sponsored by the Science Council of Canada and completed in 1984. Sentiment for "science for all" is strong. But, how should nationwide standards be set, then, short of setting a national curriculum? The answer lies in leaving school personnel some alternatives, since they have to work with the standards. But what alternatives?

"CURRICULUM EMPHASES": LEARNING CONTEXTS FOR SCIENCE

Science, like any other human endeavor, has many facets, and these are often targeted in school science programs as a central part of the objectives of science education. Discipline-based science subject matter, for example, life, earth, and physical science, is therefore only one strand of a school science program, while the other strand is an expression of some facet of science. Thus, if objectives of a school science program are to develop citizens who care about their natural environment, who have some commitment to protect it, who know the impact of technologically driven decisions related to it, and who know how steps can be taken to preserve and enhance it, in all of that the science content of ecology is only one strand of the program. It is a necessary strand, of course, but it is not sufficient. One does not become "caring" and "committed" by learning ecology only. There is a context in which that ecology is taught. Such a context could be called "science, technology, and decisions," for example.

Ecology also can be taught in the context of having students come to understand how scientific inquiry proceeds, how the knowledge structures within the subject are developed, what the "frontiers"of the subject are. This context might be called "structure of science."

One way to identify these different contexts is to look at school science textbooks across the span of history. The same science content, say kinetic-molecular theory, appears in one textbook as the basis for understanding bicycle pumps and the importance of maintaining proper air pressure in automobile tires, while it appears in another text as a way to explain the regularity expressed by Boyle's Law. The first of these we can term "everyday applications," while the second is "structure of science" again. Different contexts, same content.

Analysis of school science textbooks throughout this century shows that seven learning contexts can be distinguished. I have called these "curriculum emphases" in science education, since they express what the science program within the curriculum should emphasize. The names of the seven capture their meanings in a fairly transparent manner: Everyday Applications, Structure of Science, Science/Technology/Decisions, Scientific Skill Development, Solid Foundation, Correct Explanations, and Self as Explainer. Each of these expresses a purpose for learning science, each can be blended with science content to provide a learning context, and each can be seen to attract adherents, usually different stakeholders, in curriculum policy debate. (See figure 1.)

Probably most important, though, is the observation that no one of these is any more correct or true or right than any of the others. Each expresses a valid facet or aspect of science as a human endeavor. Each is therefore readily defensible, and certainly no one curriculum emphasis could be defended as the basis for national standards for science education for all students. At least, I fail to see how that could be done. On the contrary, there is evidence that science educators struggling to understand what people mean by "scientific literacy" have found that all seven emphases were included in the definition. So it would seem that it is difficult to single out one of these as the best curriculum emphasis for all students, and the converse is true as well: Perhaps for different groups of students heavier doses of different curriculum emphases make the most sense.

One emphasis in particular deserves some comment in that regard, the one I have called Solid Foundation. This is the most stark of the emphases in its message about the purpose of learning science: One learns this year's science in order to get ready for next year's, and so on. This emphasis is most familiar to university scientists, and to many teachers, because it quite naturally honors the cumulative, sequential nature of learning the science content. It seems to me that it is the emphasis expressed most clearly in the NSTA project on Scope, Sequence, and Coordination.

Solid Foundation is probably the least defensible science curriculum emphasis for large numbers of students in the nation's schools. It presupposes that there is some ultimate purpose for learning the scope and sequence of the content, namely a more or less full command of the subject matter itself. This, of course, is an important goal for one segment of the school population, namely those planning to be involved in science-related occupations and thus anticipating postsecondary education in science, engineering, medicine, etc.—estimated by some to be as large as 10 percent of the students. But for the other 90 percent, it is possible that a single-minded concentration on that Solid Foundation emphasis is not appropriate and not defensible.

FIGURE 1
Curriculum Emphasis In Science Education.

Curriculum Emphasis	View of Science	View of Learner	View of Teacher	View of Society
Everyday Applications	A meaning system necessary for understanding, and therefore controlling, everyday objects and events.	One who needs to master the best explanations available for comfortable, competent explanation of natural events, and control of mechanical objects and personal affairs.	One who regularly explains natural and manmade objects and events by appropriate scientific principles.	Autonomous, knowledgeable individuals who can do mechanical things well, who are entrepreneurial, and who look after themselves, are highly valued members of the social order.
Structure of Science	A conceptual system for explaining naturally occurring objects and events, which is cumulative and self–correcting.	One who needs an accurate understanding of how this powerful conceptual system works.	One who comfortably analyzes the subject matter as a conceptual system, understands it as such, and sees the viewpoint as important.	Society needs elite, philosophically informed scientists who really understand how that conceptual system works.
Science, Technology, Decisions	An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant societal issues.	One who needs to become an intelligent, willing decision maker who understands the scientific basis for technology, and the practical basis for defensible decisions.	One who develops both knowledge of and commitment to the complex interrelationships among science, technology, and decisions.	Society needs to keep from destroying itself by developing in the general public (and the scientists as well) a sophisticated, operational view of the way decisions are made about science–based societal problems.
Scientific Skill Development	Consists of the outcome of correct usage of certain physical and conceptual processes.	An increasingly competent performer with the processes.	One who encourages learners to practice at the processes in many different contexts of science subject matter.	Society needs people who approach problems with a successful arsenal of scientific tool skills.
Correct Explanations	The best meaning system ever developed for getting at the truth about natural objects and events.	One whose preconceptions need to be replaced and corrected.	One responsible for identifying and correcting the errors in student thinking.	Society needs true believers in the meaning system most appropriate for natural objects and events.
Self as Explainer	A conceptual system whose development is influenced by the ideas of the times, the conceptual principles used, and the personal intent to explain.	One who needs the intellectual freedom gained by knowing as many of the influences on scientific thought as possible.	One deeply committed to the concept of liberal education as exposing the grounds for what we know.	Society needs members who have had a liberal education—that is, who know where knowledge comes from.
Solid Foundation	A vast and complex meaning system which takes many years to master.	An individual who wants and needs the whole of a science, eventually.	One who is responsible to winnow out the most capable potential scientists.	Society needs scientists.

CURRICULUM DEVELOPMENT, RESEARCH, ASSESSMENT: A COMMENT

The curriculum emphasis concept is a conceptual tool for analyzing the complexities of science curriculum development. It is not a prescription for what should be done. What should be done in the name of science education for any given student is ultimately the responsibility of a science teacher, penultimately of a school district, at a further remove of a state department of education. But, the curriculum emphasis concept can provide some sense of the broad range of defensible alternatives for science programs developed by those who are responsible. The alternatives have an honorable history, have their counterparts in university studies, and are otherwise acceptable as serious candidates to form different learning contexts for the variety of segments of the population which schools have to educate. In short, a student can achieve a degree of scientific literacy through a variety of curriculum vehicles.

Several vehicles appear in the NRC standards called "general categories of school science content": Science as Inquiry, Science Subject Matter (physical, life, earth and space science), Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science. These are similar to the four curriculum models proposed by Project 2061. The four categories neatly subsume the seven curriculum emphases found in science education history, thereby constituting a composite definition of scientific literacy. Here is the combination:

- Science as Inquiry subsumes "Structure of Science" and "Scientific Skill Development." The counterpart for systematic study of these aspects of science at the university level is found in history and philosophy of science. The Project 2061 model similar to this is called an "Inquiry" model.
- Science Subject Matter incorporates "Solid Foundation" and "Correct Explanations." The systematic counterpart is the scientific disciplines themselves. This is similar to the Project 2061 model called "How The World Works."
- Science in Personal and Social Perspectives subsumes "Self as Explainer" and "Science/Technology/Decisions." The university counterpart is found in some aspects of the history of science, in the sociology of science, and in practical philosophy. Project 2061 has such a model, called "Human Concerns."
- Finally, Science and Technology is similar to "Everyday Applications," and reflects increasing emphasis on technology since the time I completed the original study of texts in 1980. It is obviously connected at a university level with such areas of study as architecture and engineering. Project 2061 calls this a "Design" model.

As learning contexts or vehicles for curriculum development, these four can readily provide viable alternatives for state departments of education, school districts, and individual teachers to plan for the unique configuration of segments of the population they serve. By recognizing the four in a set of national curriculum standards, the project gives leadership but still provides scope for decisions that have to be made by other professionals such as science teachers, supervisors in school districts and in state departments, science educators and scientists in colleges and universities, curriculum developers, and policymakers.

The four "general categories" of the *National Science Education Standards* or Project 2061 models also provide a range of alternatives for developing assessment instruments and procedures. This aspect of science education has received a lot of attention lately, with promising results in a variety of alternative assessment strategies. As well, the ways in which professionals implement the alternatives give scope for a variety of exciting research questions in science education and in curriculum theory. Finally, keeping the options open for different curriculum emphasis gives "science for all" half a chance of succeeding, while a monolithic approach to the matter raises some serious doubts about the possibility of developing a scientifically literate citizenry.

ESSAY

Equity and Excellence

BY ARTHUR EISENKRAFT

"Little boxes on the hilltop, little boxes made of ticky tacky ... little boxes all the same." American democracy is built on two pillars, one which recognizes the differences among people and the other which requires that all people are treated equally. The history of education reveals a policy of tracking students that attempted but failed to provide students of different abilities with equal opportunities. Research indicates that students in lower tracks were not held to high expectations, received poorer instruction, often had less experienced teachers, and each year fell further behind the students in the higher tracks.

The new science curricula must provide for equal access to education. It must open the doors of science understanding to all students, irrespective of their ethnicity or gender. It must help end a history of science being dominated by white males. Yet, the science curriculum also must challenge all students. It must maintain high standards and be honest in its appraisal of what students are able to do upon completion of science courses. The National Research Council documents support the policy of "science for all" as being of primary importance in the development of national standards for science education. Such a democratic principle can hardly be debated, but its implementation must be carefully scrutinized.

Imagine a random grouping of fifth-grade students. Some of these students are quite talented in sports. Their innate skills have been reinforced by involvement and success in sports activities. Some of the children can run very fast and some run very slowly. Similarly, some of the students are able to read at a 10th-grade level, while others are still struggling with second-grade books. It appears to me that the fast-running students are never asked to slow down. They are never told that, "It's better if you run at the same speed as most of the other students." In contrast, many of the academically talented students are asked to read fourth-grade books, to solve 50 math problems that are trivial, and to "not get too far ahead of the other students." This retardation in the intellectual growth of some students seems unconscionable and yet it occurs in schools across our country.

Can a science curriculum provide for equal opportunity and celebrate the differences among students? I think it can and it must. Each student must be challenged. Each student must struggle with learning. It is not permissible for an academically talented student to breeze past fourth grade and fifth grade and only find out in 12th grade or college that learning is difficult and that we all have a lot to learn. All students have the right to grow and become all that they are capable of being. We coach the best athletes to run even faster, to jump even higher; we must provide this type of coaching in academics as well.

The opportunities that are available to science education to provide for better curriculum are shaped by the research results of the past decade that have provided a better focus on how students learn, what they learn versus what we would like them to learn, and the [in]ability to transfer the content of school science to issues in their daily lives. A new science curriculum should reflect these findings.

Students who study science should not be learning larger and larger sets of facts and vocabularies of science. The sizes of the textbooks and the glossaries of the available texts speak to an agenda where vocabulary is the prime concern. Students should be approaching science topics and finding answers to questions such as, "Why do we believe? How do we know? and What does it mean?" The habit of mind we want of students leaving science classes is to confront new information and ask, "How do we know? What is the evidence?" As curriculum developers, we also must provide a rationale for the content, an answer to the student question, "Why should I care?"

These questions require an understanding of the processes of acquiring scientific knowledge and performing science experiments. They require more than a memorization of facts: Students must learn thinking skills. When people use "less is more" as a rallying cry, I can agree if the intended meaning is for less facts and memorization and more depth, more experiments, and more thought. I worry that what we may be moving toward is less facts, less vocabulary with no addition of these other features. Writers of new curriculum must be very careful to strike a balance between the required vocabulary and facts and the higher order thinking skills, for a curriculum that focuses on process to the exclusion of any facts amounts to a great deal of hand waving.

The key to building a curriculum for all students that can simultaneously challenge all students is in the construction of the assessment. All students can be asked to study the tides. Within the assessment, we must ensure that the students who are the least motivated are held to a high enough standard—the acceptable minimum for a literate citizen. Such a minimum standard might require a student to discuss the periodicity, ways of observing the periodicity, and correlation of the size of tides and the phases of the moon. The more motivated students must have an assessment that pushes further. The more motivated student may have to explain mathematically that the moon's pull on the different sides of the earth is responsible for the tides. The most motivated student should be dared to derive the general equation for the differential pull of one planet on another. This student should be able to explain clearly why the tides due to the moon are greater than those due to the sun. In all areas of the curriculum, the assessment tasks must be so rich that all people can begin but that no one can reach closure in the allotted time frame. And, it is the responsibility of the education professionals to ensure that students are pushing themselves to the depth of treatment and complexity of a problem that stretches them intellectually and represents a standard that is high enough for our societal needs. Recent studies of the U.S. Department of Education portray an American public where a larger minority cannot perform simple data accessing exercises such as reading a train timetable. The expectations for these citizens (many of whom are high school graduates) confirms that standards and expectations for them as students were too low or did not exist at all.

One of the virtues of our country is our belief in egalitarianism. We must not allow egalitarianism to be confused with mediocrity or, worse yet, to view mediocrity as evidence for egalitarianism. We must be extremely cautious that we do not lower the achievements of the most motivated students while we raise the standard of the less academically motivated students. We must not accept "above average" as a measure of success and then withdraw support and stifle the above-average children. "Science for all" is a laudable goal. And, as we ensure that the least able students get the attention they deserve, we also must ensure that the most able students get the enrichment that they need.

ESSAY

The Centrality of Inquiry

BY ROBERT TINKER

The reform of science education, as described in the new standards, requires major changes in how science is taught, to stimulate a transition from a didactic, text-and-teacher model of instruction about science to a collaborative, student- centered model of learning science through participation. The standards state that widespread opportunities for student inquiry and scientific research is "key," "critical," and "essential" to this transition. This is a consistent theme in both the NRC and AAAS projects. The February 1993 draft of the National Research Council (NRC) *National Science Education Standards: An Enhanced Sampler* and the draft AAAS *Benchmarks for Science Literacy* of January 1993 spell this out early and often:

> The key is for students to experience doing science themselves in ways that mirror how science actually gets done and that emphasize the mores of science. (NRC, p. 11)

> Inquiry is a critical component of the science curriculum at all grade levels and in every domain of science. (NRC, p. 55)

> Student investigations are an essential part of the total science experience .... The investigations help students to learn how science works. (AAAS, p. 9)

The definition of inquiry is broad, and includes original scientific research at the high school level:

> Before graduating from high school, students working in teams, preferably self-formed, should approach [investigations], estimate the time and costs involved, calibrate instruments, conduct trial runs, write a report, and finally, respond to criticism. (AAAS, p. 7)

This is easy to require, but the implications are staggering. This vision of science education is so far from much of current practice that it represents a complete revolution in how science is taught. But, of course, if we really intend to improve science education, nothing less than a revolution is required.

SCHOOL-BASED RESEARCH

Following the line of argument for genuine inquiry, one is led to the conclusion that schools must undertake scientific research. Implementing this could drive needed reform throughout schools and is, therefore, a highly leveraged point on which to focus our attention and resources.

Science itself holds the key to improved science teaching, and the basic challenge of the standards is to bring genuine science into schools. Since one cannot teach science without doing it, some teachers at every school will have to be engaged in investigations and research that parallels the work expected of students. These master teacher/researchers will not only provide research experiences for the most advanced students, their excitement and engagement with science will influence the entire curriculum, helping create a commitment to research and a culture that supports student investigations at all levels.

The need to create a culture of research in high schools is, at the same time, the most challenging and potentially the most significant implication of the standards. It is challenging not only because it conflicts with the bureaucratization of schools and demands new levels of staffing excellence, but also because it is not required explicitly. It is potentially significant for the same reasons—it will require administration commitment to nonquantifiable excellence and staff with true scientific values. Students and teachers will have to be supported in their research and be evaluated, in part, on the basis of their scientific work. This will require the school community to understand what this means.

School-based research must be different from research in higher education because its role is explicitly to support student learning. This restricts the range of possible topics, but not their rigor. The ingredients that are necessary for the successful implementation of research in schools include the following:

Comprehensibility. School-based research must be understandable, interesting, and attractive to all students.

Feasibility. The research must be accessible given the financial constraints of schools.

Scientific Need. The research must be real, in the sense that it contributes needed results to some areas of scientific exploration.

Involvement of Scientists. Bringing research into schools is facilitated greatly if the research community is committed to assisting.

Curriculum Integration. Because school-based research must support the educational mission of schools, the research must be related through curricula to the content goals of the standards.

A Research Community. School research cannot flourish if teachers and students are isolated from others with similar research interests. Whereas university researchers have access to colleagues in their department and at frequent professional meetings, alternative mechanisms must be provided to teachers.

If schools take this call for inquiry leading to student research seriously, there will be a huge demand for assistance. This demand cannot be met with traditional curricula and textbooks; it requires a shift in the culture of schools and a huge staff education effort.

IMPLICATIONS

If there are no mechanisms in place to respond to the demands for implementation assistance by the educational community, the consequences could be grave. Some of the problems associated with the reforms of the 1960s were due in part to pressure on the schools to move away from the old without giving a clear image of the new. As a result, many relaxed old standards but could not substitute new values and expectations. Structured, disciplined classrooms, where there had been some learning, too often became chaotic with less learning. The same could happen again. In response to the standards' call for more sophisticated styles of learning, many schools might offer poorly conceived activities. The final result could be the broad rejection of the reform effort and a return to our present, inadequate form of science instruction.

Let me suggest what we should do to be ready and lead the required changes:

School Models. Much of the change we envision will come from peer sharing between schools. We need to identify schools that exemplify our interpretation of the standards, assist others to become exemplars, study the process and effects, and disseminate information about these models.

Massive Teacher Education. We must be ready to respond to large-scale demand for teacher enhancement with thoughtful and effective teacher education strategies. In addition to the traditional short courses and seminars, this will require full university courses, telecomputing-based courses, and other distance-learning strategies.

Real Research Initiatives. We will have to provide assistance and development for school-based science research that fit the criteria I listed above. This will involve identifying potential research topics, developing and locating supporting materials, designing low-cost instrumentation, and recruiting and orienting scientists.

Communications. Digital networks, television, and face-to-face meetings will be needed to support all these initiatives. Software to support and simplify these communications will be needed.

Lab Renewal. Labs have received very little attention since the 1960s and are generally outmoded and unsupportive of the kinds of inquiry required. Labs provide an opportunity to integrate vocational and science goals though an inquiry focus, but only with new materials and approaches.

ESSAY

Curriculum Development as Learning for All

BY SUSAN LOUCKS-HORSLEY

Editorials, by definition, are personal statements. My favorites are those written by people whose general points of view are known but who choose not to reiterate the familiar, but take a turn. Further, I like them to recount stories of experiences that helped people think about things differently. So, I've chosen to mimic my favorite editorial styles and share some current thinking stimulated by recent experiences.

First, though, a note about the content focus of the editorial. The invitation was to write about school change, professional development, and the science curriculum, as input to a conference that would consider rethinking the science curriculum. Because of my commitment to professional development and change, I have chosen to consider, not the curriculum as a whole, but the part that is about learning, because therein lies the common threads: Curriculum is a design for student learning, both content and process; professional development is all about learning opportunities for the adults that bring the curriculum to young people; and change involves learning—the change process is in essence the learning process.

This editorial reflects my current thinking about what all science reform leaders can and must do to make the promotion of learning the core of their reform work—to, in the fullest sense, make learning science, learning how to teach science, learning how to support science teaching, and learning how to change schools and all the organizations that touch them, the everyday "steady work" (to borrow a phrase from Milbrey McLaughlin and Richard Elmore) of reform.

The *National Science Education Standards* will include some important ideas about how people learn that many of us have been working with for a long time, for example, that people construct their own knowledge on the foundation of what they already know and believe; that knowledge is socially constructed; that he/she who does the work does the learning (that is, learning is an active phenomenon). My contention is that if we believe in these principles of learning, then we have to start applying them to our own lives and our work. We have to believe that the principles apply to adults as well as young people. We have to start being learners ourselves and being teachers of adults in the ways we want young people to learn. Some experiences I've had recently will illustrate what this means and what this has to do with making a critical thread that weaves through every part of the *National Science Education Standards*—that of learning—our wedge in the door to real transformation for science education.

This summer, I spent a large number of days working on the standards, in particular, the standards for professional development. After the first few days, I developed a passion. Being a person who cares deeply about change in schools and all the organizations that support them, I was struck with the important work of keeping the carefully and painstakingly developed standards document, once "finished," off of dusty shelves and out of cluttered closets. I, for one, have always been naive enough to think that the standards can be more than just a banner for people already "in the choir" to march behind—to help teachers and others who are already teaching science "to the standards" justify and get support for what they're doing. Rather, I think the standards have potential to transform the learning of science for even current nonbelievers—but not without some work.

The passion I developed mid-summer was for a system that would make that happen—one that would touch the lives of everyone vital to improved science learning, in ways that modeled how science should be learned—interactively, experientially, incrementally, with relevancy, all those good words. One that would use all we know about adult learning, professional development, and change. One that would cause people to become excited, begin to ask good questions, search for ways of reaching young people better, work together with a common vision—a system that would acknowledge that even people in positions of leadership for science education reform can use help and support, and so provide them with the tools and strategies to facilitate change. My energy was flowing!

The passion didn't last very long. I started to imagine what we all know is required for systemic change. I imagined all the major players around the table: federal and state agencies, science and science education associations, teacher educators, curriculum developers, assessment experts, technology and science firms, teachers, principals, district and state science supervisors, scientists, PTAs, and so on. The bubble burst from its own weight. What seemed exciting before died. What could possibly come from such an assembly that would enable the standards implementation effort to "hit the ground running"? How could creative energies flow to develop what was needed when the turf battles, different "frames of reference" and cultures, different approaches to the same goal, needed to be navigated and considered?

Switch frames. Life goes on, fast and furiously, for those of us who dare to be in this field. It is sometime later and I'm at a conference of leaders of science and mathematics reform (representatives from most of those listed in my bubble–bursting fantasy). Tables and chairs set up in a "U" shape (to encourage interaction?), a raised dais with a podium and microphone at the top of the U. For much of two days, people speak from the podium to the group, who look sideways at the speaker or across at other passive participants. The topics are potentially exciting: what people are doing and what they're struggling with; what they could work together on; how they can find the very best science and math practices and share them; the cutting edge in technology: where their "learning edge" is and what kind of professional development they could use (how often we ignore professional development for our leaders, including ourselves). Exciting topics, deadly setting and agenda.

The passion builds again, but this time I'm seeing red. Conferences are learning opportunities, or should be. This particular conference represented at least 120 person-days that could have been for learning. Yet it fell far short because it wasn't designed for learning. It didn't take advantage of an opportunity to not only help the adults in attendance learn deeply for their precious two days of time, nor, more importantly, to model how they can and must model for all the people they work with (they are leaders) what learning looks like, so that somewhere in the chain, people who daily touch the lives of young people can experience it too—and learn what their job is. This one conference could have had enormous ripples. It could have touched thousands of adults and young people. Or, if that sounds too sappy, it could have begun to suggest new ways of using the vast hours and days we spend in meetings and conferences (not to mention the vast months students spend in similar classroom settings), encouraged leaders to begin to try something new, modeling the stumbling that comes with real change as well as the energy that comes from succeeding with something new.

Even people who are used to traditional learning settings can change. I saw this when I took the microphone (but not the podium) at the conference and immediately had people list their priorities and find somebody they didn't know with the same priorities to share their successes and struggles with; then I played a clip from a first-run movie that dramatically depicted a barn raising, which generated energetic discussion and thinking. Not only were people engaged, they were taking notes about where they could use those very activities with people they work with. You don't even need to know how to spell constructivism to begin to design effective learning environments (although, at some points, learning about it greatly enriches the nature of those environments).

Learning is critical for change. We have to make it live for people—show them what it looks like and get them involved. Without adopting the role of learner and teacher who models effective learning principles, leaders of science education reform—be they curriculum developers, school and district staff, state framework developers—cannot begin to rethink science curriculum.

My intent is to carry a general message to those who are serious about rethinking the science curriculum. While we make sure that students (and teachers) learn the important concepts of the scientific disciplines through topics that engage their minds and hearts, it may be even more important that every interaction that science reform leaders have with each other and with those they serve and that teachers have with young people—and every other interaction in between—be crafted to facilitate learning.

The implications of this simple idea for curriculum development, teacher development opportunities, curriculum implementation strategies, strategic planning—all activities required to change the school science curriculum in ways indicated by the standards—are enormous. For example, curriculum development in itself is a very powerful professional development strategy, for it engenders many of the principles of learning. Yet, we know that everyone can't invent their own curriculum—so the nature of the curriculum development process, the nature of the curriculum that is developed, the nature of the activities that introduce it to teachers heretofore uninvolved, and the nature of the experiences that engage and support teachers in its use over time, all need to be influenced by principles of learning. Just exploring what that would mean could take a conference or two in and of itself!

Lifelong learning is a phrase too bandied-about to have much meaning any more, yet one of the greatest compliments I ever received was to be called a model lifelong learner. New science curricula need to embody this value, in their development and, ultimately, in their content, process, staff development and implementation strategies, and in the very people engaged in helping teachers change how they work with young people. Down with formats for lessons, meetings, work sessions, workshops, strategic plans, and so on, that don't model effective learning principles—and full steam ahead!

ESSAY

Beyond Explicit Standards for Science Education

BY SUSAN SPRAGUE

It is no coincidence that groups in so many disciplines are developing national standards. Current reform methods reflect today's society. Global awareness has forced us to look beyond the assumption of American superiority. Without this comfortable assumption, questions of accountability arise. In addition, we are forced to accept change as natural and unavoidable. As the pace of change accelerates, we have less faith in the ability of today's specific answers to satisfy tomorrow's questions. We search for frameworks that will support and accommodate future changes. The current movement toward standards documents may be partly our attempt to provide accountability in a changing world.

For those of us in science education, it is fortunate that a common vision prevails across our documents. Terminology varies. Specifics remain unresolved. Deeply felt disagreements continue, but they are largely minor in scope. On the whole, the most striking aspect of these documents is their underlying similarity. This similarity makes the job of science curriculum developers easier than most.

To write toward this shared vision, curriculum developers need to have personal experience in the type of instruction the shared vision defines. With a strong personal base of experience, a good curriculum developer should be able to translate the stated goals of any of the standards documents into appropriate instructional packages. While that job will be difficult, it will be fairly straightforward.

A more difficult task will be to write to the unwritten concerns of the standards movement. These implications may or may not be defined in the documents. The ability of curriculum writers to reflect the implicit needs as well as the explicit structure of the documents will be important. These implicit implications will be important factors in the successful acceptance and implementation of new curriculum. Three implicit implications need consideration.

The first of these factors is the need for security. We need the security of knowing that the right thing is being done. With the comfortable supports of assumed American superiority and traditional practices, the standards movement has found a place. The explicit call for accountability will speak to diagnosis, mid-course adjustment, and summative achievement. Implicitly, the assessment opportunities in the curriculum also must reassure. The teachers, students, and community need to verify that they are on the right track. Occasionally, assessment should remind everyone of the success that has occurred. Opportunities for celebration are most clear when they are separate from the diagnosis of the next skill.

The second implicit factor for consideration is the extension of the constructivist model of learning. The constructivist model of learning contends that each student must build his or her own understanding. In such a process, understanding can never be completed. Each student must work through his or her own path toward deeper and deeper understanding and skills. Although many of the paths are similar, each student's pace and exact route are different. Virtually every science standards model in the current movement assumes a constructivist model of learning for students. Curriculum developers will face a difficult task as they try to find what students know. Even more difficult will be the development of a variety of different materials and methods that will help students build new understandings from their old. This will be difficult. Yet, because every document will explicitly speak to this need, efforts will be made, and many developers will succeed. Many programs will stop here. Those that stop here will not demonstrate a real belief in learning as constructivist.

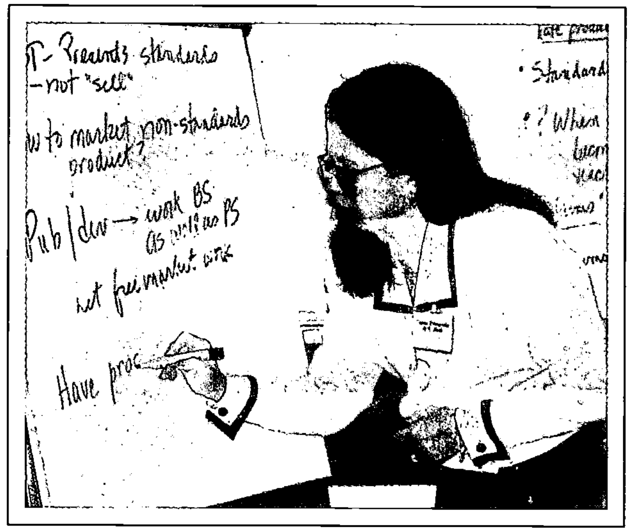
If constructivism is right about learning, it also would be true for learning about learning. Each teacher must build his or her own understanding. In such a process, understanding can never be completed. Each teacher must work through his or her own path toward deeper and deeper understanding and skills. Although many of the paths are similar, each teacher's pace and exact route are different. The curriculum developed must reflect a constructivist model of how teachers learn about teaching.

It will be difficult to develop curriculum that allows teachers to begin teaching at different levels of understanding. It will be even harder to provide materials that allow teachers to adjust their teaching mid-course as their understanding and skills grow. For real success, curriculum developers need to develop a system that speaks to constructivism for teachers. We must promote, or at least allow, teachers to grow naturally.

Current programs that express concern for this process sometimes say, "We'll step up the level of teacher expertise in the next edition." Such a plan does not allow for the teachers who would be ready for several next levels long before the next adoption cycle. Such a plan certainly does not allow for the teachers who missed this adoption and will be asked in the next revision to start out at the higher level. Teachers, like students, are everywhere in their readiness. Teachers, like students, need curriculum materials that accept these differences.

The third factor for consideration is that the standards movement reflects a broad-based desire for a closer tie to science learning. Explicitly, each document calls out the need for a broader base of students to become personally involved with science learning. Curriculum developers will have to be more sensitive and creative in finding ways to actively intrigue more students. These ways must reach far beyond photographs of students of color. Experimentation in vocabulary, materials, and culturally linked problem solving must all be explored. As difficult as this will be, it will get done. As the standards explicitly call for these changes, they will begin to happen.

More subtly, the entire standards movement implicitly reflects a broader base of critics of science teaching. Curriculum developers need to be aware of the diversity of passionate interests through which instructional choices will be screened. We are in a time where the National PTA, the Wild Blueberry Council, and the president of the National Council for the Social Studies, all publish what they think about science teaching. Major corporations are beginning to invest heavily in long-term systemic change in science education rather than in one-shot speakers. Real estate agents selling in middle-income areas report that their home buyers consistently ask about the math and science programs in the local schools. The days of leaving science to the scientists are over.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CONCERNS AND RECOMMENDATIONS

Introduction

Redesigning the science curriculum involves more people than a few scientists and developers. Indeed, the full community associated with science education must be involved in the translation of standards to curriculum frameworks, actual materials, and the implementation of new curricula in schools and classrooms.

The conference on which this monograph is based included individuals representing the many and diverse aspects of the science education community. During the conference, small groups representing various constituents met to consider various issues associated with national standards. The following sections present a synthesis of concerns and recommendations from those meetings.

SUMMARY—ELEMENTARY SCHOOL TEACHERS

Participants: Kathleen Roth (moderator), Thomas Fitzgerald, Nancy Landes, Kathrine Backe, Roberta Jaffe, Gail Foster (recorder)

The participants regarded the standards as a positive force in continuing efforts of elementary school teachers to improve their effectiveness through the elementary school science curriculum. The group agreed that (1) the standards movement has the potential to help teachers create new perceptions—an appealing vision of science education with children, and (2) such perceptions among elementary school teachers promote the dialogue necessary for personal visions to become common visions, and thus affect change.

For the standards to have maximum impact in changing the direction of science education, the elementary school teachers urge the developers of the standards, as well as all in the science education community, to consider the concerns and recommendations listed:

CONCERN
Elementary school teachers perceive the standards as evaluation and compliance. Elementary school teachers might regard the standards as a "STOP" sign; a measure of final results imposed on teachers by the administration.
RECOMMENDATION
School personnel should focus on a commitment to the improvement of elementary school science rather than compliance to standards. Market the standards as long-awaited tools that elementary staff can use to guide them in the process of change and improvement. Through the use of thoughtful language and deliberate presentation, the standards should signal elementary school teachers as a "GO" to begin changing and improving rather than ending.

CONCERN
Elementary school teachers will not see the standards as their issue. They perceive themselves as lacking a formal science background. Thus, a common response has been, "Tell us what to teach and how to teach it."
RECOMMENDATION
The science education community should identify what elementary school teachers already do well in all disciplines and relate these competencies to the standards. Point out how elementary school teachers can make important contributions to secondary school teachers. Elementary school teachers are specialists in teaching children, rather than in subject matter. Link what teachers already know about children to what they know and don't know about science. With guidance and support, elementary school teachers should be able to confidently discern what is developmentally appropriate and to help children construct their understanding of science. Even though elementary school teachers might lack background in science content, they are marvelous windows into the process of inquiry. Through the standards, promote the teacher as a role model for lifelong learning in a community of learners. The language of the standards should enlist elementary school teachers as advocates, and empower them to make choices for change.

CONCERN
Because of the structure of their day, elementary school teachers lack the time to study the standards, and to reflect on the relationship of the standards to

their teaching, to children learning, and to the science curriculum. The organization of the student's day does not lend itself to promoting the goals of the standards.

RECOMMENDATION

Consider providing summaries of the standards in a "Learning Magazine" approach for the teachers. In the summaries, make the connections between the goals of language arts and mathematics to science. Elementary school teachers need help in seeing the big picture, so they realize **why** science education is just as important as language arts and mathematics. Consider developing an implementation guide to the standards, inviting teachers to identify where they already are in relation to the standards, and take incremental steps for sustained, supported change. Encourage elementary school teachers to use the standards as a license for change. The standards lend support to staff development, reflective time for teachers, collegial alliances, integrated curricula, longer blocks of time for inquiry, and so forth.

CONCERN

The standards for primary-age students and teachers of primary-age students should be different from other levels. Do the standards adequately reflect this difference? Should the processes of science take precedence over science content at the primary level? Does the similarity of the standards for each level reinforce elementary school teachers' fears of teaching watered-down high school science?

RECOMMENDATION

As the developers continue to revise the standards, they should consider addressing the differences inherent in all levels, in the format, tone, emphasis, and direction of the standards. It seems logical that the standards for levels K-4 should differ in more than science content and detail from those of levels 5–8, and standards for levels 5–8 should differ substantially from those for levels 9–12. Write the standards for each level in ways that reflect the special nature of the learner and teacher.

CONCERN

Do the standards clearly represent an invitation for elementary school teachers to change? Do the words reflect certain values and communicate a more focused vision of the need for change?

RECOMMENDATION

To the degree possible, the developers of the standards should carefully select words that will address these concerns. In addition, members of the science education community should encourage teachers to examine, rewrite, and shape the standards to their particular visions. In such an exercise, the dialogue is the essence of the task; the means is more important than the end.

SUMMARY—MIDDLE SCHOOL TEACHERS

Participants: Eugenie Scott (moderator), Paul Kuerbis, Paul DeHart Hurd, Michael Taber, Wilbur Bergquist, Mary McMillan (recorder)

The group underscored recognition of middle schools by noting standards and benchmarks specifically identified for grades 5–8 (standards) and 6–8 (benchmarks). They thought that such recognition would support and enhance the reform of middle-level education.

CONCERN

Do the standards reflect the special nature of middle school students? Have the biological, social, and psychological changes of early adolescence been incorporated in the standards and benchmarks?

RECOMMENDATION

Sections should address middle-level education and reflect the special needs of early adolescents.

CONCERN

The standards represent floors, or minimum levels, rather than ceilings or higher expectations of accomplishment.

RECOMMENDATION

Special efforts must be taken to clarify standards and benchmarks as expectations for all students. Although some burden for clarification of this issue rests with NRC and AAAS, a major responsibility lies with those who design curriculum materials for middle-level science education and with those responsible for translating the standards at state and local levels and implementing new curriculum materials, teaching practices, and assessment strategies.

CONCERN

How useful will the standards be for classroom teachers in middle schools?

RECOMMENDATION

Standards should have useful examples of content, curriculum, teaching, and assessment. More importantly, school-based reform should generate the development of science curricula for the middle school, specifically based on standards and benchmarks.

SUMMARY—HIGH SCHOOL TEACHERS

Participants: Nancy Ridenour (moderator), Michele Girard, Sandra Henderson, William Lehman, Patricia Smith, Michael Taber, Anne Tweed, David Ulmer, Philip G. Goulding (recorder)

Although most high school science teachers think there is need for reform, many teachers have negative perceptions of standards-based reform. This group thought that, as a whole, science teachers think that standards are just a fad, require considerable energy, and they will not result in much change. Still, there is need for reform of science teaching in high schools.

CONCERN

The standards will not result in substantial changes.

RECOMMENDATION

Some teachers who are risk-takers are already making changes toward standards-based curriculum. These teachers should be identified and rewarded. School districts should create a climate in which those interested in change can proceed. The group felt that without strong support from administrators, science teachers would make very few changes. In order to make the required changes, science teachers must have time to adapt curriculum materials, to develop new courses, and to learn new teaching strategies. The group also recommended that the "industry" must develop new curriculum, thus translating standards into actual materials.

CONCERN

How can science teachers teach something they have not experienced?

RECOMMENDATION

The National Science Foundation (NSF) and other agencies such as the U.S. Department of Education must support workshops, courses, institutes, and other programs that will enable science teachers to develop the background and identify the resources for effective implementation of national standards.

CONCERN

How will science teachers gain support for improving the high school science curriculum?

RECOMMENDATION

The group responded to this concern by identifying the critical issue of peer support as a complement to staff development. School personnel should encourage peer contact and support through such mechanisms as common planning and lunch periods for teams of science teachers, release days for discussion and development of teaching strategies, inservice and staff development programs through regional labs, involvement with NSF-supported State Systemic Initiatives (SSI), and submitting grants for the improvement of teaching skills.

The group also recognized that the national standards would provide the support needed with parents and communities. That is, once science teachers initiate change, the standards documents provide the foundation that the community needs for assurance that the local changes are focused and aligned with national recommendations.

SUMMARY—INFORMAL AND PUBLIC EDUCATION

Participants: David Heil (moderator), Michael Dougherty, Ellen Friedman, Paul DeHart Hurd, Cheryl Merrill, Sherman Rosenfeld, Randy Backe (recorder)

Informal and public education as a resource and as an industry is positioned to support the kinds of connections, thematic instruction, conceptual learning, and process-oriented science programs we will develop in the future. By nature of their public access, choice-oriented learning approach and support from families, communities, and reform-minded foundations and corporations recognize the informal community is a giant ally for change. Yet, perpetually, this segment of American education is regarded as an afterthought or an "ancillary" to the real curriculum arena. Such a mistake cannot continue. Science museums, public television, popular print literature, and the press are all in touch with the public in ways that teachers and curriculum developers can only admire. The numbers that learn through informal means are huge, and the potential impact is tremendous. If we can bring formal and informal education closer together, wed them as complementary resources, we can go beyond acknowledging that the "total community educates" as Paul Hurd points out, and actually engage in that "total community" educational endeavor.

CONCERN
Who is the audience for informal and public education?
RECOMMENDATION
The current definition of informal education includes science museums, zoos, aquaria, parks, and public television. Perhaps we need a broader definition to include all learning that takes place outside of a formal school setting, and it should reflect lifelong learning.

CONCERN
There is a conceptual and physical gap between schools and informal education.
RECOMMENDATION
National standards could build bridges between school and nonschool settings. Standards also should reflect "people as scientists," since science is regularly done by people in a variety of everyday activities. Standards should represent the needs of those outside the formal educational structure and should push for

better dialogue between the formal and informal community. The informal setting can be a rich resource for formal education, and is often the only resource for individuals no longer affiliated with a school facility or program.

CONCERN
Can curriculum for school science reflect some important characteristics of informal programs?
RECOMMENDATION
Informal education includes the element of choice and caters to the individual in need of a safe place to learn. It also should include the element of accessibility. There should be ways to build these elements into formal school learning.

CONCERN
Will the public come to support standards-based reform?
RECOMMENDATION
There is a need for a public information campaign for promoting and building comfort with science education and science learning. This should employ clear statements to and for the public. The standards should be mentioned, but should not be the focus of the campaign. Guidelines might be suggested for communities to rally their resources and work together to promote science learning. "Engageability" rather than accountability should be emphasized.

CONCERN
Will there be links between the formal and informal settings for science curriculum?
RECOMMENDATION
Curriculum materials should link directly to nonschool learning. The current emphasis should shift from the school-age learner to the lifelong learner. Educational products, museum exhibits, and curricula can be designed with this in mind. The standards should promote the lifelong learning skills of **problem finding** and **questioning** as well as problem solving. Parent and child interaction should be encouraged and civic- and community-based resources can be employed to facilitate this. Since science learning for preschool-age learners is dependent on the nonschool resources, this is particularly important for them. Likewise, outreach efforts should extend into communities where nonschool-age learners need special access.

The concept of staff development also needs to be expanded to include public and community development. There is a definite role for business and industry to help facilitate and build awareness for science learning. This role might include public information awareness and appreciation sessions for parents and nonstudents. It should be noted here that the call for reform is coming from groups of parents, even though these groups can be categorized as policymakers, business leaders, etc. Another reason to engage the total community in science education is to garner support, assuming that support will follow understanding and appreciation.

Classroom learning should incorporate student experiences that occur outside of the classroom (for example, in museums, homes, and outdoors). Teachers should be sensitive to the power of such experiences to promote habits of lifelong learning in their students.

Just as a standards document should reflect community links in the social, cultural, and economic arenas, curricula of the future should model and illuminate those links. Without them, the community at large, such as parents, funders, and policymakers, cannot find themselves in the materials. The curricula becomes separate from life, nonessential, and simply science. With the links, these materials become advocate builders as well as instructional tools for the school.

SUMMARY—SCIENCE SUPERVISORS AND ADMINISTRATORS

Participants: Gerry Madrazo (moderator), Mary Gromko, Mark Koker, Laura Laughran (recorder)

At the same time as the National Research Council is developing national science education standards, states also are developing and implementing science teaching standards. The status of science education standards varies from state to state, but the trend appears to be nationwide. For example, Arizona has implemented science education standards and is developing assessment instruments to measure achievement of these standards. In Colorado, a bill passed recently that mandates districts to set standards in basic subjects, including science. California has developed science education standards but has not mandated schools to implement them. North Carolina also is beginning to move toward the development of state standards.

CONCERN

Conflicts will arise among science education standards created by local, state, and national committees. Different groups are working to achieve similar goals but none of the groups are communicating with each other. What will be the response of the schools and teachers? Will they merely rubber stamp the first set of standards they see without giving them much thought? Or, will they completely resist changing the way science is taught because the different sets of standards contain conflicting ideologies?

RECOMMENDATION

Despite these problems, national science education standards can be implemented. This will require a variety of tools in the toolbox; no single process, or tool, will accomplish this goal. A first step in implementing national science education standards is to increase awareness among all school personnel that national science standards are being developed.

CONCERN

The trend toward science education standards development puts mounting pressure on science supervisors and administrators to do something. The number of such individuals available to do anything is rapidly diminishing. Science supervisors are a dying breed; their positions are being cut to save money. Their tasks fall into the hands of teachers who become part-time science curriculum coordinators and part-time teachers. These individuals have little time to promote standards implementation in their districts. Instead, districts must rely on nonscience educators to promote change in science education.

RECOMMENDATION

Local supervisors, administrators, and school personnel have a responsibility to ensure that national science education standards meet the needs of their communities. They must reach out into their communities to seek liaisons with concerned individuals and organizations. They also should seek alliances among state personnel, businesses, and their schools. Such alliances could provide resources, in the form of both money and human resources, necessary for the implementation of new science education standards. State education departments can aid in the formation of such alliances. They also can find ways to encourage interaction among supervisors of small school districts or hire consultants to help schools restructure their science programs.

CONCERN

There are no resources to support staff development aligned with implementation of the standards.

RECOMMENDATION

Administrators need to build time for professional development into teachers' contracts. Teachers will become leaders and promoters of change only when they are given time and opportunities to develop professionally. One possible way to accomplish this development within the limited budgets of most schools is to establish a system of mentors in buildings that operate using site-based decision making. If principals in these buildings buy one release period per day for the mentors, these teachers will have time to become the promoters and implementers of change.

CONCERN

Supervisors and administrators are held accountable to improve test scores in science but achieving high scores with limited resources is becoming increasingly more difficult. This situation will be exacerbated when science education standards are mandated because implementation of standards implies increased use of performance assessment to measure achievement of the standards.

RECOMMENDATION

Supervisors and administrators must become district-wide advocates for science standards. They must remain aware of the shifting paradigms in science education and become agents of change for their schools and communities. A part of advocating for science education standards must be the reallocation of funds to support an adequate implementation of science curriculum aligned with national standards, including contemporary teaching approaches, student assessment, and program evaluation. Another aspect of standards-based reform is opportunities for the professional development of science supervisors and administrators.

SUMMARY—CURRICULUM DEVELOPERS

Participants: Carolee Matsumoto (moderator), Roberta Jaffe, Douglas Lapp, William Leonard, Ivo Lindauer, Patricia McClurg, Jackie Miller, Janet Carlson Powell, Robert Tinker, Herbert Thier, Lynda Micikas (recorder)

Curriculum developers voiced support for the standards efforts, noting (1) the standards have the potential to stimulate the reform of science education, and (2) curriculum developers see a role for themselves in the reform process. The developers expect to be responsive to the standards, but also to maintain their traditionally proactive roles as some of the individuals and organizations responsible for pushing the leading edge of curriculum. Professional curriculum developers look to the standards to encourage that creativity and development. For the standards to have the greatest possible impact on science education, the group suggests that standards developers consider the concerns and recommendations listed below.

CONCERN

The standards should define their audience clearly. Are the standards written only for the science education community? Or, are they written for the general public (of which science educators are one part)?

RECOMMENDATION

The standards should be communicated in ways that their various audiences will find accessible and useful. For example, if the broader audience is the American public, then the standards probably should be more general, more narrative in character, and more eloquent.

CONCERN

Currently, there are three sets of science standards: the *National Science Education Standards* developed by the National Research Council (NRC), the *Benchmarks for Science Literacy* developed by Project 2061 of AAAS, and *Scope, Sequence, and Coordination of Secondary School Science The Content Core: A Guide for Curriculum Designers* developed by the National Science Teachers Association (NSTA). Although science educators can identify common elements among the sets, the general public may have the impression that teachers, schools, and school districts move down separate and sometimes confusing paths, instead of coalescing behind one set of goals. It also may threaten the credibility of the science education community in the eyes of a public that is looking to it for clear leadership.

RECOMMENDATION

The standards developers should "break bread" and agree to create one set of standards to which parents, teachers, and school boards can look to as an example of what scientists and science educators have said about excellent science education. If this is not feasible, perhaps the groups involved can prepare a joint statement that identifies common goals and elements among the three sets of standards, and that offers some help to users as they attempt to make sense of the standards documents. In any case, each of the current groups should acknowledge the contributions the others have made, and all of the groups should commit themselves to working collaboratively to modify the standards during the next five years. The next set of standards should be generated collaboratively, and should be accompanied by proper acknowledgement of each group's contributions.

CONCERN

The standards have the potential for being too narrowly defined. They also may lead to various abuses, such as the use of standards as assessment criteria or the use of standards (and their supporting examples) to assemble episodic programs of study that have no internal coherence or structure.

RECOMMENDATION

The standards should be written with an "open architecture." Standards should "lay out the playing field," but not "describe each blade of grass." Standards should be inclusive enough to allow creative change and should expand opportunities for future development, not restrict them.

CONCERN

The structures for reform that the standards create will be useful and successful only as teachers are able to make sense of them, take ownership of them, and apply them. Models and strategies for broad implementation and teacher development have not been and may not be addressed adequately in the standards.

RECOMMENDATION

The standards should be written in ways that stimulate the development of multiple approaches to and models for curriculum. Because new curricula can play an important role in educational reform, the individuals involved in creating new science curricula should build in strategies for teacher and administrator development and support, plans for curriculum implementation, and suggestions for how teachers, schools, and districts can solicit support from the broader community, including business, institutions of higher education, and state departments of education.

SUMMARY—STATE AND LOCAL INITIATIVES

Participants: Nancy Kellogg (moderator), Jane Butler Kahle, James Ellis, Ceanne Tzimopoulos, Harold Pratt, Gerry Madrazo, David Ulmer, William Lehman, Mary McMillan (recorder)

This group consisted of individuals who had experience developing science curriculum at the local or district levels, and individuals who are currently working on NSF-supported State Systemic Initiatives (SSI). The concerns and recommendations reflect both local and state perspectives.

In general, the group supported the *National Science Education Standards* but expressed the following concerns and recommendations:

CONCERN
Will the larger science education community and the public understand and support standards-based reform of the science curriculum?
RECOMMENDATION
Develop a small booklet describing the standards, their purpose, and who was involved in development and feedback. State the purpose of the pamphlet as a "Guide to Decisions for Science Curriculum." This document should provide examples or models for implementation of the standards. This can be used as part of professional development. Include concrete examples for the standards so that teachers see how diverse strategies can address the same standard.

CONCERN
School personnel at all levels, from local science teachers to chief state school officers, will have to be involved with implementation of the science education standards.
RECOMMENDATION
Address the need for professional development. State and local initiatives should include collaboration between master teachers and university researchers, enlisting science teachers who understand the standards and who continue to work in classrooms and have more credibility with their peers. The national standards should recognize that the process of implementing standards-based reform is long-term, and professional development is an ongoing process. Collaboration among professional development teams can facilitate the process; for example, teams from other states and local districts that have successfully implemented the standards and designed new science curriculum could work with states and districts initiating reforms.

CONCERN
Local and state administrators will view science standards as the curriculum.
RECOMMENDATION
Present the standards as a tool to allow for the development of diverse science

curricula. The de facto curriculum in this country is what is currently in textbooks, and that is typically very uniform. Through examples and narrative, individuals reviewing standards and benchmarks should realize that these documents allow for diverse approaches to science curriculum. The National Science Foundation (NSF) should support several new programs, or revisions of extant science curricula, to demonstrate the variety of approaches that may emerge as the science education standards are translated to science curriculum.

CONCERN

The various standards and benchmarks will cause confusion about goals and science curricula at state and local levels.

RECOMMENDATION

It is critical that the NRC *National Science Education Standards*, AAAS *Benchmarks for Science Literacy*, and NSTA *Scope, Sequence, and Coordination* come to an agreement about what students should know and be able to do. They may not agree on all points. However, the document produced should reflect the major points of agreement. One document or primer about 15–25 pages should be produced on the agreements that is reader friendly for a diverse audience.

CONCERN

The standards and benchmarks are not clear on the place of integrated or interdisciplinary science curriculum. Since the documents are not clear and do present science content generally aligned with disciplines, many will see these documents as supporting traditional approaches to science curriculum.

RECOMMENDATION

In the emerging NRC *National Science Education Standards*, AAAS *Benchmarks for Science Literacy*, and NSTA *Scope, Sequence, and Coordination*, it would be useful to show how integration can occur in each science strand (for example, life science). The documents need to reflect that teachers can integrate the science and/or teach specific disciplines showing integrated connections wherever possible.

SUMMARY—PUBLISHERS, SUPPLIERS, AND SOFTWARE DEVELOPERS

Participants: Larry Loeppke (moderator), Joe Clark, Ceanne Tzimopoulos, Ray Flagg, Jean Milani, Mary McMillan, Laura Laughran (recorder)

Publishers, suppliers, and software developers supported the development of NRC *National Science Education Standards* and AAAS *Benchmarks for Science Literacy* and recognized the possibility of these documents subsequently improving science curricula and increasing the demand for science textbooks, kit materials, and software aligned with national standards.

A first step in developing science curricula that respond to the *National Science Education Standards* is to ask, "What will science standards implementation look like?" Publishers will be among the first to seek answers to this question.

CONCERN

How will publishers respond to the national standards?

RECOMMENDATION

Once the *National Science Education Standards* are understood by the market, publishers will initiate new, or revise extant programs, and send a message throughout the nation saying, "Our materials meet the guidelines of the *National Science Education Standards*." Local assessment of publishers' materials, by parents as well as by schools and districts, will determine whether the communities agree with a publisher's claims. If they do, they will purchase that publisher's materials and thus, send a message back to the publishers indicating the degree to which new programs and software align with national standards.

CONCERN

Will publishers recognize the needs of those who have to implement national and state standards?

RECOMMENDATION

The transformation of national standards from a set of policies into implemented science programs is a long-term and multifaceted process. It may take many years for this transformation to occur. Meanwhile, science teachers will be taking the initiative to implement national and state standards. They are likely to begin asking more standards-based questions in classroom and nonclassroom settings. They then will look for suppliers to provide kits and software that promote standards-based teaching. Independent developers will respond to teachers' perceived needs by developing new programs and then using a correlation to the *National Science Education Standards* as a feature to promote the programs. Initially, such activities may result in publishers and suppliers marketing more bricks (small, specialized curricula) than walls (comprehensive curricula). This will occur because less risk is involved in marketing bricks. Ideally, as feedback returns regarding which bricks are sound and which are faulty, more sound bricks will be incorporated into walls. Comprehensive curricula will appear only where venture capital is provided by public funding, such as the National Science Foundation and the U.S. Department of Education, during the early stages of this process.

CONCERN

Publishers will only respond to standards-based reform in economically viable ways, that is, in ways that produce immediate profit.

RECOMMENDATION

A key role that publishers and suppliers can play in implementing the *National Science Education Standards* is to provide professional development in teaching and assessing the national standards. As always, a limiting factor to what publishers, suppliers, and software developers can accomplish in this role is the availability of funds. To increase available funds, publishers, suppliers, and software developers can lobby national organizations and the federal government to provide funds for districts to implement the standards. It is likely that the federal government will continue to neglect implementation needs unless we lobby them to fund local implementation efforts.

In addition, lobbying efforts should focus on parents, because it is parents who are elected to school boards where curriculum decisions are made. Schooling in the home is a growing segment of the education market. We should focus some of our lobbying efforts on this group.

Lobbying also should include science teachers. A central focus of lobbying science teachers must address the barriers, problems, and opportunities for teacher implementation of national standards. We must find ways to make standards implementation time and cost effective for science teachers and schools. Our curricula must give teachers an increased sense of control in their classrooms. This can be done by promoting the development of curriculum materials that are flexible, emphasize a constructive model of learning, have accurate science content, and relate learning to the everyday lives of students.

CONCERN

Implementing standards-based programs will require financial commitments by school budgets that will stress an already tight budget. The result will be a slower process of reform or no reform of science curriculum.

RECOMMENDATION

As profit-making organizations, publishers, suppliers, and software developers must focus on ways to drive the implementation process profitably. Publishers are hard pressed to find funds to offer staff-development institutes in the quantity needed. Therefore, we need a long-term, practical plan for implementation of national standards. We will need to create a marketing focus that promotes the advantages of long-term strategies for implementation of national standards.

Within the schools, we should pursue a two pronged approach. First, we should encourage schools to purchase standards-based materials in a sequential manner. For example, they can begin implementing the standards in kindergarten, and then they can add materials year by year as these students progress through the grades. Secondly, we should encourage colleges to educate teachers in implementing the standards. For schools of education, we should produce university-level materials that emphasize practical teaching techniques related to educational theories and practical suggestions at the heart of the national standards.

CONCERN
Valuable time and money will be spent developing inappropriate materials.
RECOMMENDATION
Publishers, suppliers, and software developers need to be early partners in curriculum development that originates at organizations, such as BSCS, NSRC, TERC, LHS, and EDC. It is imperative that curriculum developers construct products that sell. It is absolutely useless to spend time and money developing a curriculum if no one will buy it. Publishers, suppliers, and software developers have an important perspective on what works and what does not work in schools and classrooms. Sharing such information and data with curriculum developers in an interactive partnership would ensure the development of a product that will sell well.

In addition, it is critical that a few catalytic models of the national standards be developed early and marketed extensively by curriculum developers and publishers, suppliers, and software developers. Funding for such projects could come from public and private sources. Without these few, relatively easy, catalytic applications, the national standards will not be seen as useful to building-level teachers and administrators.

SUMMARY—COLLEGES AND UNIVERSITIES

Participants: Jerry Waldvogel and Roger Olstad (moderators), Ron Anderson, William Cairney, Michael Dougherty, Cad Dennehy, Karen Worth, Timothy Goldsmith, Paul Kuerbis, Patricia McClurg, Ellen Friedman, Lynda Micikas, Kathrine Backe (recorder)

At the beginning, the group noted that the challenge of stimulating and supporting reform at the college and university level would be easier if there were a single set of standards on which the scientific and educational communities could coalesce their efforts. Nevertheless, the groups gave a resounding voice supporting the standards and made it clear that they expect the standards to have a dramatic effect on K–12 education.

The participants also noted that it would be difficult to recommend or to impose one set of solutions for all college and university faculties and programs. The participants identified four concerns and priorities for encouraging reform in science education at the college and university level.

CONCERN
Many college and university personnel are either unaware of or only have a vague and incomplete understanding of the national standards.
RECOMMENDATION
Communicate the standards to college and university faculty. Many college science faculty are unaware of the standards initiatives. Faculty who are aware of these initiatives may not be familiar with the content of the different standards. An effort to communicate the standards to this audience might be organized through various professional organizations, especially through the education committees of specific scientific associations.

CONCERN
Colleges and universities will be late in recognizing the implications of national standards.
RECOMMENDATION
Point out the implications of the standards for teaching and learning at the college level. It will be particularly important that the standards influence the teaching of teachers and the teaching of nonmajors. Departments also may need to establish better mechanisms to help preservice secondary education students bridge the gap between their science and the pedagogies that are effective in delivering that science to high school students.

CONCERN
Colleges and universities will focus on critiquing rather than implementing the national standards.

RECOMMENDATION
Encourage reflection and discussion among faculty, both within individual departments (for example, biology, education) and across discipline boundaries. To ensure that these issues receive proper attention, some institutions may need to consider cultivating within each science department one or more individuals who have a strong commitment to precollege science education.

CONCERN
Colleges, universities, and individual science and education faculty will not provide leadership.

RECOMMENDATION
Institutions and individuals should take action as they are able to do so. The audience in the reform of science education is not just teachers in our public schools. Educators cannot be content to wait for others to take the lead and major role in the reform movement. Because different institutions have different missions, the types of action that would be appropriate will vary, but might include initiatives as described in the following paragraphs.

- Some individuals actually could participate in the reform of science curriculum within their institutions. Institutions may need to look at teacher preparation programs more broadly than they have in the past. For example, high school science teachers often are asked to teach in several different disciplines, yet colleges and universities continue to grant degrees in single disciplines, such as biology, chemistry, physics, and geology.

- ▼ Changes in admissions and in certification requirements. Some institutions may need to align their admissions criteria with new K–12 outcomes. Universities and colleges also need to encourage dialogue across state boundaries to ensure uniformity in teacher certification models.
- ▼ There is the ever-present need to provide good models of science teaching. This implies changes in how institutions and departments educate and use teaching assistants and changes in the way college and university faculty deliver science content in their courses.
- ▼ Efforts to offer faculty development programs with incentives that encourage college and university faculties to take the lead in modeling new initiatives. It also will be important to identify colleges and universities where new models are working well and to explore why those models and those faculties have been successful. Funding agencies should be encouraged to channel more money into educational research.
- ▼ Efforts to facilitate the development of effective coalitions between colleges and universities and local school districts, schools, and teachers. This might include the college or university offering inservice workshops for school administrators and teachers interested in implementing the standards in their districts or schools, as well as more specific, discipline-focused types of collaboration and assistance. It will be important that inservice activities of this type flow out of the real needs of schools and teachers. This is not likely to be the case if the departments involved take a top-down approach to developing such initiatives. Instead, successful collaborations should be based on a shared vision that involves all parties in a commitment to change in science education.

6

CONCLUSION

STANDARDS AND BENCHMARKS IN SCIENCE EDUCATION: REQUIEM OR REVOLUTION?

BY TIMOTHY GOLDSMITH

The reform of science and math education is poised in a metastable state, and it is an open question whether the nation will move forward with effective educational change or slip—not back—but sideways, into a sort of Social Darwinist swamp of competition, vouchers, and misdirected ideology.

The impetus for reform has reached its present state with a growing national awareness that a poorly educated electorate cannot underpin a successful economy in a world of effectively shrinking dimensions. This is a philosophically thin argument, but it is right as far as it goes, and its economic ring is politically sound. A faltering economy, rife with individuals for whom the education system has failed, produces a society full of discontent, of crime, and in our peculiarly American myopia, an inability to see the causal relations between firearms and a culture in which frustration so frequently leads to violent death. It is, in fact, one of the profound failures of our educational system that so many citizens are unable to think clearly about the complexity of causes in biological systems in general and social systems in particular. That, however, is another theme for another day. Nevertheless, who could argue with the proposition that a national concern with education is a first step in the right direction? To flip the old adage, every silver lining has its black cloud. It is not just the public susceptibility to seemingly cost-free nostrums that darken my darker moments, it is my concern that this nation is capable of only one truly revolutionary social change per generation. Perhaps not, but it has taken about half a century from the introduction of social security for the nation to become focused on the need for universal medical coverage. The resolution of that important matter is far from clear. So one has to ask, how many revolutionary social changes can the American public internalize in a generation?

I am putting the problem this way because I have come to believe that what is needed to reform mathematics and science education, to say nothing of history and other subjects, is revolutionary change. I am not the first to apply that word to the present dilemma; my colleague at Yale University, Seymour Sarason, has been asserting for years that the needed changes in education are not recognized and confronted because they are revolutionary (see, for example, *The Predictable Failures of Education Reform*). I have come to believe that he is quite right.

I would like to describe some of the features of schools and school systems we ought to have in order for national standards to play a central role. First, we need to have a word about where standards must originate and what they are attempting to accomplish. The teachers of mathematics have led the way in creating standards for their discipline, and the National Research Council is trying to do similar things for science by providing a catalytic center in which the best thinking—the wisdom —of teachers and other educators from all levels, from elementary school to universities, can be pooled. That collaboration of teachers and scientists is what gives the process credibility. Project 2061 of the AAAS, running in parallel, is trying to capture the same magic.

I deem it essential that the public perceive these projects to be delivering one and the same message, for otherwise we court disaster. There is a place—indeed a necessity—for open architecture in the details of implementation, but the philosophical underpinnings of standards and benchmarks had better be seen as monolithic. Herein lies a problem for the architects, a difficult and subtle problem that should not be underestimated. One danger is that the word "standards" —particularly "national standards"—suggests a straightjacket of conformity in which the creativity of teachers is certain to be undermined. The press is even today parroting that criticism, even though the central intent of standards and benchmarks is to foster thought, questioning, and understanding in the classroom. A second objection comes from the opposite direction when the standards are viewed and judged by people outside the profession whose views of education have been molded by their personal experiences of yesteryear. For them, if the physics lesson appears to lack some familiar feature, such as electrical circuits and bulbs and batteries, "Where's the content?" becomes the "Where's the beef?" of public dialogue. So, it is essential for everyone to understand the richness of what the standards and benchmarks are trying to accomplish.

In what follows, I will use language that relates to the NRC-catalyzed standards, but I judge the aims of Project 2061 to be largely overlapping. Standards are a tripod, and as we know, a tripod is only steady if it has three equally strong legs. Mention of standards evokes an image of content, of the details of what is taught, but that is only one of the three legs. The second deals with the substance of how content is taught—the art, the craft of teaching—the means by which a teacher can engage the minds of students, diverse in background, in abilities, and even in language, and make the material seem a natural part of their individual worlds. The third leg is the task of devising assessments in which students are presented with attainable goals and in which teachers discover what is working, and why, and for whom. In this, we should aspire to some broader and more meaningful goal than reducing the future value of a child to a two- or three-digit number on a normalized scale.

I do not want to dwell on the structure of the tripod, for that is not my principal goal. I wish instead to remind you about the uneven ground on which we are trying to place the tripod, for in clearing away the rubble, we will encounter the real need for revolution.

The central challenge in finding a hospitable home for standards and benchmarks is to professionalize the profession of teaching. Teaching is spoken of as a profession, but to what extent are the professionals responsible for setting the standards of their profession? Do they have the autonomy of lawyers? Of physicians? Or, are the standards that govern their education, their certification, and the goals of their classroom functions set by individuals outside the profession, frequently lawyers in state legislatures or in Congress with attention spans fixed by the next election?

Clearly, in a democracy, the activities of professional organizations are subject to public scrutiny and even regulation. The profession of teaching has been largely deprofessionalized by this process. The profession must take charge of its own destiny if it is to buffer its core values from political whims. To this end, the professional organizations of teachers should have more and continuing responsibility for the continued evolution of standards.

Standards are going to evolve, indeed they must change. In the first place, the underlying science changes, for that is the nature of scientific understanding. Second, we are continuing to learn more about how people learn. It is no longer seen as maximally productive to train a mind as one would train a dog, in a sort of pre-Pavlovian pedagogy in which the cerebral cortex becomes a suburb of the spinal cord. My parents' generation, now unable to remember where they put the grocery list, can recite poetry that was committed to memory at the age of 10 or 12. This did generate a certain kind of mental discipline, but it did little or nothing to prepare one to live in a rapidly changing world where familiar modes of employment have a way of disappearing, and culture, whether we like it or not, is so driven by technology.

What is the process by which standards will change? What is the process by which legislators and the public will come to understand that science is a dynamic form of understanding, and that standards, like scientific understanding, cannot be frozen in time, inscriptions on a cultural tombstone? What is the process by which an expanding portion of the public becomes comfortable with a broader goal of education than simply the inculcation of local cultural values? We do not know the answers to questions, because we are only now trying to answer them. One thing is clear: More teachers must be centrally, creatively engaged in the dialogue that will lead to that evolution.

The professionalism of teachers must penetrate to the very marrow of schools. There is no one best way to teach. Within schools, science teachers must be free to experiment, to take risks, to respond to the needs of their pupils as the context demands. The context cannot be legislated; it is local, frequently as local as an individual student. Real teaching is a creative process, and it is impossible to be very creative when one is marching lockstep in someone else's parade.

A redefined professionalism of science teachers implies new and enlarged responsibilities, not only in their individual schools, but in their professional organizations, where their input on the refinement of curricular policy can be made at the state as well as the local level and where their collective voice in the evolution of standards can be most effectively heard. There also is implied an individual responsibility for lifelong learning that should be instilled in their early education and then supported by school systems throughout a teaching career.

Probably the major impediment to these kinds of changes is the lack of time science teachers have to function in a professional manner: to prepare something new, to consult with colleagues about curriculum, or assessments, or techniques, or their shared responsibility for particular students, or even to develop the sense of mutual trust on which everything else depends. As important as Internet and other technological support systems can be, they do not address the impossible way the teacher's day is now organized.

Principals and other administrators should realize that their most important role is to create a school environment in which these things can happen, while at the same time fostering understanding—and the support that will follow—from parents and other interested and concerned citizens. There are places at the table for many voices at the local level while preserving the central, professional function of science teachers. Principals are not trained for this task now, nor are they generally supported by superintendents, and those that have taught themselves how to play the role are frequently local heroes.

It follows from what I am saying that the entire system needs to be reformed. There is currently much talk about "systemic" reform, principally because the NSF has had some money to spend under that banner. My impression is that most people who are spending that money are still clueless about the real meaning of "systemic" in State Systemic Initiatives, Urban Systemic Initiatives, and Rural Systemic Initiatives.

Simply put, it means changing the culture of schools, and to do this, one must change practices in the entire, hierarchical administrative structure as well as the processes by which teachers are recruited, apprenticed, mentored, and supported for a career in the profession. Needless to say, you do not do that with a few summer workshops.

At this juncture, some of you may be thinking, these are dreams which could only be coming from someone who is detached from the realities of public schools. If that is what you think, I respond by saying, "Ahh, you are beginning to understand what I mean when I describe our challenge—the nation's challenge—as revolutionary." It is revolutionary in the most profound sense of the word, shaking the assumptions and beliefs and behaviors of virtually everyone who is engaged in the system: politicians, principals and parents, school boards and school administrators, writers of texts and of tests, teacher educators, and most importantly, the teachers themselves, who must come to believe that things not only can be different, they must be different.

Let me close with an assertion that our nation's colleges and universities bear their share of responsibility for the present system, for it is we who teach not only the teachers but the politicians and the parents as well. One simple example of abject failure is the total absence of any effort to present science in a meaningful way, a useful way, to individuals who aspire to teach K–6. There is ample blame to go around.

To be successful, a revolution in education must engage the hearts and minds of everyone with a concern for education. Those who are involved in the design of science curricula and the development of appropriate means of assessment have an especially important task, for out of your labors must come the translation of standards and benchmarks and all their attendant goals and principles in forms that persuade all constituencies that the revolution is worth winning, can indeed be won, and maybe can even be won in our generation.

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APPENDIX B
FINAL AGENDA

Rethinking the Science Curriculum
A Conference-Science Curriculum in an Era
of Standards-Based Reform
Organized by the Biological Sciences Curriculum Study (BSCS)
Supported by the National Science Foundation (NSF) and
the Biological Sciences Curriculum Study (BSCS)

Cheyenne Mountain Conference Resort
Colorado Springs, Colorado
20–22 October 1993

Wednesday, 20 October

3:00 – 5:00 P.M.	Arrival and Check–in
	WHITE RIVER GALLERY
5:00 – 6:00 P.M.	Informal Reception
	WHITE RIVER I/II ROOM
6:00 – 7:30 P.M.	Dinner
7:30 – 8:00 P.M.	Welcome, Introductions, and Overview of Conference • Roger Olstad, Chair-BSCS Board of Directors • Joseph McInerney, Director, BSCS • Rodger Bybee, Associate Director, BSCS
8:00 – 9:00 P.M.	Keynote Address: "Reinventing the Science Curriculum: Historical Reflections and New Directions" • Paul DeHart Hurd, Professor Emeritus, Stanford University

Thursday, 21 October

	MOUNTAIN VIEW DINING ROOM
7:00 – 8:00 A.M.	Breakfast
	PLATTE/ARKANSAS ROOM
8:00 – 10:30 A.M.	The National Science Education Standards • Rodger Bybee, Chair, Content Working Group, National Research Council • Karen Worth, Chair, Teaching Working

	Group, National Research Council • Audrey Champagne, Chair, Assessment Working Group, National Research Council • Harold Pratt, Senior Program Officer, National Research Council • David Florio, Director, National Education Initiatives, National Research Council
10:30 – 11:00 A.M.	Break
11:00 – 11:30 A.M.	The Project 2061 Benchmarks • Jo Ellen Roseman, Director of Curriculum, Project 2061, American Association for the Advancement of Science
11:30 A.M. – 12:00 Noon	The NSTA Project on Scope, Sequence, and Coordination • Gerry Madrazo, President of NSTA
12:00 Noon – 1:00 P.M.	REMINGTON'S Lunch and Discussion of Standards–Based Reform of the Science Curriculum • Participants will have opportunities for extended discussions with individuals who have worked on AAAS Benchmarks, NSTA Scope, Sequence, and Coordination, and the NRC Standards. These discussions will continue through lunch.
1:00 – 1:30 P.M.	REMINGTON'S Luncheon Address • "Standards for Standards: Too Much Too Early, Too Little Too Late?" Elizabeth Stage, Director, New Science Education Standards Project
1:30 – 2:00 P.M.	Free Time
2:00 – 2:30 P.M.	PLATTE/ARKANSAS ROOM Charge to the Working Groups
2:30 – 4:00 P.M.	BREAKOUT ROOMS: PLATTE/ARKANSAS, GUNNISON, WHITE RIVER II Perspectives and Issues on Standards–Based Reform of the Science Curriculum (Working Groups in Concurrent Sessions)

- These working groups will identify different perspectives, issues, and concerns that influence the science curriculum. Questions these groups address may include the following:

  How will standards be translated to effective science curricula?

  How will individuals resolve conflicts among local, state, and national standards?

  How can we achieve the standards and maintain a diversity of approaches to science curriculum?

  What is the role of the National Science Education Standards, Project 2061–Benchmarks, and NSTA–Scope, Sequence, and Coordination?

3:00 – 3:30 P.M. Break

3:30 – 4:00 P.M. Each working group will develop a two- to three-page statement of the critical issues and proposed solutions of standards-based reform of the science curriculum.

PLATTE/ARKANSAS ROOM
Science Teachers (High School)
Nancy Ridenour–Moderator/Reporter
Phil Goulding (BSCS)–Recorder

Science Teachers (Middle School)
Eugenie Scott–Moderator/Reporter
Mary McMillan (BSCS)–Recorder

Science Teachers (Elementary School)
Kathleen Roth–Moderator/Reporter
Gail Foster (BSCS)–Recorder

GUNNISON ROOM
Science Supervisors/Administrators
Gerry Madrazo–Moderator/Reporter
Laura Laughran (BSCS)–Recorder

State Systemic Initiatives
Jane Butler Kahle–Moderator/Reporter
Donald Maxwell (BSCS)–Recorder

Colleges and Universities: Scientists and Teacher Educators
Jerry Waldvogel and Roger Olstad–Co–Moderators/Co–Reporters
Kathy Backe (BSCS)–Recorder

GUNNISON ROOM
Informal Education
David Heil–Moderator/Reporter
Randy Backe (BSCS)–Recorder

Publishers/Suppliers/Software Developers
Ceanne Tzimopoulos–Moderator/Reporter
Joseph McInerney (BSCS)–Recorder

WHITE RIVER II ROOM
Curriculum Developers (National Organizations)
Carolee Matsumoto–Moderator/Reporter
Lynda Micikas (BSCS)–Recorder

Curriculum Developers (Local)
Harold Pratt–Moderator/Reporter
Kathy Winternitz (BSCS)–Recorder

PLATTE/ARKANSAS ROOM

4:00 – 5:00 P.M. Reporting and Feedback on Perspectives and Issues

- Science Teachers (High School)
- Science Teachers (Middle School)
- Science Teachers (Elementary School)
- Science Supervisors/Administrators
- State Systemic Initiatives
- Colleges and Universities: Scientists and Teacher Educators
- Curriculum Developers
- Publishers/Suppliers/Software Developers
- Informal Education

5:00 P.M. Adjourn to Special Interest Groups

GRAND RIVERS GALLERY

6:00 P.M. Reception Hosted by BSCS

GUNNISON/RIO GRANDE ROOM

7:30 P.M. Dinner

Friday, 22 October

7:00 – 8:00 A.M.	MOUNTAIN VIEW DINING ROOM Breakfast
8:00 – 8:55 A.M.	PLATTE/ARKANSAS ROOM Curriculum Developers – Perspectives from Schools, States, Regions, NSF Projects (Panel Discussion) • Arthur Eisenkraft–Fox Lane High School, Bedford, NY–(Moderator) • Judy Capra–Jefferson County, Golden, CO • Peggy Carnahan–San Antonio, TX • Cad Dennehy–Greeley School Dist. 6, CO • Bill Leonard–Clemson University, SC • David Ulmer–Coronado High School, CO • JoAnne Vasquez–Wolf–Mesa Public Schools, AZ
9:00 – 9:55 A.M.	Curriculum Developers – Perspectives from National Organizations (Panel Discussion) • Janet Carlson Powell BSCS–(Moderator) • Robert Tinker–TERC • Herbert Thier–LHS • Carolee Matsumoto–EDC • Douglas Lapp–NSRC
9:55 – 10:00 A.M.	Charge to the Working Groups
10:00 – 10:30 A.M.	Break
10:30 A.M. – 12:00 Noon	Priorities and Recommendations for Science Curriculum Development (Working Groups in Concurrent Sessions) • Each working group will be responsible for developing a two– to three-page summary statement of recommendations. PLATTE/ARKANSAS ROOM Local School Districts Nancy Kellogg–Moderator/Reporter Mary McMillan–Recorder State Agencies Mary Gromko–Moderator/Reporter Don Maxwell–Recorder

	COLORADO III ROOM Funding Agencies Paul Kuerbis–Moderator/Reporter Joseph McInerney–Recorder
	Colleges and Universities Jay Hackett–Moderator/Reporter Lynda Micikas–Recorder
	RIO GRANDE ROOM Publishers/Suppliers/Software Developers Larry Loeppke–Moderator/Reporter Laura Laughran–Recorder
	Public Education **(Outside of the School System)** David Heil–Moderator/Reporter Randy Backe–Recorder
	Other Gail Foster–Recorder
	Other Phil Goulding–Recorder
	PLATTE/ARKANSAS ROOM
12:00 Noon – 1:00 P.M.	Lunch
1:00 – 1:30 P.M.	Luncheon Address • "Perspectives on the Reform of Science Education" • "Timothy Goldsmith, Yale University, Chair of Panels for the NRC report *Fulfilling the Promise* and the Nation Wide Education Support System for Teachers and Schools
	BREAKOUT ROOMS: PLATTE/ARKANSAS, COLORADO III, RIO GRANDE
1:30 – 3:00 P.M.	Continue Work on Priorities and Recommendations
3:00 – 3:30 P.M.	Break
3:30 – 4:45 P.M.	Final Presentations of Priorities and Recommendations
4:45 – 5:00 P.M.	Concluding Statements

Publication of *National Science Education Standards* in 1995 and the 1993 publication of *Benchmarks for Science Literacy* provide the science education community with goals that have profound implications for the science curriculum. The science curriculum represents only one aspect of the equation for educational reform, but it is an essential part of that reform. *Redesigning the Science Curriculum* presents the results of a project conducted by the Biological Sciences Curriculum Study (BSCS) with support from the National Science Foundation (NSF). The book is a compilation of background papers and recommendations directed to those responsible for curriculum reform, regardless of their roles in local school districts, state agencies, or national organizations.

▼

What is sought [in redesigning the science curriculum] is a broader and richer perspective of science education, one that considers the demands of a changing knowledge-intensive society; the interrelation of science culture, and social progress; and the adaptive needs of learners. Each of these factors is seen as essential for responsible citizenship in a democratic society characterized by achievements in science and for a rational consideration of human affairs.

Paul DeHart Hurd
Stanford University

▼

The new science curriculum must provide equal access to education. It must open the doors of science understanding to all students ... The science curriculum also must challenge all students.

Arthur Eisenkraft
Fox Lane High School

▼

It is no coincidence that groups in so many disciplines are developing national standards ... For those of us in science education, it is fortunate that a common vision prevails across our documents.

Susan Sprague
Mesa Public Schools

▼

The reform of science and math education is poised in a metastable state, and it is an open question whether the nation will move forward with effective educational change or slip - not back - but sideways, into a sort of Social Darwinist swamp of competition, vouchers, and misdirected ideology.

Timothy Goldsmith
Yale University

This project was supported, in part, by the
National Science Foundation
Opinions expressed are those of the authors and not necessarily those of the Foundation

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