Scientific Literacy: Another Look at Its Historical and Contemporary Meanings and Its Relationship to Science Education Reform

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Abstract: *Scientific literacy* is a term that has been used since the late 1950s to describe a desired familiarity with science on the part of the general public. A review of the history of science education shows that there have been at least nine separate and distinct goals of science education that are related to the larger goal of scientific literacy. It is argued in this paper that instead of defining scientific literacy in terms of specifically prescribed learning outcomes, scientific literacy should be conceptualized broadly enough for local school districts and individual classroom teachers to pursue the goals that are most suitable for their particular situations along with the content and methodologies that are most appropriate for them and their students. This would do more to enhance the public's understanding and appreciation of science than will current efforts that are too narrowly aimed at increasing scores on international tests of science knowledge. A broad and open-ended approach to scientific literacy would free teachers and students to develop a wide variety of innovative responses to the call for an increased understanding of science for all.

Introduction

The term *scientific literacy* has defied precise definition since it was introduced in the late 1950s (Hurd, 1958; McCurdy, 1958; Rockefeller Brothers Fund, 1958). Although it is widely claimed to be a desired outcome of science education, not everyone agrees what that means. The problem is magnified when scientific literacy becomes the goal of science education reform. Without a clear idea of what scientific literacy is, reform becomes a vague notion at best. Many attempts have been made to define it, but none has yielded anything that even approaches universal acceptance. There are a number of reasons for this. Most important is the fact that scientific literacy is a broad concept encompassing many historically significant educational themes that have shifted over time. Some writers have even admitted that it may be no more than a useful slogan to rally educators to support more and better science teaching (Bybee, 1997). If that is true, then to speak of scientific literacy is simply to speak of science education itself. In

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this paper I will review some of the most important ideas related to the term *scientific literacy* in the hope that this will help us understand the confusion that surrounds the concept and enable us to productively reorient our thinking about it.

Historical Review

Pre-1950s

Science became part of the school curriculum during the 19th century, both in Europe and the U.S., in large part because of the urgings of scientists themselves. Notable among those who publicly spoke in favor of science teaching were Thomas Huxley, Herbert Spencer, Charles Lyell, Michael Faraday, John Tyndall, and Charles Eliot (DeBoer, 1991). Their job was not an easy one. The humanities were firmly entrenched as the subjects that were thought to lead to the most noble and worthy educational outcomes. Scientists had to be careful when arguing the utility of science not to present science as too crassly materialistic and without higher virtue. So in addition to discussing the practical importance of science in a world that was becoming dominated by science and technology, they also said that science provided intellectual training at the highest level—not the deductive logic that characterized most of formal education, but the inductive process of observing the natural world and drawing conclusions from it. Students would learn this way of thinking by carrying out independent inquiries and investigations in the laboratory. An attitude of independence would help protect individuals from the possible excesses of arbitrary authority and enable them to participate more fully and effectively in an open democratic society.

Independence of thought and the intellectual development of all students were also themes of the 1893 report of the National Education Association's (NEA) Committee of Ten. Charles Eliot, who chaired the Committee and who had introduced laboratory instruction while he was president of Harvard University from 1869–1895, summarized the goal of science education this way:

> Effective power in action is the true end of education, rather than the storing up of information .... The main object of education, nowadays, is to give the pupil the power of doing himself an endless variety of things which, uneducated, he could not do. An education which does not produce in the pupil the power of applying theory, or putting acquisitions into practice, and of personally using for productive ends his disciplined faculties, is an education which missed its main aim. (Eliot, 1898, p. 323–324)

John Dewey also defended science as a legitimate intellectual study on the basis of the power it gave individuals to act independently. Dewey said: "Whatever natural science may be for the specialist, for educational purposes it is knowledge of the conditions of human action" (Dewey, 1916, p. 228).

During the early years of the 20th century, largely because of the influence of writers such as Dewey, science education, and education in general, was justified more and more on the basis of its relevance to contemporary life and its contribution to a shared understanding of the world on the part of all members of society. In 1918 the Commission on the Reorganization of Secondary Education (CRSE) of the National Education Association issued its report entitled *Cardinal Principles of Secondary Education* (NEA, 1918), and in 1920 the science committee of the NEA submitted a related report entitled *Reorganization of Science in Secondary Schools* (NEA, 1920). The proper role of education according to the Commission was to develop the individual for effectiveness in a social world. Speaking specifically of science, Clarence Kingsley, who chaired the Commission, said that what was important was "the application of [scientific] knowledge to the activities of life, rather than primarily in terms of the demands of any subject as a logically organized science" (NEA, 1918, p. 8).

By 1932, however, there was some concern that curriculum developers had gone too far in making subject matter "relevant" and had forgotten the fundamental reason why science was being studied, which was to provide a broad understanding of *the natural world* and the way it affected people's personal and social lives [italics added]. The National Society for the Study of Education (1932), in its Thirty-first Yearbook, *A Program for Teaching Science*, reexamined the goals that had been identified in the Cardinal Principles fourteen years earlier with the intention of making them clearer and more substantive. The challenge was to find the right balance between a broad intellectual understanding of the natural world and the scientific way of thinking on the one hand, and the utility of science for effective living on the other. The Yearbook Committee believed that science should be studied for its usefulness to individuals and to support their intelligent participation in a democratic society, but also as a powerful cultural force and a search for truth and beauty in the world.

In 1947, the National Society for the Study of Education published its Forty-sixth Yearbook, *Science Education in American Schools*. The theme of social relevance, which had been prominent in the NSSE's Thirty-first Yearbook, was evident again. This time the Yearbook Committee made special reference to a 1945 report of the Harvard Committee on General Education concerning its position on the appropriate education of students at the elementary and secondary school level:

> Science instruction in general education should be characterized mainly by broad integrative elements—the comparison of scientific with other modes of thought, the comparison and contrast of the individual sciences with one another, the relations of science with its own past and with general human history, and of science with problems of human society. These are the areas in which science can make a lasting contribution to the general education of all students. (NSSE, 1947, p. 20)

The Yearbook Committee also expressed faith in the link between science and human progress, an idea that had been so much a part of 19th and early 20th century thinking about science and technology. But in the years just following World War II, this optimism was tempered by a new realization that scientific developments also had the potential to destroy society. The Committee quoted one anti-science statement that said:

> The present prospect is that, no matter what its way of working may be, science may itself be the end of the human enterprise. The belief in social progress, of which science has nearly always been viewed as the efficient cause, has come to a low state in our time. Few people . . . any longer believe that mankind is moving forward in the direction of a desirable goal. Even the hope that this might be so is rapidly waning . . . . Indeed, security, peace of mind, loyalty, friendship, kindliness, and the general attitudes associated with the brotherhood of man appear to be becoming less as science moves forward. (NSSE, 1947, p. 16)

Concern about the public's attitudes toward science and their ability to serve as thoughtful critics of the role of science in society produced new reasons for teaching science. On the one hand, if there were risks associated with science, the public needed the knowledge and skills to make intelligent judgments about those risks. On the other hand, to the extent that science was a benign force in the world, it was hoped that citizens would be supportive of science. This support would come if they were familiar with the work that scientists did. But the Committee also remained sensitive to the personal and cultural benefits of science education, and they were careful to say that an education in science was ‘‘for all pupils for their own and society’s benefits and only incidentally involves concern for the welfare or future of science’’ (NSSE, 1947, p. 61).

Another change in the relationship between science and society involved the growing perception that scientific and technological developments were an important resource for national security. In the decade immediately following the war, there was an increasing concern in the U.S. about our economic and military status internationally and the role of science education in assuring that the U.S. would remain a significant force in the world. The President’s National Research Board, established to study the country’s research and development activities and science training programs following the war, said:

> The security and prosperity of the United States depend today, as never before, upon the rapid extension of scientific knowledge. So important, in fact, has this extension become to our country that it may reasonably be said to be a major factor in national survival. (President’s Scientific Research Board, 1947, Vol. 1, p. 3)

Here again, the public’s support of the scientific enterprise was crucial. As the Board put it:

> [A]ccount must be taken of the degree of comprehension of science by the general population. For in a democracy it is upon the popular attitude toward science that the attractiveness of the profession, the resulting selectivity for those finally entering the profession, and the degree of support obtainable for their work will depend. (President’s Scientific Research Board, 1947, Vol. 4, p. 113)

Late 1950s to 1983

As the 1960s approached, the science education community was becoming more and more interested in the strategic role of scientific knowledge in society, especially given the recent launching of the earth orbiting satellite Sputnik by the Soviet Union in 1957. In 1960, the National Society for the Study of Education again focused on science education in its Fifty-ninth Yearbook entitled *Rethinking Science Education*. As in the immediate post-war years, it was proposed that science educators should work to produce citizens who understood science and were sympathetic to the work of scientists. Also very much in evidence was the civic responsibility theme which had emerged following World War II with regard to both the threats and promises of science. In the Yearbook Committee’s words: ‘‘In our society many demands peculiar to a democracy are placed on all citizens.... One is the responsibility to help decide how scientific knowledge will be used’’ (NSSE, 1960, p. 113).

Not everyone was comfortable, however, with science education being justified on the basis of national security concerns. One member of the National Science Foundation urged educators to remain focused on the general, liberal education theme. In his words:

> Not because there are satellites following their elliptical orbits about the earth nor because other nations have given emphasis to training in technology and science, and not because of any alteration of our scale of values, should it suddenly be declared that science must occupy the commanding position at all levels in our educational system. . . . [W]e live in an environment molded by the applications of science, and we believe some of the processes used in arriving at conclusions in science have a relevance to our thinking and, indeed, to

> our behavior in other phases of life. Hence, education in science should be a part of the intellectual heritage of all. (NSSE, 1960, p. 24)

But many science educators did believe that the goals of science education should be qualitatively different. Science teaching should still be for personal development and to help individuals adjust to life in modern society, but that world was changing. Explosive developments in technology and concerns about national security that arose following World War II were compelling enough to command a new approach to science education. The goals of science teaching for general education purposes within this new environment came to be called scientific literacy. In June of 1958, a report was issued on the state of education in the U.S. by the Rockefeller Brothers Fund. The report on education was one of five reports dealing with various aspects of American society at mid-century. The reports focused on how the country should respond to the ''startling'' rate of scientific and technological change taking place in such areas as nuclear energy, space exploration, cell biology, and brain physiology, as well as the vastly more complex social organizations that were developing. In the report on education, the question was how the educational system could be used more effectively to prepare people to live and work in such a rapidly changing world. Although all fields of endeavor were requiring higher levels of skill to perform, the shortage of technically trained personnel was particularly critical.

The response to these challenges was ''to turn to organized intellectual effort as never before in history'' (Rockefeller Brothers Fund, 1958, p. 347), especially on the part of the most talented and highly educated members of society. This was to be done so that we could keep pace with the ''breathtaking movement into a new technological era'' (p. 367). But along with needing an adequate supply of technically trained scientists, mathematicians, and engineers, the society also needed a highly educated citizenry that understood the scientific enterprise. In the words of the report: ''Among the tasks that have increased most frighteningly in complexity is the task of the ordinary citizen who wishes to discharge his civic responsibilities intelligently'' (p. 351). The answer was scientific literacy. The Board said:

> [J]ust as we must insist that every scientist be broadly educated, so we must see to it that every educated person be *literate in science* [italics added]. ... We cannot afford to have our most highly educated people living in intellectual isolation from one another, without even an elementary understanding of each other's intellectual concern. (p. 369)

Scientific literacy was to provide a broad understanding of science and of the rapidly developing scientific enterprise whether one was to become a scientist or not.

In an article published in *Educational Leadership* in October of 1958, Paul DeHart Hurd also used the term scientific literacy to refer to the new goals of science education. Just as in the Rockefeller Report, Hurd expressed a deep sense of urgency because of how fast the world was changing, a concern that went far beyond the immediate fears about Sputnik, and a belief that these changes necessitated a new approach to education. A more important worry to Hurd, however, was that the intellectual goals of a liberal education might be in conflict with the immediate and practical goal of building a technically trained workforce. In his words: ''Will curriculum workers be able to devise the educational program necessary to maintain the delicate balance of scientific, social, and economic forces that will be found in this period?'' (Hurd, 1958, p. 14). Although meeting the demands of a technically trained workforce was important, it was also important for all students to continue to develop an appreciation for science as a cultural force. Hurd said: ''Further efforts are required to choose learning experiences that have a particular value for the development of an appreciation of science as an intellectual achievement, as a procedure for exploration and discovery, and which illustrate the spirit of scientific discovery'' (pp. 15–16).

Neither Hurd nor the authors of the Rockefeller Report attempted to define scientific literacy except very broadly as knowledge of science and the scientific enterprise, especially in the context of science's newly acquired strategic importance in society. Hurd used the term only twice, once in reference to the NSF-sponsored curriculum projects, which had just gotten underway, where he said: ''Hundreds of scientists are giving help by suggesting experiences of greater potential significance for the development of scientific literacy in the young people of America'' (p. 15). He also spoke of ''closing the gap between the wealth of scientific achievement and the poverty of scientific literacy in America'' (p. 14).

In November of 1958, Richard McCurdy, President of the Shell Chemical Corporation, addressing the new goals of science education, also used the term scientific literacy, this time to contrast scientific literacy with what we might call technological literacy. McCurdy argued that because of fundamental and dramatic changes that were taking place in science, science teaching should move away from an emphasis on technology and toward the principles of science. According to him, a study of technology had been appropriate in science classes in the past because this is where the public gained an appreciation for the contributions of scientists, but with ''the splitting of the atom and the consequent purposeful search into what things are and how they work'' a new approach to science teaching was called for. This was not to be a casual intellectual pursuit, but something that ''will help prepare the student to participate in human and civic affairs, whatever his calling may be'' (McCurdy, 1958, p. 366). In defining scientific literacy for the general student, McCurdy referred to the ideas of Frederick Seitz, chairman of the American Institute of Physics. Seitz said that we should ''place primary emphasis on a continuing course in general science at the secondary school level, which gives familiarity with the history and accomplishments of science and its relation to the matters of everyday life. This should be descriptive and inspirational, placing emphasis upon the cultural roots and the goals of science and the countless ways in which it affects our understanding of the world about us'' (Seitz, 1958, quoted in McCurdy, 1958, p. 368).

But for all the talk of a broad understanding of science as a cultural force, it was the perceived poverty of scientific knowledge itself that motivated most science educators in the decade of the 60 s. In 1963, Robert Carlton, executive secretary of the National Science Teachers Association, asked a number of scientists and science educators what the term scientific literacy meant to them and found that most focused on greater content knowledge in a broad range of science fields; only a few spoke of the relationship between science and society. For example, Howard Meyerhoff, chairman of the geology department at the University of Pennsylvania, said that scientific literacy implied ''familiarity with scientific methods and...sufficient knowledge in the several fields of science to understand reports of new discoveries and advances'' (Carlton, 1963, p. 34). The approach to science teaching that was emerging was characterized by a more demanding treatment of the academic disciplines, and was based on the belief that within the science disciplines lay the knowledge that would put our country on track both economically and militarily. The new science courses, designed in large part by scientists themselves, were academically rigorous, and special efforts were made to attract exceptionally bright students to study science. Very few applications of science or links to the daily experiences of students were included. Instead, the courses focused on teaching abstract models of the natural world that had been organized by scientists. The preferred pedagogy was an inquiry approach, not to develop independence of thought as 19th century scientists had argued, but to mirror and thereby appreciate the way scientists themselves did their work. The main goals of the science community were the preparation of future scientists and a general public that would be knowledgeable enough to be sympathetic to the work of scientists.

This emphasis on disciplinary knowledge, separated from its everyday applications and intended to meet a perceived national need, marked a significant shift in science education in the post-war years. The broad study of science as a cultural force in preparation for informed and intelligent participation in a democratic society lost ground in the 1950s and 1960s to more sharply stated and more immediately practical aims. But by the1970s most science educators realized that it was pedagogically unwise to focus so heavily on the structure of the disciplines at the expense of the interests and developmental needs of learners. The relationship between science and society, along with the technological applications of science were once again promoted as goals of the science curriculum, and the term *scientific literacy* was now used to describe a broader study of science, especially in relation to its everyday applications—a *new progressivism*, as Diane Ravitch (1983) labeled it. Scientific literacy, as the relationship between science and society, gained additional prominence when the National Science Teachers Association (NSTA) identified it as the most important goal of science education in its position statement *School Science Education for the 1970s*. The scientifically literate person was one who "uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and with his environment" and "understands the interrelationships between science, technology and other facets of society, including social and economic development" (NSTA, 1971, pp. 47–48).

Throughout the 1970s and early 1980s scientific literacy came to be even more strongly identified with science in its social context. According to Gallagher (1971): "For future citizens in a democracy, understanding the interrelations of science, technology, and society may be as important as understanding the concepts and processes of science" (p. 337); and to Hurd (1970), the social context of science was the *only* appropriate context for teaching science for general education purposes. In 1982, the NSTA board of directors adopted a position statement entitled: *Science-Technology-Society: Science Education for the 1980s*. They said that the goal of science education was "to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making" (NSTA, 1982). In a 1982 article by Hofstein and Yager, the authors argued that science should be taught in relation to the personal needs of students and in relation to important aspects of contemporary life—such as chemistry in the context of agricultural production. Students should also be made aware of science as a social and cultural force and of the relationship between science and the rest of human knowledge. The aim of a science-technology-society (STS) curriculum was to give students knowledge about the science/society interface and the ability to make decisions about science-related social issues. To many STS advocates, the highest goal of an STS education was social action. Students should be able to identify science-related social issues, analyze the context in which the issues are played out in society, know the key individuals and groups involved in making decisions, investigate these science-related issues themselves, develop an action plan, and implement that plan where appropriate (Ramsey, 1989).

What made these proposals especially controversial was the suggestion that social issues, and not disciplinary content, should be used as organizing themes of science teaching. Earlier in the century William Heard Kilpatrick (1918) had introduced his "project method" in which socially relevant problems were the basis for organizing the curriculum, but except for this very popular innovation, science instruction had always been organized around science content regardless of the ultimate end that justified that content. The content was a given—the backbone of the science curriculum. The rest was built around that content whether the goal was to prepare future scientists, to give students the knowledge they would need to function successfully in modern society, or to make students aware of the importance of science as a cultural force.

The major concern of STS critics was that science would lose out to technological issues and social analysis since technology would become the starting point for virtually all problems that had contemporary interest at the science/society interface. As Kromhout and Good (1983) put it, under such an organization, social issues "do not convey any real understanding of the structural integrity of science" and "the basics simply do not get taught" (p. 649). In addition, because of the transient nature of science-based social problems students would have no stable basis for assessing issues that they might encounter in the future. In their opinion, the STS approach would be "counterproductive in the struggle for scientific literacy" (p. 649). Others were concerned that the goals of STS would not be attainable since most real-world issues involving science and technology are complex and require either more knowledge of science than can be expected of school students or a more mature understanding of relevant political and economic forces than they possess. In 1985, Good et al., in their response to STS advocates argued that science education is "the discipline devoted to discovering, developing, and evaluating improved methods and materials to teach science," which means teaching the knowledge of the physical world and the processes of seeking that knowledge (p. 140).

At the same time that the science education community was busy defining itself as a discipline and debating whether science education was primarily about science content or primarily about science-based social issues, the National Commission on Excellence in Education (1983) was issuing its report, *A Nation at Risk: The Imperative for Educational Reform*. The report argued that academic standards had fallen in the U.S. as evidenced by the embarrassingly low test scores of American youth, especially in math and science, and that this poor academic performance was the cause of our declining economic position in the world. The solution was to create a more rigorous academic curriculum for all students built around the basic academic subjects of English, mathematics, science, and social studies, as well as computer science and foreign languages. This would be accompanied by higher standards for all students and new means of assessment and accountability. In 1989, the National Governors Association along with President Bush endorsed the idea of establishing "clear national performance goals" as a way to raise standards in education to "make us internationally competitive" (U.S. Department of Education, 1991).

By the 1990s, most science educators were again talking about reforming science education. Articles dealing with reform were common in science education journals, and in 1992 an entire issue of the *Journal of Research in Science Teaching* was devoted to the subject. Reform to the Commission on Excellence in Education and the National Governor's Association meant higher standards, academic rigor, and accountability regarding content knowledge. Some educators linked this new standards-based reform movement to scientific literacy, but others were still committed to an STS-type of scientific literacy or at least to a program that, if content-based, included the social and cultural implications of science.

Published in 1989 by the American Association for the Advancement of Science (AAAS), Project 2061's *Science For All Americans* was one response to the call for standards-based reform. The purpose of the report was to clarify the goals of science education so that educators could begin to make scientific literacy attainable by all students. The need for reform was based on the conviction that the U.S. had not responded as quickly as other countries in preparing its young people for a world in which science and technology play such a large part, and now the U.S. needed to catch up. The process of reforming science education was to be comprehensive. It would include reaching a consensus on what things students needed to know to be scientifically literate, overhauling the educational system so that the importance of science was recognized by everyone, rewriting textbooks to match the new objectives, and preparing teachers with the skills needed to deliver appropriate instruction.

The learning outcomes that were suggested by Project 2061 included ‘‘being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes’’ (AAAS, 1989, pp. xvii–xviii). The common core of learning was selected on the basis of five criteria: (a) Does the content enhance one’s long-term employment prospects and the ability to make personal decisions? (b) does the content help one to ‘‘participate intelligently in making political decisions involving science and technology?’’ (c) does the content ‘‘present aspects of science, mathematics, and technology that are so important in human history or so pervasive in our culture that a general education would be incomplete without them?’’ (d) does the content help people ponder the enduring questions of human existence? (e) does the content enrich children’s lives at the present time regardless of what it may lead to in later life? (AAAS, 1989, pp. xix–xx).

Following soon after the publication of *Science For All Americans*, the National Academy of Sciences joined the effort to ensure that all students achieve scientific literacy. Begun in 1992, the *National Science Education Standards* (1996) is part of the U.S. government’s approach to education reform, an approach that involves setting national goals and the standards for meeting them. The objective of the *National Standards* was for all students to achieve scientific literacy by mastering a set of content standards. Students who met the content standards would be considered scientific literate. Five main assumptions justified the identification of the content standards: (a) ‘‘Everyone needs to use scientific information to make choices that arise everyday.’’ (b) ‘‘Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology.’’ (c) ‘‘Everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world.’’ (d) ‘‘More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the process of science contributes in an essential way to these skills.’’ (e) ‘‘To keep pace in global markets, the United States needs to have an equally capable citizenry’’ (National Research Council, 1996, pp. 1–2).

The *National Science Education Standards* were prepared by a wide range of individuals representing many constituencies (Collins, 1998). As might be expected from a document that was written by so many people, the definition of scientific literacy is broad and includes virtually all of the objectives of science education that have been identified over the years. And as can be seen in the following statement, the document aims high. The goals for science education are all-inclusive and formidable:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods

> used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (p. 22).

It is through clearly defined content standards that individuals are expected to accomplish these ambitious goals.

The most significant critic of such a broad and wide-ranging interpretation of scientific literacy has been Morris Shamos (1995). Shamos argues that efforts to achieve scientific literacy are futile and a waste of valuable resources. He says it is naïve to think that our students can learn to think like scientists. He says that the science-related social issues that might interest students often have very little science associated with them, and when they do it is at a level too complex for students to understand. He says that empowering individuals to make rational, independent judgments on science-related social issues is impractical. Instead, the most important thing is to give people access to responsible, expert advice on such issues.

What Shamos calls for is scientific awareness. In his proposed science program, content would be primarily about technology because technology is more useful and easier to grasp than the abstractions of science. Science teaching would include the nature of science and the processes of science, but very little science content itself. He says that this information about the nature of science is "more likely to be imprinted on a student's mind than a lot of isolated facts about nature" (p. 224). Science content should be used only to exemplify the nature of science and how science is practiced. But for the most part, the content of the curriculum would focus on technology itself-"transportation systems, weather systems, food and water supplies, and personal health and safety . . . " (p. 225)—technology as technology, not as a vehicle for learning science.

Under Shamos' proposal, scientific literacy would mean: "(a) having an awareness of how the science/technology enterprise works, (b) having the public feel comfortable with knowing what science is about, even though it may not know much about science, (c) having the public understand what can be expected from science, and (d) knowing how public opinion can best be heard in respect to the enterprise . . . " (p. 229). Shamos recognizes that "[t]his form of functional literacy is out of step with virtually all current efforts to achieve scientific literacy, as these efforts continue to focus on traditional science knowledge as the mark of a literate individual" (p. 229). He questions whether any science is needed at all except as a way of discussing the nature of science. The proposal is radical, especially in the way it de-emphasizes science knowledge in favor of technology in the curriculum, and in the way it removes responsibility for decision-making regarding science-based issues from the general public in favor of science experts.

Summary of the Goals of Science Teaching

Clearly, the history of science education suggests a variety of goals for teaching science and a wide range of meanings of scientific literacy. Before moving into a discussion of these goals and their implications for the teaching of science today, let me summarize them under the following nine statements.

1. Teaching and Learning About Science as a Cultural Force in the Modern World.
   Science merits a place in the curriculum on the basis of its importance as part of our intellectual heritage. It is a major part of our cultural experience that should be passed on from generation to generation. At least since the middle of the 19th century, proponents of science in the curriculum have argued that a well-informed, cultured,

literate individual must know something about the way the natural world works, about the scientific way of thinking, and about the effect of science on society. As a cultural study, it is appropriate to teach both the historical development of scientific ideas as well as current understandings in science.

2. Preparation for the World of Work.
   Science classes should give students the knowledge and skills that are useful in the world of work and that will enhance their long term employment prospects in a world where science and technology play such a large role. Science can provide students with an awareness of potential science-related careers and an opportunity for further study that may ultimately lead to a career as a scientist. The connection between the study of science and successful employment in technical fields is a point that has been made often since the 19th century.
3. Teaching and Learning About Science That Has Direct Application to Everyday Living.
   Knowledge of the way the natural world works is useful for everyday living. Science concepts and principles can be selected and taught in such a way that students see the applications of science in their daily lives. An understanding of such things as friction, light, electricity, heat, evaporation and condensation, plant nutrition, human anatomy and physiology, health and disease, photosynthesis, metabolism, and microbiology all contribute to a more informed and intelligent experience with the natural world. This has been a particular goal of science teaching at least since the early years of the 20th century and was a hallmark of education in the Progressive Era. This is not to be confused with a familiarity with technological applications which has also been a popular part of science teaching at various times during our history.
4. Teaching Students to be Informed Citizens.
   Science education can help develop informed citizens who are prepared to deal intelligently with science-related social issues, to vote responsibly, and to influence, where appropriate, policies related to the impact of science on society. Questions regarding genetically altered foods, lake source cooling, nuclear power plants, global warming, fluoridated water, and energy conservation confront us every day. Citizens need to have an awareness of these issues, an understanding of the way decisions regarding them are made in society, and the skills to investigate them on their own so that they can intelligently influence policy that affects them and their communities. The success of a democratic society depends on citizen participation of this kind.
5. Learning About Science as a Particular Way of Examining the Natural World.
   Science is a particular way of looking at the natural world. Students should be introduced to this way of thinking and learn how to use it themselves since it is such an important means of generating knowledge of our world. Students should also be able to recognize when the methods of science are used correctly by others and when they are not. The validity of data, the nature of evidence, objectivity and bias, tentativeness and uncertainty, and assumptions of regularity and unity in the natural world are all important concepts for students to be aware of. At the same time, students need to recognize the limits of science and the power of other ways of thinking that are also functional in the world. There are emotional and spiritual aspects to our existence that fall outside the realm of science, and the line between these and the nature of scientific thought needs to be drawn so that students can more fully comprehend what science is and what it is not.
6. Understanding Reports and Discussions of Science That Appear in the Popular Media.
   Science education should develop citizens who are able to critically follow reports and discussions about science that appear in the media and who can take part in conversations about science and science-related issues that are part of their daily experience. Individuals should be able to read and understand accounts of scientific discoveries,

follow discussions having to do with the ethics of science, and communicate with each other about what has been read or heard. Democratic principles require that everyone have a reasonable opportunity to develop the knowledge, intellectual skills, and interest to stay informed and to offer opinions about these issues where appropriate.

7. Learning About Science for its Aesthetic Appeal.
   The natural world has a strong aesthetic appeal and knowledge of it can offer a great deal of personal satisfaction to people. Students should be introduced to a study of natural history so that they can develop an appreciation for the great variety of plants and animals, the fascinating intricacies of animal behavior, the natural beauty found in geologic formations, and the mysteries held by sea and sky. Science classes can offer direct experience with these phenomena of nature with aesthetic considerations in mind. In the 19th century, when naturalistic studies were more common than they are today, science teaching was often justified on the basis of its search for truth and beauty in nature.
8. Preparing Citizens Who are Sympathetic to Science.
   Science education should advance the field of science itself by preparing a citizenry that has a sympathetic attitude toward science and a willingness to make use of scientific expertise. This goal appeared most prominently just after World War II in response to a growing antiscience attitude in the country. The 19th century faith in human progress and in science as a driving force behind that progress started to give way to doubts about science as a purely beneficent force. This goal is based on the assumption that science is, on balance, a force for good and that an awareness of science and the methods of science will lead to an appreciation of science on the part of students.
9. Understanding the Nature and Importance of Technology and the Relationship Between Technology and Science.
   Because of the practical importance of technology in the world and because of the close relationship that technology has had to science, science education should include a discussion of the nature of technology and the interdependence of science and technology, and it should include practice in the skills needed to plan, carry out, and evaluate technological designs. Technology is a legitimate part of the science curriculum because the subject matter deals with the physical world, technological design depends on scientific principles and parallels the methods of scientific inquiry, and the study of technology has the potential to be more immediately interesting and motivating to students since it deals with concrete objects from their everyday experience. Technology has been closely linked with science teaching throughout our educational history, but its role in the science curriculum has been somewhat uncertain. Through the first half of the 20th century, science teaching often focused on technological applications. In the late 1950s there was a concerted effort to move away from teaching about technology and toward teaching the principles of science. Only in the last few decades has the explicit integration of science with technology taken on such importance among science educators.

Implications for Contemporary Views of Scientific Literacy and Education Reform

What can we learn from this history of science education goals? Do they help us define scientific literacy? Do they help us understand the present reform movement and efforts to achieve scientific literacy? Is the reform movement motivated by a failure to meet one or more of these goals? Can a program in science education reasonably hope to accomplish all of these goals? If not, who should decide which goals will be pursued?

Scientific Literacy

A review of educational history shows us that scientific literacy is a general concept that has had, and continues to have, a wide variety of meanings. The one specific thing we can conclude is that scientific literacy has usually implied a broad and functional understanding of science for general education purposes and not preparation for specific scientific and technical careers. Scientific literacy defines what the public should know about science in order to live more effectively with respect to the natural world. Recently, the goals of science education have been accumulated into several comprehensive definitions of scientific literacy which, in turn, have become the stated outcome of science education reform. The all-inclusive nature of these definitions has led some to conclude that the object of reform is too vague and imprecise. According to Schauble: "Although the standards movements have been important in helping to develop a sense of good science learning and teaching, there are still far too many visions at play, ranging from science concepts, processes, the history of science, and the nature of science, to science, society, and technology" (National Center For Improving Student Learning & Achievement in Mathematics & Science, 1999, p. 9). Similarly, Bybee (1997) noted that: " . . . a clear definition of scientific literacy has not been generally accepted and used. Even the *National Science Education Standards*, a document that has to be one of the most complete statements of scientific literacy, is used selectively" (p. 63). The implication of these statements is either that we need a narrower definition of scientific literacy or that we need to do a better job of addressing all aspects of scientific literacy. I believe that both of these efforts would be futile. Instead we should accept the fact that scientific literacy is simply synonymous with the public's understanding of science and that this is necessarily a broad concept. We also need to realize that we cannot do everything. From a wide range of valuable knowledge and experiences, choices have to be made, and these choices will very likely vary from person to person and place to place.

Scientific Literacy, Standards-Based Reform, and the Current "Crisis" in Science Education

The tendency recently has been to define scientific literacy as a measurable outcome and to include everything possible in the definition. Since the U.S. government declared that American students should be number one in the world on tests of science knowledge by the year 2000, specific content standards have been identified by both state and federal agencies to define the science program for students so that everyone can become "scientifically literate." The question of whether scores on such tests are a legitimate measure of the state of science education in this country or whether our students' relatively poor performance on international tests should be taken as evidence of a national crisis has been asked by some, but for the most part, test results have been accepted as a valid indicator of the current state of affairs and sufficient justification for state and federal governments to exert more control over the direction the science education program should take.

There is some evidence, however, that things may not be as bad as has been suggested. The American economy has done extraordinarily well in the years since *A Nation at Risk* was published. Casual observation would suggest that most citizens get by quite well at work and at home even without thinking like scientists all of the time. In fact, people with extremely limited understanding of science function very well in society, many of them at the very top levels of their professions. In addition, the rate of new scientific and technological breakthroughs shows no sign of slowing down. One might even conclude from these observations that the level of understanding of science in our society, collectively anyway, is quite adequate. Audrey Champagne (1986) has said: ''The perception of crisis is partially a product of hyperbole employed in the many national education reports. ...The rhetoric notwithstanding, there is no reason to believe that the national security, economy, democratic way of life, and science prominence are threatened by the low level of scientific and mathematical literacy in the general population'' (quoted in Shamos, p. 5). In a paper presented at the First International Symposium on Scientific Literacy in Kiel, Germany, Jurgen Baumert said: ''Scientific literacy in the sense of being able to participate in a discourse on scientific and technological matters may well be an important educational goal or at least a promising educational vision but certainly it is not a fundamental cultural tool comparable to the ''three R's''' (Baumert, 1997, p. 167). And Nel Noddings (1992) has reminded us of the tendency we have to exaggerate the importance of our own subject matter. She said: ''...in point of fact, many people who are widely recognized as well educated exhibit the lacks so deplored by specific groups. One can play this game just so long before stumbling on one's own ignorance'' (p. 35). Fortunately we do not have to master all areas of knowledge to live successfully in our society, and awareness of this fact may free us to explore more creatively how to deal with questions of scientific literacy.

It is also important to recognize that standards-based reform does not come without its own problems and controversies. A number of people have observed that the standards movement has significantly reduced the amount of control that individual teachers and school districts have over their own science programs. Although the authors of the *National Standards* make it clear that the content standards do not constitute a curriculum and that implementation is the responsibility of individual teachers, they also say that scientific literacy is *defined* by the content standards and that none of the standards should be omitted. As William Kyle (1996) has said, the standards approach ''effectively strips each individual of the opportunity to be an active agent in the democratic processes through which educational policies and decisions are made'' (p. 1043). When local communities are not able to devise programs appropriate to their own needs, then mandated programs run the risk of being misused. As Kyle put it: ''In recent years, members of various professional organizations, including members of the science education community, have been caught up in the process of creating and promulgating academic standards, but they have not attended to the social, economic, and political agenda that engaged them in this process. Nor have they analyzed the terrain in which such standards will be utilized. Science educators should not be surprised, then, in the likely event that such standards are used in unintended ways'' (p. 1044).

The negative effects of the present emphasis on standards and high-stakes testing were also pointed out by Wood (1988). He looked at the effectiveness of state-mandated standards testing as a way to improve students' scientific literacy. He found that standards testing ''...constrains and routinizes the teachers' behavior, causing them to violate their own standards of good teaching. They feel pressured to 'get through' the materials so students will score well on tests. The classroom interaction is structured in such a way as to inhibit students from asking questions of their own. As a result, students' opportunity to express curiosity and inquiry—central processes in scientific thinking—are constrained. These unintended consequences of the implemented state policy, instead of improving science teaching and learning, continue to reduce science instruction to the literal comprehension of isolated facts and skills'' (p. 631). In addition, ''teachers feel they have lost what they enjoyed most about teaching, a sense of inner satisfaction and control of their work. They have become technicians rather than professionals'' (p. 640). In New York State, where for many years student success in college preparatory courses has been determined by scores on state-mandated Regents exams, many teachers use the Regents exams to structure their syllabus and to justify to students why they must learn certain content (Howe, 1999). The daily mantra in these classrooms is: “Because it will be on the Regents exam.” Student teachers, who are unfamiliar with the New York State system of testing when they begin their student teaching, are astonished at the hold the exams have on teachers and how the exams limit what can be done in the classroom. And teachers are often reluctant to work with student teachers who are prone to falling behind or wanting to experiment with methods that take them off the Regents track and timetable.

Standards As Guideposts, Not Blueprints

Standards are certainly not without merit. In fact, most of the goals that science educators have been pursuing over the past century are clearly elaborated in current reform documents. But as National Council of Teachers of Mathematics (NCTM) Board of Directors member Francis Fennel noted in reference to the NCTM standards in mathematics: “It would be my hope that readers of the Standards are caused to reflect on the mathematics they teach, how they teach it, and how it is assessed. If this would happen, the mission would be accomplished. The Standards (all of them) are guideposts, not blueprints” (In Wheelock, 1996, p. 3). Standards give everyone involved in education something to look at, a basis on which to compare their own ideas. They are statements of what prominent educators think is important at a particular point in time. They are not universal or timeless truths. As Project 2061 says: “*Science for All Americans* represents the informed thinking of the science, mathematics, and technology communities as nearly as such a thing can be ascertained. ...The process cannot be said to have led to the only plausible set of recommendations on the education in science, mathematics, and technology for all children, but it certainly yielded recommendations in which we can have confidence” (1989, p. xxiii). Standards will rightly motivate some to change what they are doing and to align their teaching with what they see as valuable. But not everyone will see wisdom in them and will prefer to develop their own approaches and philosophies. In an article that appeared in the *Harvard Education Letter*, the experience of James Randolph, Science Supervisor for the Chattanooga Public Schools, is recounted. Randolph “explains that the standards first became ‘real’ to him only when he had a chance to analyze a set of lesson plans with his peers. At first, he says, he thought the plans were ‘pretty good’; but after critiquing them in relation to the standards, he realized ‘they were not reaching a very high cognitive level.’ Randolph notes, ‘Teachers need to sit down with each other and give each other a critical review of what they’re doing in relation to the standards. That’s when eyes can be opened...” (In Wheelock, 1996, p. 3).

Historically, it has been the role of science education leaders to offer comprehensive suggestions for the teaching of science in the schools—the what, the why, and the how of science teaching. And it has been the job of professionals in the schools, both teachers and administrators, to take these suggestions seriously and to use them as they see fit. We know from past experience that to force teachers to use these ideas uncritically is to doom them to failure. Administrators, students, parents, and especially teachers need to feel invested in change. They need to believe that what they are doing is worth doing. The strength of the American educational system is in the freedom that local school districts have to experiment with curriculum and with pedagogy. Classroom teachers, in particular, believe deeply in their right to use their professional judgment in making decisions about what to teach and how to teach it. History has shown how important the creative energy of individual teachers is for educational innovation. In 1986 Robert Yager reported on the results of the NSTA’s Search for Excellence Program, a program that identified exemplary course designs across the country. According to Yager: “In every case, [the] ‘design’ could be traced to a single person—a person with an idea, a vision. ...In no case was the exemplary program an adoption of some national/commercial program. ...In all cases there was time and energy expended into developing a unique program for the particular school district. In every case this situation resulted in a strong sense of ownership, strong pride in what had occurred and what had been developed'' (Yager, 1986, p. 213).

The Many Routes to Scientific Literacy

We have seen from this historical analysis that scientific literacy is about the public's understanding of science. That understanding is open-ended and ever-changing. It is organic, not static. Because its parameters are so broad, there is no way to say when it has been achieved. There can be no test of scientific literacy because there is no body of knowledge that can legitimately define it. To create one is to create an illusion. The goal of scientific literacy is achieved when the public learns about science and about the scientific enterprise in the many different ways that that can be accomplished. Obviously, and perhaps unfortunately, choices need to be made. We might want to do everything, but it goes without saying that if students spend time designing and evaluating technological devices, there is less time to investigate science-related social issues like global warming or the effects of acid rain on plant life. If students spend time studying the history of science, there is less time to explore career opportunities. Those who have responsibility for making decisions about what to teach must determine the importance of each of these goals and the extent that each will be used to guide their science program. Will students focus on the *science* that applies to their everyday lives or the *technology* that applies to their everyday lives? Will they learn what it means to critically read accounts of science that appear in the daily press? Will they view science study as a road to a career or as an important intellectual activity? Certainly there is overlap among these goals. Reading about science in the daily newspaper may very well give students information about possible careers, the motivation to influence policies that affect them and their communities, knowledge of the relationship between science and technology, and a greater understanding of science as a way of thinking about the natural world. But that does not mean that we can do everything. If time is simply distributed among all of the various goals, the resulting program may be too disconnected and fragmented. Schools and teachers need to set their priorities and look for connections between the goals so that the science program can meet as many of them as possible while at the same time providing an education that is coherent, substantive, and intellectually satisfying.

The Best Route to Scientific Literacy

With such a wide range of goals to select from and such a rich array of activities that can be organized to accomplish them, is it possible to prescribe one best route to scientific literacy? Each of the nine goals identified here presents its own rationale for conceptualizing scientific literacy. There are many ways to be scientifically literate. As this historical review has shown us, there is no single right way to teach science, and within some fairly broad limits it probably doesn't matter much which path is taken. The important thing is that students learn something that they will find interesting so that they will continue to study science both formally and informally in the future. Scientific literacy is primarily about the level of scientific understanding that exists in the adult population, something that changes and grows over time. It is really not about what students know when they are in school—although what they learn in school will certainly affect their attitudes about science and their desire to continue to learn in the future. Few if any students can be said to be ''scientifically literate'' upon graduation from high school in any meaningful sense of the word. At best, students have been introduced to science and the issues that science raises in society, and they like science and care enough about it to stay informed as adults.

Given that their objective is to give students an introduction to the world of science so they may pursue it throughout their lifetimes, local school districts should decide what to teach and how to teach it based on student interest, the expertise of teachers, and other local considerations. Professional educators should provide leadership, offer suggestions about curriculum and pedagogy, and prepare instructional materials that can be used to address the various goals of science teaching. And teachers should act according to the highest standards of their profession. They should utilize established principles of student learning, treat students with dignity and respect, use class time wisely and productively, and choose content that moves students toward the attainment of reasonable and justifiable outcomes in science education. There are things the public might rightly learn about science that will enable them to live more intelligent lives in a world where science and technology have such importance, and there are reasons for teaching these things that are consistent with our democratic and intellectual values, but the range of this knowledge is enormous and artificially narrowing it has more negative effects than positive. What we need in the science education community are honest dialogues about what that knowledge is, not so students can get higher scores on international tests, but so that individual teachers and local school districts have the rich sources of information they need to make intelligent choices. Similarly, accountability should not be a function of student test scores but rather the established norms of professional behavior for each participating group—teachers, administrators, and leaders in science education.

Ultimately what we want is a public that finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society. Not everyone will develop the same knowledge and skill, but feeling that one can continue to learn and participate are key elements to life in a democratic society. Some will find the study of science compelling enough to pursue scientific careers; others will provide leadership in their communities regarding science-based social issues. The important thing is that everyone should have an opportunity to learn enough so they will not be left out of this dimension of our modern experience.

How Much Content to Teach

We are still left with a very important question about content: How do we deal with the facts and principles of science? With few exceptions, science content has formed the backbone of the science curriculum since its inception. This will most likely continue to be the case in the future since most of the goals of science that we have examined require a basic understanding of the natural world. The challenge is to find a reasonable balance between science content and other important goals of science teaching. We know that the vast majority of what goes on in science classrooms today centers on conveying information about science, mainly through the use of textbooks. There is a common perception on the part of teachers that they have to “cover” a certain amount of content. Pressure from standards, benchmarks, and high-stakes testing will only perpetuate that attitude. We also know that the link between specific facts and principles of science and any of the stated goals of science education is weak. Although all of these goals depend to some extent on being familiar with the facts and principles of science, exactly what content is needed is impossible to specify. For this reason, efforts at scientific literacy will be much more successful if we remove the burden of requiring all students to achieve mastery of a specific body of content. Then local teachers can feel free to experiment with alternative goals and approaches that might be more interesting and appropriate for them and their students.

Even without the pressure of standards, benchmarks, and high-stakes testing, the facts and principles of science will in most cases continue to form the basis of the science curriculum because this content provides an organizational structure that is understandable and recognizable. But teachers should also be free to balance and integrate the content of science that they select with the other goals that they choose to pursue. Should teachers feel that they have to provide comprehensive summaries of the fields of chemistry, biology, physics, and earth science to high school students, overview courses that teach the organization of each of these disciplines as such? Certainly not for general education purposes. Although there is a great deal that students and teachers will find useful and interesting from the field of biology, there is little reason to teach a comprehensive overview of the field itself. For some students, this approach might be reasonably interesting and satisfying, but there is too much else that is worth doing in a biology class and it is not clear that a systematic overview of a particular science discipline merits the time that has to be devoted to it to accomplish student comprehension. Teachers should be free to organize their science courses around as many of the goals of science education as they feel comfortable with, selecting the content that makes the most sense to them. There is nothing wrong with teachers teaching as much scientific content as they wish to, as long as that content is meaningful and important to them and is taught in a way that students are able to comprehend and appreciate, not as lifeless abstractions.

Conclusion

There is considerable evidence that, although well-intentioned, standards-based education has the potential to inhibit the autonomy and creativity of classroom teachers and their students. With broadly stated goals and freedom from benchmarking and high-stakes testing, local school districts and individual teachers would have more flexibility to choose their own science content and teachers could teach to their own strengths and to the interests of their students. In addition, they would be free to experiment creatively with pedagogical approaches that are unlikely within the present standards-based educational environment.

As Millar and Osborne (1998) suggest in *Beyond 2000*: "...the critical principle that must guide any assessment framework adopted for the science curriculum . . . must be that assessment should exert a positive and benign influence on the teaching and learning of science" (p. 25). The same can be said for content standards. The influence of standards-based education must be positive and helpful. If standards give teachers a clearer sense of what is important and guide the development of curriculum in positive ways, they are beneficial. But if they create a learning environment that is excessively limiting, then both content and assessment standards need to be rethought as an appropriate vehicle for pursuing the goal of scientific literacy for all.

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