SCIENCE EDUCATION

For over a hundred years traditional and progressive ideals have competed with each other in science education. To traditionalists, education is a process of transmitting knowledge. Traditionalists value discipline, hard work, and intellectual rigor. Progressives value student interest and opportunities for students to construct meaning out of their own experiences and the experiences of others. In a progressive classroom there is a greater reliance on active participation in which students are engaged physically and intellectually in a learning task. Progressive educators often criticize what they see as passivity on the part of students in traditional classrooms. Progressive teachers are more likely to share decision making with students so that students develop responsibility for their behavior and for their learning. Progressive educators find the testing that dominates traditional education inadequate for measuring the complexity of learning that they value in progressive classrooms. In science education, these differences are played out in debates over child-centered vs. teacher-centered teaching; disciplinary knowledge vs. societal applications; and discovery vs. receptivereception learning.

SCIENCE TEACHING IN THE PROGRESSIVE ERA

During the first half of the twentieth century, science education was often justified explicitly in terms of its societal value. Education in general sought to address pressing problems that the rapidly growing country faced—issues related to immigration, urbanization, public health, and other socially based problems. The trend in all of education was toward practical work for students, both because it would be more interesting to them and because practical studies could address issues having importance in society.

John Dewey, who is generally regarded as the father of progressive education, argued that citizens in a democratic society should be inquirers regarding the nature of their physical and social environments and active participants in the construction of society. They should ask questions and have the resources to find answers to those questions, independent of external authority. To prepare them for life in a democratic society, formal education should give students the skills and dispositions to formulate questions that were significant and meaningful to them. And because there is a shared, collaborative aspect to life in a democratic society, students also should develop a capacity for cooperative group inquiry.

In one of the first formal statements on the importance of engaging students in the solution of real world problems, the science committee of the National Education Association's Commission on the Reorganization of Secondary

Education (CRSE) said that "the unit of instruction, instead of consisting of certain sections or pages from the textbook, or of a formal laboratory exercise, should consist of a definite question, proposition, problem, or project, set up by the class or by the teacher (National Education Association, 1920, p. 52). In the same report, the CRSE's physics committee said the laboratory should be a place for genuine inquiry rather than as a place to "verify laws." Many science educators during the early years of the twentieth century thought that the laboratory should be used as a place where students could work on problems of interest to them that had social, as well as scientific, relevance and importance. Numerous studies were conducted to determine if students learned more from laboratory experiences than from teacher-led demonstrations and if laboratory instruction could be cost effective. Researchers also investigated whether the laboratory could precede or must follow classroom instruction because, when following a truly inductive approach, laboratory work should be exploratory and therefore should come first. But this often created scheduling problems that could not be easily overcome.

THE AGE OF REFORM

By the 1950s, a growing number of scientists, science educators, and industry leaders were becoming concerned about the practical orientation of many science courses and what they saw as an over-emphasis on social relevance and student interest. To them, the appropriate role of schools was the training of disciplined intelligence and the transmission of the cultural heritage, not teaching the practical applications of science. Science also had become important for national security and economic development and, in such an environment, the appropriate goals of science teaching should include preparing students to become scientists and developing a public that was sympathetic to science.

In the mid 1950s, the National Research Council (NRC) and the National Science Foundation (NSF), as well as various professional organizations in science and mathematics, developed plans to revise the science and mathematics curriculum to accomplish these new goals. The interest in reform was stimulated by questions about the adequacy of the country's technical expertise, especially vis-à-vis the Soviet Union in the years immediately following World War II. It was also asked if progressive education, which had enjoyed the support of the education community for most of the first half of the twentieth century, was adequate to meet the new challenges involved in preparing individuals for work in technical fields. Many argued that progressive education was anti-intellectual and was failing to transmit the cultural heritage to the youth of this country.

Largely because of U.S. postwar tensions with the Soviet Union, President Truman in 1946 established the President's Scientific Research Board to study and report on the country's research and development activities and on science training programs in the country. The board 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). In a 1953 report published by the U.S. Office of Education, a committee of the American Association for the Advancement of Science (AAAS) said: "The present struggle for the very existence of our freedoms causes the need for the improvement of the instruction in science and mathematics to become increasingly important" (U.S. Office of Education, 1953, p. 1).

By the time the Soviets launched Sputnik, the first Earth orbiting satellite, in 1957, the country was prepared for the reforms that many scientists and mathematicians had been recommending. In this high-stakes environment, mastery of the disciplines was seen as the way to achieve the intellectual rigor that critics said was missing. This was to be accomplished in part by deliberately excluding most of the existing social and technological applications from the science courses and focusing instead on the organized disciplines themselves. This emphasis on the structure of the disciplines was in direct opposition to the conventional wisdom of science educators in the first half of the twentieth century, who said that subject matter should always be taught in connection with its social and cultural meanings, especially its relevance to the lives of the students themselves.

Leaders of the movement instead thought that science should be taught as it was practiced by scientists to give it the most authenticity possible. Students should learn the fundamental ideas of the disciplines and they should learn those ideas through investigations that mirrored the way scientists themselves generated new knowledge. Although most often referred to as inquiry teaching, the various approaches to teaching and learning that were modeled after scientific inquiry were also described as discovery learning and inductive teaching.

The individual most often associated with the reform movement's ideas about scientific inquiry was Joseph Schwab. To Schwab, scientific content and process were intimately connected and inseparable. An accurate representation of science required that the principles of science be taught in relation to the methods that generated that knowledge. Content should not stand alone and neither should method. The key difference between this kind of science teaching and earlier approaches was that it was linked even more closely to actual scientific inquiry as performed by scientists. Learning the structure of the disciplines meant learning the disciplines in the way that scientists understood them, including both the content and the modes of inquiry that were used. Whether learned through the laboratory or through a textbook, the conclusions of science and the evidence that supported those conclusions would go hand-in-hand. For future scientists this would give them the advantage of an early introduction to the logic and methods of their chosen field of work, and for those who would choose other careers, it would give them a truthful and accurate picture of the nature of science and an appreciation for the methods of science. Public understanding and appreciation were of critical importance in a political environment where scientific research had come to depend so much on public funding. The scientific community realized that it needed the support of the public to continue its work.

Reformers wanted students to understand the interconnectedness of the content and methods of the science disciplines. In general, most reformers thought that it was more effective for students to conduct their own investigations than to study what scientists themselves had done, because it would promote deeper intellectual engagement with the content and more meaningful understanding of the nature of scientific inquiry. It was also thought that students would be more likely to understand and retain science concepts learned in this way and that the approach would be more motivating because they would be asking genuine questions about the world.

Although probably unintended, linking scientific method so closely with disciplinary content had the effect of making it less accessible to the general public. Whereas early twentieth-century educators promoted scientific method as a systematic approach that could be applied to a wide range of scientific and social problems that were within the range of the general population to investigate, mid-century reformers saw scientific inquiry as discipline-specific. Thus the science courses that were developed during this period were inaccessible to many students because of their conceptual difficulty and theoretical sophistication, and because they failed to address the social world of students, their personal interests, or practical concerns. In a major shift from the approach taken during the first half of the twentieth century, student investigations became much more closely tied to the logically organized science content and much less to phenomena in their everyday social experience.

SCIENCE LITERACY

By the early 1970s, the educational focus began to shift away from disciplinary study and toward preparing an enlightened citizenry that would have the skills to function effectively in a scientific world. Although not without its critics, science education for social relevance and democratic participation regained much of the popularity it had held during the first half of the twentieth century. The idea of science education for a broad and functional understanding of science came to be referred to as science literacy. This neoprogressive attitude could be seen in newly developed programs in environmental education, values education, humanistic education, and in a science, technology, and society (STS) movement, which focused on the societal applications of science.

In this new intellectual environment, science knowledge and the processes of science were aimed at questions that people encountered in their everyday lives. Science was to be practical and useful to people. Science teaching was to focus on science as a social and cultural force, on the relationship between science and technology, and on preparing citizens who could use scientific knowledge and processes to solve problems they encountered in everyday living. A position statement on scientific literacy from the National Science Teachers Association (1971) said: "The major goal of science education is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action" (p. 47). Issues that students would investigate might include endangered species, genetic engineering, global warming, nuclear waste disposal, or air and water pollution.

Of less interest was the study of science as a structured discipline. The discipline-based approaches of the 1960s treated scientific inquiry as fundamentally linked to the disciplines and not as a general method that could be applied to a wide range of scientific and societal-based problems. In those reform-based curricula of the 1960s, students practiced scientific inquiry to acquire an understanding of the disciplines. In the more socially oriented period that followed, student activities were not aimed so much at the basic principles and concepts of science as they were toward science-related issues that had social relevance. The inquiries they engaged in were often more appropriately called problem-solving, or personal and social decision-making activities. In this new intellectual environment, the logic of science and the scientific way of thinking were important for solving practical problems that citizens faced in their everyday lives. Science teaching was no longer to take place just in the classroom and the laboratory but also in the communities where students lived. Students were to learn skills of data collection, interpretation, and communication of results by investigating science-related social issues directly.

Critics of an issues-oriented approach to science teaching said that such an approach lacked substance and did not convey a sense of the structural integrity of science. They also questioned whether it was appropriate for the methods of science to be taught and learned in the context of science-related social problems. Reformers of the 1960s had insisted that scientific inquiry should be intimately connected to the content of the science disciplines. The question was not whether the methods of science *could be* generalized to the study of social problems but whether this is the kind of activity students in our science classes should engage in. Dewey and other early twentieth-century educators spoke of general method that had broad application to a wide range of problems that could be studied in the science classroom. Neoprogressives of the 1970s and 1980s agreed with that position, whereas discipline-based reformers of the 1950s and 1960s did not.

THE PAST TWO DECADES

By the late 1980s, goal statements in science education included an understanding of science content and process for their cultural, disciplinary, and intellectual value, and for their application to everyday decision making and problem solving. Rather than settling on a single approach to science teaching, the tendency was to combine these goals under the general heading of science literacy.

Published in 1989, Project 2061's *Science for All Americans* (AAAS, 1989) was an attempt to reach consensus on what students should know to be scientifically literate in the broadest possible sense. The common core of learning was selected on the basis of five criteria: (1) Does the content enhance one's long-term employment prospects and the ability to make personal decisions? (2) Does the content help one to "participate intelligently in making political decisions involving science and technology?" (3) 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?" (4) Does the content help people ponder the enduring questions of human existence? (5) Does the content enrich children's lives at the present time regardless of what it may lead to in later life (pp. xix–xx)? Both the goals of personal intellectual development and responsible citizenship were included in these statements.

The authors of *Science for All Americans* also recommended that science teaching be consistent with the nature of scientific inquiry. Accordingly: "Students need to get acquainted with the things around them—including devices, organisms, materials, shapes, and numbers—and to observe them, collect them, handle them, describe them, become puzzled by them, ask questions about them, argue about them, and then try to find answers to their questions. . . . Students should be given problems . . . that require them to decide what evidence is relevant and to offer their own interpretation of what the evidence means" (p. 201). Furthermore: "Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty" (p. xiv).

Following soon after the publication of *Science for All Americans,* the National Research Council (NRC) published the *National Science Education Standards* (NRC, 1996). The goals for school science identified by the *National Standards* were to prepare students who would be able to:

- experience the richness and excitement of knowing about and understanding the natural world
- use appropriate scientific processes and principles in making personal decisions
- engage intelligently in public discourse and debate about matters of scientific and technological concern
- increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers (p. 13)

As is *Science for All Americans,* the *National Science Education Standards* is an all-encompassing document that includes goals of personal intellectual development as well as responsible citizenship. In the *Standards,* inquiry teaching is presented as a pedagogical approach that is consistent with the nature of science and that provides useful skills for investigating problems of personal interest or social concern. In both *Science for All Americans* and the *National Science Education Standards,* there is recognition of the importance of science teaching for portraying scientific investigation accurately, for contributing to one's personal intellectual development, and for offering a way of thinking that could be used in the solution of everyday problems.

SUMMARY

In the early twentieth century, students were encouraged to apply general methods of scientific inquiry to problems of social concern. By the 1950s and 1960s the focus had shifted away from practical and applied problem solving to a rigorous intellectual treatment of the individual scientific disciplines. This was in part for purposes of personal intellectual development but mainly so that personnel needs could be met in technical and scientific fields and so that lay people would have sufficient understanding of science to offer their support for scientific research. Within a relatively short period of time, however, science educators revisited the idea that it was important for students to acquire skills in scientific problem solving so that they could investigate issues of personal and social concern and be active, contributing citizens in a democratic society. Finally, by century's end, goal statements in science education recognized the validity of a wide range of approaches to science teaching that had been made over the years—those that recognized the value of the scientific disciplines and the applications of scientific knowledge to issues of concern to the broader society.

Further Reading: American Association for the Advancement of Science, 1989, *Science for all Americans,* New York: Oxford University Press; Dewey, J., 1916, *Democracy and education,* New York: McMillan; National Education Association, 1920, *Reorganization of science in secondary schools: A report of the commission on the reorganization of secondary education* (U.S. Bureau of Education Bulletin No. 20), Washington, DC: U.S. Government Printing Office; National Research Council, 1996, *National science education standards,* Washington, DC: National Academy Press; National Science Teachers Association, 1971, NSTA position statement on school science education for the 70's, *The Science Teacher, 38,* 46–51; National Society for the Study of Education, 1932, *A program for teaching science,* Chicago: University of Chicago Press; President's Scientific Research Board, 1947, *Science and public policy,* Washington, DC: U.S. Government Printing Office; Schwab, J., P. F. Brandwein, 1962, The teaching of science as enquiry, in *The teaching of science*, Cambridge, MA: Harvard University Press; U.S. Office of Education, 1953, *Education for the talented in mathematics and science,* Washington, DC: U.S. Government Printing Office.

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