CHAPTER 2

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HISTORICAL PERSPECTIVES ON INQUIRY TEACHING IN SCHOOLS

INTRODUCTION

There is a tendency to treat inquiry teaching as if it were something new and innovative, a recently invented approach to science teaching. But in one form or another, inquiry teaching has been part of the educational landscape at least since the middle of the nineteenth century (Bybee and DeBoer, 1994; DeBoer, 2001). The purpose of this chapter is to review the history of inquiry teaching to clarify the various meanings that this pedagogical approach has had. The term "scientific inquiry" will be used to refer to the general process of investigation that scientists use as they attempt to answer questions about the natural world, and the term "inquiry teaching" will be used to refer to pedagogical approaches that model aspects of scientific inquiry. Inquiry teaching mirrors scientific inquiry by emphasizing student questioning, investigation, and problem solving. Just as scientists conduct their inquiries and investigations in the laboratory, at field sites, in the library, and in discussion with colleagues, students engage in similar activities in inquiry-based classrooms.

Science, as practiced by scientists and as studied in classrooms, is both process and product. It is both a body of richly interconnected observations and interpretations regarding the natural world, and it is a set of procedures and logical rules that guide those observations and interpretations. The same is true of classroom science. Science can be studied for its interconnected concepts, but science can also be practiced in the classroom in ways similar to those used by scientists themselves. Inquiry teaching uses the general processes of scientific inquiry as its teaching methodology. And just as scientists seek to understand the natural world through their investigations, students in inquiry classrooms try to advance their understanding of the principles and methods of science through theirs. It is important to note, however, that inquiry teaching does not require students to behave exactly as scientists do. Scientific inquiry is simply a metaphor for what goes on in an inquiry-based classroom.

In addition to being a model for teaching science, the processes of science themselves can be an object of study, and learning activities can be explicitly organized to teach the nature of science as process. For example, in studying how science is done, students might learn how to control variables in an experimental design; or they might learn what is required to make claims regarding one variable influencing or causing a change in another variable; or they might learn about the

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importance of mathematics in the development of scientific knowledge. These are all examples of scientific inquiry being an object of study. The fact that the term "inquiry teaching" is used in different ways has sometimes led to confusion about what inquiry teaching is. Does inquiry teaching suggest a pedagogy that is modeled after the investigative nature of science or does it suggest a content to be studied, i.e., the nature of science? In this chapter, the discussion will be limited to inquiry teaching as pedagogy. When scientific inquiry becomes an object of study it falls under the category of the nature of science (NOS), a topic that is being dealt with by other contributors to this volume.

It should also be noted that inquiry teaching and teaching *about* inquiry do not necessarily go hand-in-hand. Just because scientific inquiry is the thing being studied does not mean that inquiry teaching is being practiced. In fact, the nature of scientific inquiry can be taught in very non inquiry-oriented ways. Teachers can provide students with examples of scientific investigations, explain the logic of these studies, and show students how evidence was used to answer the question being raised in the inquiry. Teachers can introduce the language of scientific inquiry by describing the differences between theories, hypotheses, evidence, conclusions, observations, and inferences. All of these things can be accomplished using traditional, teacher-directed methods. Of course, teachers can also introduce the methods of science through inquiry-oriented activities, and students can develop an understanding of the processes of science by engaging in actual scientific inquiries. The important thing to realize is that inquiry teaching and teaching about scientific inquiry are not necessarily one and the same, and using the term *inquiry teaching* for both of them often leads to confusion.

The Nature of Scientific Inquiry

Before beginning this historical overview of inquiry teaching, it is useful to briefly review some of the more general characteristics of scientific inquiry that are related to inquiry teaching as well as some of the reasons inquiry teaching is used as a pedagogical approach. Although it is impossible to provide an exact definition of scientific inquiry or elaborate to any significant degree the nature of science here, it is at least worthwhile to state some of the more general aspects of scientific inquiry, especially as they relate to inquiry teaching. In its most essential form, scientific inquiry is what scientists do when they investigate the natural world. According to the *National Science Education Standards* (National Research Council, 1996): "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p. 23). Inquiry means looking into or investigating something. It is a search, an attempt to find out. According to St. John (1999) "…inquiry entails the perception of depth. It has the quality of penetrating into something, going deeper, so you can see what you haven't been able to see before. When you begin an inquiry, you are deliberately setting out to search for what you don't know" (p. 109). How that search is conducted, the rules concerning what constitutes evidence, the logic that is applied in drawing conclusions, the special techniques that are used to gather information—all this is developed by a community of practicing scientists and described by philosophers of science. At one end of the spectrum, using an inquiry approach to teaching may simply mean modeling the inquisitive, questioning nature of science, and at the other it may mean learning how to apply very detailed procedures and protocols of a particular field of science.

Scientific Inquiry as a Model for Pedagogy

There are many purposes that can be served by having students model scientific inquiry either in a general or in a more focused way. One purpose might be the preparation of future scientists. Prospective scientists need to engage in scientific investigations and gain experience as scientists-in-training. They need to become increasingly familiar with the methodologies used in the various disciplines, with appropriate equipment, and with ways of taking and recording measurements. They need to learn how to collect data, how to analyze it, and how to test it against their predictions. They need to learn what constitutes evidence that will support or refute their predictions. Laboratories, as well as natural field sites, are places where students as potential future scientists can collect data that is important to their investigations. How early this initiation into the work of scientists should begin and how extensive early training in the actual practice of science should be are questions that are open to debate and discussion.

A second purpose that can be served by having students model scientific inquiry is the development of citizens who may not become scientists themselves but who will be autonomous, independent thinkers. As informed citizens they should have an inquisitive and questioning attitude and a faith in their ability to ask important questions and seek answers to those questions, be able to solve problems by drawing together necessary resources, and work alone or with others on projects to see them through to completion. What is needed pedagogically is an open and supportive learning environment where students receive assistance in generating questions that are interesting and important to them and in designing productive strategies for investigating those questions. Student inquiries and investigations may be laboratory based or archival, and they can focus on science-related societal issues or on the natural world itself. Because the main purpose is to encourage autonomy and independence of thought, students need to be given as much practice as possible in generating their own questions and in devising their own strategies for answering those questions. Inquisitive students can find answers to their questions through conversations with their teacher, from print and electronic resources, or from investigations of the natural world. The goal is to develop citizens with an inquiring attitude and the skills needed to search for answers to questions they feel are important.

Inquiry teaching can also be used as a pedagogical tool for accomplishing other goals. For example, it has long been recognized that the direct, hands-on experience that accompanies scientific investigations is an important way to strengthen not only an understanding of the methods of science, but also the content and principles of science. Hands-on experiences provide students with a deeper understanding of the way the world works as well as a way to personally confirm and verify the principles of science. Scientific investigations put the learner in direct contact with the natural world so that the phenomenon in question becomes more real to the student. Scientific inquiry, especially when it involves direct hands-on investigations, has often been promoted as a way to support an understanding of scientific content.

Another way that inquiry teaching can be used indirectly to support other educational goals is by taking advantage of inquiry teaching's motivational power. There is a psychological justification for having students actively involved in hands-on inquiries and investigations known as self-determination theory (Deci, 1975; Deci & Ryan, 1985). According to this theory, individuals have a need for competence, autonomy, and relatedness. When these needs are met, students' intrinsic motivation is increased and their efforts are more effective and meaningful. Inquiry-oriented classrooms give students more control over their own learning. When students can select questions that are interesting to them, when they can be active in the design of investigations, and when they can interact with their classmates in doing the work and in reporting and discussing the results, then they develop a greater sense of control and autonomy, and the activity becomes more enjoyable to them. In addition, children and adolescents have social instincts that are satisfied by working collaboratively with their classmates on problems of mutual interest, and the physical activity that usually accompanies scientific investigations adds to the intrinsic satisfaction that students experience when compared to more passive reception-style learning.

Given the range of benefits that can come from inquiry teaching, it is no surprise that educational leaders have forcefully promoted it as a valuable part of the science program over the years. What is surprising is that inquiry teaching has not met with more success. (See Hurd, et al., 1980; Welch, Klopfer, Aikenhead, and Robinson, 1981; Costenson and Lawson, 1986; and Bybee, 2000). Some have blamed this failure on a misunderstanding of the purposes of inquiry teaching or a misconception concerning exactly what inquiry teaching is, especially given that there are so many ways that students can engage in inquiry activities and so many different reasons that justify its use. Perhaps the reason inquiry teaching has been so difficult to implement is because educators have not paid enough attention to the basic purposes which they want inquiry-oriented classroom activities to serve or the outcomes they wish to achieve. The modest success that inquiry teaching has enjoyed may be due to a failure by educators to pay careful attention to their own educational goals and a failure to employ just those strategies that are most suited to their own particular situations. There is no single method of inquiry teaching (NRC, 2000). The exact way that scientific inquiry is used as a guide to classroom teaching depends on the specific goals and purposes a teacher has. Inquiry teaching is a broad array of approaches that has as its most general characteristic a problem to be solved or a question to be answered. If science educators were clearer about their goals and felt confident in choosing those aspects of inquiry teaching that were best suited to those goals, the many and varied methods of inquiry teaching would be much more widely and successfully used.

But perhaps the most important reason why inquiry teaching has not enjoyed more success is because its essential nature is often misunderstood. Successful inquiry teaching demands a significant intellectual commitment by students and a depth of engagement in the subject they are studying. An inquiry—a question or problem or issue to be investigated—should provide focus, direction, and purpose to a student's work. It should provide the drive and motivation needed for students to move toward deeper understanding of the content. Unfortunately, inquiry teaching has too often been misunderstood as simply having students do things, with students performing activities as if the activity were an end in itself. Activities without intellectual substance are pointless. Keeping students busy with hands-on activities is not enough. When inquiry teaching is identified with low-level activity-based teaching, it is bound to fail.

Finally, it is important to remember that inquiry teaching is not the only way to teach science or even the best way in all circumstances. To use inquiry-based approaches is not a black-and-white, either-or decision. For one thing, classroom activity can vary according to the degree of direction that the teacher provides and the degree of independence the student is given. If the questions students are investigating and the methods they employ are too highly prescribed by the teacher, then the activities may not lead to a genuine desire on the part of students to find something out, and student engagement may suffer. On the other hand, if the teaching is too open-ended, there is the possibility that students will become lost in their investigations and learn little. Questions of how much inquiry teaching and what type of inquiry teaching are appropriate must be answered by individual teachers in the context of the goals they have for their own students, and always with an eye toward the student's level of intellectual engagement. The variety of ways that inquiry teaching can be used to advance student learning are discussed in the National Research Council's publication, *Inquiry and the National Science Education Standards* (NRC, 2000).

HISTORICAL PERSPECTIVES

In what follows a number of the arguments that have been made over the years to justify incorporating aspects of scientific inquiry in the classroom are presented. With this as background, it should be easier for educators to choose those reasons that make the most sense to them and to have their students conduct inquiries and investigations in the ways that are most appropriate for their particular situations. Certainly it is easy to be confused by the interconnectedness of the various goals and approaches related to scientific inquiry, but that challenge can be met by a careful examination of each of these goals and by being careful not to be misled by what are often exaggerated claims of the benefits of inquiry in the classroom.

Nineteenth-Century Efforts to Incorporate Scientific Inquiry into the Classroom

Before the middle of the nineteenth century, the school curriculum was dominated by classical studies. It was not until scientists in Europe and the United States began promoting the value of science for its contribution to intellectual development that it became a regular part of the school curriculum. They argued that science was fundamentally different from the other school subjects because it offered practice in inductive logic. Mathematics and grammar, which were mainstays of the school curriculum, begin with rules and clear logical inferences that follow from those rules. Inductive science, on the other hand, begins with specific detailed observations and moves toward general principles. Scientific knowledge depends on the empirical observations upon which the generalizations are built. To justify its entry into the school curriculum, science was presented as something different from the other subjects already being taught. What was special about science was its basis in observation and inductive reasoning. That meant that students had to learn how to observe the natural world and draw conclusions from those observations. The study of science was justified largely on the basis of its ability to develop the intellect in ways that were fundamentally different from what was usually done in schools. This form of intellectual development was thought to be especially important because science was taking on an increasingly significant role in the modern world and because life in a modern democratic society depended on the independence of mind that was characteristic of science.

A key advocate for science was the prominent British biologist, Thomas Huxley (1825-1895). Huxley, who served as president of the Royal Society, was a staunch defender of Darwinism, popularized science, and a frequent lecturer and essayist on many subjects including the importance of science in the school curriculum.

According to Huxley:

> The great peculiarity of scientific training, that in virtue of which it cannot be replaced by any other discipline whatsoever, is this bringing of the mind directly into contact with fact, and practicing the intellect in the completes form of induction; that is to say, in drawing conclusions from particular facts made known by immediate observation of Nature. ...In teaching him botany, he must handle the plants and dissect the flowers for himself; in teaching him physics and chemistry, you must not be solicitous to fill him with information, but you must be careful that what he learns he knows of his own knowledge. ...And especially, tell him that it is his duty to doubt until he is compelled, by the absolute authority of Nature, to believe that which is written in books. (Huxley, 1899, p. 126-127)

This view of how science should be taught became the justification for the emerging science laboratory. Laboratory instruction and teaching science as a process of investigation received support from another prominent nineteenth century British intellectual, Herbert Spencer (1820-1903). Spencer was primarily a social scientist and philosopher but he also published a two-volume work on biology (Spencer, 1864, 1867). Spencer introduced the term "survival of the fittest" and was best known for applying theories of evolution to the study of society. His most lasting contribution to the field of education was his essay "What Knowledge Is of Most Worth" (Spencer, 1864) in which he argued for the inclusion of science in the school curriculum. According to Spencer, the laboratory should provide the opportunity for students to develop a clear conception of natural phenomena, something that could not be accomplished through book learning alone. In addition to giving precise mental images to go along with the verbal abstractions found in books, the laboratory also provided practice in drawing conclusions from observations, what Spencer called "judgment":

> No extent of acquaintance with the meaning of words can give the power of forming correct inferences respecting causes and effects. The constant habit of drawing conclusions from data, and then of verifying those conclusions by observation and experiment, can alone give the power of judgment correctly. And that it necessitates this habit is one of the immense advantages of science. ...By science, constant appeal is made to individual reason. Its truths are not accepted upon authority alone; but all are at liberty to test them—nay in many cases, the pupil is required to think out his own conclusions. Every step in a scientific investigation is submitted to his judgment. He is not asked to admit it without seeing it to be true. (Spencer, 1864, pp. 88-89)

Spencer believed that placing students in direct contact with natural objects and phenomena and having them draw their own conclusions from those observations had other advantages as well. The generalizations that were discovered by students through their own inquiries would be remembered longer and the process of inquiry would make the learner independent of the authority of the teacher. According to Spencer: "Children should be led to make their own investigations, and to draw their own inferences. They should be *told* as little as possible, and induced to *discover* as much as possible" (pp. 124-125).

Inductive approaches to teaching were also supported by Johann Friedrich Herbart (1776-1841), the German philosopher and educator whose work became popular in the United States toward the end of the nineteenth century. He and his followers in the U.S. (DeGarmo, 1895) believed that the best way for students to develop an understanding of new concepts was by having them discover the relationships between phenomena on their own and by having teachers relate new concepts to the experiences of the learner. Like Spencer, he felt that independent discovery would produce a fuller and more meaningful understanding of concepts. Herbart also believed that inductive teaching was greatly aided by informal conversation among students and teachers. Conversation would give the student an opportunity "to test and to change the accidental union of his thoughts, to multiply the links of connection, and to assimilate, after his own fashion, what he has learned" (Herbart, 1835/1901, p. 56).

Support for the laboratory and for student investigations to develop inductive reasoning abilities also came from Charles Eliot, a chemist and president of Harvard University from 1869 to 1895. In addition to introducing laboratory study into the college curriculum at Harvard, Eliot was also a vigorous advocate for science education in the schools. According to Eliot, science teaching in both schools and colleges should "develop and discipline those powers of the mind by which science has been created and is daily nourished—the powers of observation, the inductive faculty, the sober imagination, the sincere and proportionate judgment" (Eliot, 1898, p. 6).

The laboratory allowed students to observe the world and reason into the nature of things on their own. The direct and independent contact with the natural world that could be accomplished in the laboratory would provide a clear and unbiased view of the world that could not be achieved through book study, and learning how to conduct independent investigations would free individuals from the authority of both the text and the teacher. The specific skills that were needed to accomplish these goals included training of the sense organs, practice in organizing and comparing sense impressions and drawing inferences from them, training in making accurate records of these sense impressions in written form or in memory, and training in the ability to formulate clear logical statements about the conclusions drawn from observation (Eliot, 1898, p. 322).

Eliot's leadership in getting science taught inductively was most evident when he became chair of the prestigious Committee of Ten of the National Education Association (NEA) in 1892. Each of the science groups that were represented there strongly supported the use of the laboratory in science teaching. The purpose of laboratory instruction was to develop the students' reasoning skills and their ability to acquire knowledge independently. Students would come to understand "the reason of things." They would observe changes and processes as well as static facts and they would examine cause and effect relationships (NEA, 1893, p. 213). At all times teachers would keep in mind that the topics they were teaching were for the purpose of exercising the students' personal intellectual powers. The important thing was that students should not be taught dogmatically. They needed to be taught inductively so that they could develop their own ways of seeking knowledge.

Despite these efforts to introduce inquiry-based teaching into the classroom, especially by means of the laboratory, textbook-based methods remained the dominant mode of teaching at the turn of the century. According to one New York State report: "While the laboratory method is almost universally approved by the science teachers, the text-book method prevails in the schools, to such an extent that laboratory work is incidental, inefficient, and in many cases excluded altogether" (University of the State of New York, 1900, p. 706). In a book published in 1902 by Smith and Hall, the authors argued against the textbook approach to school science teaching and offered specific suggestions on how the science program could be strengthened. Smith, speaking for chemistry, felt that the high school course should be laboratory-based, utilize as much independent discovery by students as possible, focus on a meaningful understanding of the facts and principles of chemistry, and be oriented toward practical applications in everyday life.

Studying chemistry would help students develop their ability to think, including their ability to compare, to discriminate, and to reason inductively. The laboratory would be used both as a place for the verification of chemical principles and as a place for independent discovery. Verification labs and practical illustrations would "make the understanding of the law more vivid, the recollection of its content more lasting, and, above all, to show...what the nature of its experimental basis is" (Smith & Hall, 1902, p. 106). The most important feature of the laboratory, however, was that it could be used to place the student in the role of discoverer. Smith cited Armstrong (1898) as the founder of the *heuristic method* in England, an approach where no books or directions from the teacher were used and students raised their own questions as they examined materials that they were given.

But Smith also recognized the impracticality of having students spend all their time in independent discovery activities because of the additional time required, and so he opted for teacher-guided inquiry as the preferred approach. Under this method the teacher raised the questions, provided the materials, offered suggestions about what to look for next, and asked leading questions to move students along the path of discovery. Students still made careful observations and reasoned from those observations, but they did not have the same degree of independence that characterized the heuristic method.

Hall, speaking for physics, likewise offered a range of inquiry-based teaching methods and analyzed the advantages and disadvantages of each. The first he called the true discovery or heuristic approach in which students were given the maximum amount of freedom to explore the natural world on their own. As did Smith, Hall felt that this method required too much time and that students were often not well enough equipped to draw anything but the most superficial conclusions from their investigations. The second method he called the verification approach in which students confirmed scientific facts or principles in the laboratory. Although the approach helped strengthen students' understanding of the concepts of science, Hall felt that the method led to unscientific attitudes because students were too tempted to look for the right answer or consider only the evidence that supported the expected result. The third method was the guided discovery approach, what Hall called inquiry. Using this method, students did not have to discover everything on their own but they did have to seek solutions to questions for which they did not have the answers. In this way they would still be acting as genuine investigators and not simply confirming something that was already known to them.

Inquiry Teaching During the First Half of the Twentieth Century

During the latter half of the nineteenth century the goals of science education were expressed mainly in terms of individual personal development. These goals included having a familiarity with the facts and principles of science essential to living in a scientific age and the mental discipline that comes from practice in inductive reasoning. Being able to draw conclusions independently from evidence would free individuals from a dependence on the intellectual authority of others, something that would serve them well as citizens in a democratic society. But during the first half of the twentieth century, these personal benefits began to take on less importance and science education came to be justified more explicitly in terms of its societal value. Education took on a more pragmatic bent as it sought to address the pressing problems that the rapidly growing country faced--issues related to immigration, urbanization, public health, and other socially-based problems. There was also a growing belief in the importance of child-centered approaches to education that was due in large part to the influence of John Dewey (1902/1990). The trend in all of education was toward more practical work for students both because it would be more interesting to them and because practical studies could address issues having importance in society.

In this changing atmosphere, inquiry-style teaching was now seen as a way to develop the abilities needed to solve specific problems having social significance rather than as a way to discipline the mind through inductive reasoning. Throughout the first half of the twentieth century, Dewey 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 democracy, formal education needed to give students the skills and dispositions to formulate questions that were significant and meaningful to them, and since there is a shared, collaborative aspect to life in a democratic society, students also needed to develop a capacity for cooperative group inquiry.

Regarding science instruction, Dewey said:

> ...students should be introduced to scientific subject-matter and be initiated into its facts and laws through acquaintance with everyday social applications. Adherence to this method Is not only the most direct avenue to understanding of science itself but as the pupils grow more mature it is also the surest road to the understanding of the economic and industrial problems of present society. (Dewey, 1938, p. 80)

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) issued a report that said:

> 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. Such a problem demands for its solution recalling facts already known, acquiring new information, formulating and testing hypotheses, and reasoning, both inductive and deductive, in order to arrive at correct generalizations and conclusions. This method calls for an organization in which information, experimental work, and methods of attack, all are organized with reference to their bearings on the solution of the problem. (National Education Association, 1920, p. 52)

Similarly, the physics committee of the CRSE addressed the importance of the laboratory as a place for genuine inquiry rather than as a place to "verify laws," to "fix principles in mind," to "acquire skills in making measurements," or to "learn to be accurate observers."

> With a project or a problem as the unit of instruction and its solution as the motive for work, the pupil should go to the laboratory to find out by experiment some facts that are essential to the solution of his problem.... With such a motive he is more nearly in the situation of the real scientist who is working on a problem of original investigation. He is getting real practice in the use of the scientific method. (National Education Association, 1920, p. 53)

Numerous practical questions also arose around laboratory instruction besides those having to do with its aims and purposes. Studies were conducted to determine if students learned more from laboratory experiences than from teacher-led demonstrations and if laboratory instruction was cost effective. There was also the question of whether the laboratory should precede or follow classroom instruction. In a truly inductive approach, laboratory work is exploratory and therefore should come first, but this often created scheduling problems that could not be easily overcome.

In 1932, the Thirty-First Yearbook Committee of the National Society for the Study of Education (NSSE) analyzed the reasons why the laboratory might be used in science teaching. They identified seven purposes of laboratory work: (1) To develop simple laboratory techniques. (2) To establish for oneself the principles of science already established and accepted. (3) To gain familiarity with the objects of science. (4) To provide illustrations to develop a better understanding of the principles of science. (5) To provide training in the scientific method. (6) To provide scientific training in the solution of the pupil's own problems. (7) To study science problems that the student might have (NSSE, 1932, p. 270).

The committee felt that the best use of the laboratory was for the solution of the students' own science problems. The committee said: "It is the very essence of the original reason for the existence of every laboratory..." (NSSE, 1932, pp. 271-272). But not everyone felt so positively about that aspect of laboratory work. Francis Curtis (NSSE, 1932) felt that the interpretation of data was generally beyond the abilities of most students and he felt that genuine scientific investigations were of little use to most students because these activities focused on the practices of actual research scientists, an unlikely career choice for most students.

During the first half of the twentieth century, there continued to be a strong focus on teaching students the scientific way of thinking. For the most part this was accomplished in the context of problems and projects that were interesting to students and that had social relevance. Because science had been introduced into the school curriculum by nineteenth-century scientists as an inductive, laboratory-based study, much of the discussion during the early part of the twentieth century was on the appropriate use that should be made of the laboratory. Should it be used to strengthen concepts, to verify scientific principles, to teach laboratory techniques, or to provide a place for students to engage in genuine investigations? Many science educators during the early years of the twentieth century felt that the laboratory should be used as a place where students could work on problems of interest to them and that had social, as well as scientific, relevance and importance.

Inquiry Teaching in the Age of Reform

By the 1950s a growing number of scientists, science educators, and industry leaders began to argue that science education had lost its academic rigor and had become intellectually soft. They were concerned about the applied, practical orientation of many science courses and what they saw as an over-emphasis on social relevance and student interest. They said that the primary job of the schools should be the training of disciplined intelligence and the transmission of the cultural heritage. Education had become too student centered and too concerned with practical applications. What was needed was a return to disciplinary rigor. This focus on rigor and the structure of the disciplines became the thrust of a curriculum reform movement that began in the 1950s and lasted throughout the 1960s and into the 1970s. The attention paid to students' intellectual development was reminiscent of a similar thrust during the late nineteenth century, although the reasons given for it were now different. In the nineteenth century the concern was for personal intellectual development, but in the 1950s it was to prepare individuals who might become scientists and to develop a public that was sympathetic to science. Science had become important for national security and economic development. Science teaching was no longer a casual activity. To many, a strong educational program in science was essential for maintaining the security of the country.

Leaders of this movement believed science should be taught as it was practiced by scientists in order to give it the most authenticity possible. Students should be taught the fundamental ideas of the disciplines and they should be taught those ideas through investigations that mirrored the way scientists themselves generated new knowledge. Scientific inquiry would be the model for classroom teaching and learning. Although they were most often referred to as inquiry teaching, other terms were used to describe pedagogical approaches that were modeled after scientific inquiry as well. These included discovery learning, inductive teaching, problem solving, and project learning.

The key difference between this version of inquiry teaching and earlier versions was that it was linked even more closely to actual scientific inquiry in order to make it as intellectually rigorous possible. 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 the general public 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.

The individual most often associated with the reform movement's notion of scientific inquiry was Joseph Schwab. To Schwab (1962), scientific content and processes were intimately connected and inseparable. An accurate representation of science required that the principles of science be taught in the context of the evidence on which they were based. Content should be taught in relation to the methods that generated that knowledge. Content could not stand alone and neither could method. In many ways this was the same argument that was made by nineteenth-century scientists who said that students should learn how to reason about science and have opportunities to develop good judgment regarding scientific facts. They should be given practice in drawing their own conclusions from observations and they should verify their conclusions by experiment. Nineteenth-century students were taught not just the conclusions of science but also the reasoning that led to those conclusions. The difference between the nineteenth-century view and what Schwab was proposing is that nineteenth-century educators were focused on the personal intellectual development of the students. Schwab's concern was different. His concern was for the welfare of the nation. In his words:

> A hundred fifty years ago, science was an ornament of a leisurely society. It was still mainly pursued by amateurs and gentlemen. It was a gratuitous activity of the enquiring intellect, an end pursued for its own sake....It is so no longer. Industrial democracy has made science the foundation of national power and productivity. (Schwab, 1962, p. 18)

According to Schwab, the nation faced three important needs. The first was to increase the number of scientists. The second was to develop competent political leaders who could develop policy agendas based on an understanding of science. The third was to educate a public that was sympathetic to the tentativeness of scientific knowledge and the fluid nature of scientific investigation so they would support basic research in the sciences. It was not Schwab's primary objective that students should be able to conduct scientific inquiries themselves but rather that they should understand the nature of scientific inquiry as a dynamic and ongoing activity and that they should understand scientific content in the context of the evidence upon which it was based. As he put it:

> Of the two components—science as enquiry and the activity of enquiring—it is the former which should be given first priority as the objective of science teaching in the secondary school. It is a view of science as enquiry which is necessary if we are to develop the informed public which our national need urgently demands. (1962, p. 72)

Despite the clear distinction that Schwab made between inquiry as content and inquiry as pedagogy, the two were often confused. Reformers wanted students to understand the interconnectedness of the contents and methods of the science disciplines in as intellectually rigorous a way as possible. They believed that this understanding of science as both process and product could be accomplished both through inquiry-based teaching methods and through non-inquiry-based methods. Students might, for example, be led step-by-step through the historical development of a particular scientific idea. They might be shown the way a problem was formulated and solved, how data was collected and analyzed, and how conclusions were drawn. In this way the logic of discovery could be explained directly to the students. But students might also be asked to formulate their own problems and solutions and learn about inquiry by practicing inquiry.

Although Schwab and other educational leaders recognized the usefulness of direct teaching about scientific discovery, they believed that it was more important to have students conduct their own investigations because it promoted deeper intellectual engagement with the content and more meaningful understanding of the nature of scientific inquiry. One such inquiry-based method that Schwab proposed had students analyze historical papers that scientists had written so they could study the logic of discovery and the fluid nature of scientific inquiry. This kind of historical investigation was just one of many inquiry-based methodologies he proposed. He also suggested that students could be asked to analyze their textbook and their teachers' lectures and to always put themselves in the position of evaluating the validity of the claims of others and the adequacy of the evidence they presented. Discussion was seen as a particularly powerful inquiry-based teaching strategy because it required an active engagement with the content and provided a richer and more varied set of ideas to work with rather than the opinions of a single expert.

It needs to be emphasized, however, that Schwab's main interest was not in preparing students to be inquirers into the nature of the physical world. His goal was for students to have the fullest and most complete understanding of science possible, both its content and its methods, so that they would have a firm foundation for further science study if they were to become scientists, and so that they would be sympathetic to the scientific enterprise if they were not destined for science careers. The primary purpose of performing investigations in the classroom was to understand more fully the nature of science, not to learn the skills necessary to conduct scientific work themselves. And it was certainly not his intention that students learn how to apply the methods of science to problems of practical or social concern. This way of conceptualizing inquiry teaching was clearly in opposition to the more functional and practical approaches proposed earlier in the century.

Although probably unintended, linking method so closely with disciplinary content also had the effect of privileging expert knowledge and making scientific method less accessible to the general public. Whereas early twentieth century educators promoted scientific method as something that could be applied to a wide range of scientific and social problems that were within the range of almost anyone to investigate, mid-century reformers saw scientific inquiry as discipline-specific. To really understand scientific method required a deep understanding of the discipline in question. Thus the science courses that were developed during this period were inaccessible to many students because of their conceptual difficulty and theoretical sophistication, and 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 so to phenomena in their everyday experience.

Science Literacy

By the early 1970s, however, the educational focus began to shift from disciplinary study to 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 importance 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 neo-progressive attitude was also represented in newly developed programs in environmental education, values education, humanistic education, and in the science, technology, and society (STS) movement.

In this new intellectual environment, science knowledge and the processes of science were to be used to answer questions that people encountered in their everyday lives. Science was to be practical and useful to people. Science teaching would 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 (Hurd, 1970). 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 students would investigate might include endangered species, genetic engineering, global warming, nuclear waste disposal, or air and water pollution.

Students would conduct independent investigations and learn to apply the methods of science to problems of personal and societal concern. 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 socially-based problems. Students practiced scientific inquiry to acquire an understanding of the disciplines that was as intellectually complete and authentic as possible. In the more socially oriented period that followed, student inquiries 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 still important but they were important for solving practical problems that citizens faced in their everyday lives. Science teaching would no longer take place just in the classroom and the laboratory but also in the communities where students lived.

Because democratic citizenship implies social responsibility, education for citizenship meant that students needed to acquire the knowledge and skills that would enable them to analyze science-related social issues and to evaluate alternative solutions for resolving them. They would learn skills of data collection, interpretation, and communication of results by investigating science-related social issues directly (Ramsey, 1997). Some suggested that social responsibility implied using science to transform society. Hofstein and Yager said: "The use of societal issues as organizers for the science curriculum of the 80s has many advantages. First of all, it helps delineate content that can be useful for improving the quality of life..." (1982, p. 542). According to Ramsay (1997), "learners would develop a sense of purpose and control about their use of science knowledge and skills in the democratic process of social change..." (p. 310). And pedagogically it was felt that the sense of purpose and control that comes with problem ownership would prove motivating to students.

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, and because society's problems are always changing, investigating today's problems would not provide students with the knowledge or skills needed to deal with problems in the future (Kromhout and Good, 1983). There was also the question of whether it was appropriate to teach scientific inquiry in the context of science-related social problems. Doing so implied that the methods of science were general and had applicability to a broad range of problems, but mid-century reformers had insisted that scientific inquiry was 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 inquiry we want students in our science classes to 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. Neo-progressives of the 1970s and 1980s agreed with that position, whereas discipline-based reformers of the 1950s and 1960s did not.

Inquiry Teaching Today

By the late 1980s, goal statements in science education included an understanding of science content for its cultural, disciplinary, and intellectual value and for its application to everyday decision-making and problem-solving. And whether it was used to develop students' abilities to solve problems that were personally and socially relevant, for personal intellectual development, or as a motivational device, inquiry teaching had a role to play. Rather than settling on a single approach to science teaching, however, the tendency was to combine all of 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 a 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*). The goals of personal intellectual development and responsible citizenship are both included in these statements.

When it came to inquiry teaching, the authors of *Science For All Americans* recommended that science teaching should 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). The goal of inquiry teaching is to "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) contributed to the advancement of scientific literacy through publication of 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; and

- increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers. (p. 13)

The *National Science Education Standards* is an all-encompassing document that includes a wide range of content and process goals. An important feature of the *National Standards* is its focus on inquiry teaching. In the *National Standards* and the follow-up volume, *Inquiry and the National Science Education Standards* (NRC, 2000), inquiry teaching is described as "a set of interrelated processes by which...students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a right understanding of concepts, principles, models, and theories." It is recommended that "...designers of curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students will then learn science in a way that reflects how science actually works" (NRC, 1996, p. 214).

In the *Standards*, inquiry teaching is 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 was recognition of the importance of inquiry teaching for giving an accurate portrayal of scientific investigation, for contributing to one's personal intellectual development, and for offering a way of thinking that would be used in the solution of everyday problems.

But perhaps the primary justification for using inquiry teaching, particularly in the NRC's publications, is the argument that inquiry teaching is a more effective teaching strategy, that it is more engaging, and that students learn more from inquiry-based approaches to teaching. Much of *Inquiry and the National Science Education Standards* is devoted to a discussion of psychological arguments about inquiry teaching's efficacy, especially as a way to learn the concepts and principles of science. The authors say, for example, that "students are much more likely to understand and retain the concepts that they have learned this way" (p. xiii). They say that the *Standards* "seek to promote curriculum, instruction, and assessment models that enable teachers to build on children's natural, human inquisitiveness" (p. 6). They point out that research on people who have expertise in a field shows that these people have "inquiry procedures available that help them solve new problems efficiently and effectively" (p. 116). Finally they argue that as students "develop their abilities to question, reason, and think critically about scientific phenomena, they take increasing control of their own learning" (p. 120) which is motivating to them.

SUMMARY

Inquiry teaching in science classrooms has had a long and varied history. The rationale for using inquiry teaching has changed according to the educational philosophy of its supporters, but regardless of the arguments used to justify its use, inquiry teaching has remained a significant aspect of science education throughout the years. In the nineteenth century, as science was becoming a regular part of the school curriculum, scientific investigation in the classroom was seen as a way to develop students' inductive reasoning skills, something that the other school subjects could not do. 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 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 unqualified support for scientific research. Within a relatively short period of time, however, there was a revisiting of the idea that it was important for students to acquire skills in scientific inquiry so that they could solve problems 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 arguments favoring inquiry teaching that had been made over the years. These documents also provided new support to inquiry teaching by pointing out the congruence between scientific inquiry and effective student-centered teaching. In addition, a developing focus on constructivist pedagogy was consistent with important aspects of inquiry teaching.

Although the essence of inquiry teaching is not always easy to grasp and implementation has proven difficult, educational leaders have consistently recognized the potential of inquiry-based pedagogies to enhance student learning and to provide students with the skills needed to function effectively in a democratic society. It is important to recognize, however, that there is no single way to think about what inquiry teaching is and no single argument that justifies its use. It is a multifaceted approach to teaching that can be used to accomplish many differing purposes. Understanding the variety of ways that inquiry teaching can be used and the range of meanings it can have should aid educators in moving toward pedagogies that are effective and motivating to students, and that deepen their intellectual engagement with scientific ideas and that give them a better sense of what science is.

REFERENCES

American Association for the Advancement of Science (1989). *Science for all Americans*. New York: Oxford University Press.

Armstrong, H. (1898). On the heuristic method. *Special reports on educational subjects, vol. II*. London: Eyre & Spottiswood.

Bybee, R. (2000). Teaching science as inquiry. In J. Minstrell & E. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 20-46). Washington, DC: AAAS.

Bybee, R. & DeBoer, G. (1994). Research on goals for the science curriculum. In D. Gabel (Ed.), *Handbook on research on teaching and learning* (pp. 357-387). New York: Macmillan.

Costenson, K. & Lawson, A. (1986). Why isn't inquiry used in more classrooms? *The American Biology Teacher, 48* (3): 150-158.

DeBoer, G. (1991). *A history of ideas in science education: implications for practice*. New York: Teachers College Press.

Deci, E. (1975). *Intrinsic motivation*. New York: Plenum Press.

Deci, E. & Ryan, R. (1987). The support of autonomy and the control of behavior. *Journal of Personality and Social Psychology, 53* (6), 1024-1037.

DeGarmo, C. (1895). Herbart and the Herbartians. New York: Charles Scribner's Sons.

Dewey, J. (1990). *The school and society; the child and the curriculum*. Chicago, Illinois: The University of Chicago Press. (Original work published in 1902.)

Dewey, J. (1938). Experience and education. New York: Collier.

Eliot, C. (1898). *Educational reform*. New York: Century.

Herbart, J. (1901). *Outlines of educational doctrine* (C. DeGarmo, Ed.; A. Lange, Trans.). New York: Macmillan. (Original work published in 1835).

Hofstein, A. & Yager, R. (1982). Societal issues as organizers for science education in the 80s. *School Science and Mathematics, 82*, 539-547.

Hurd, P. (1970). *New directions in teaching secondary school science*. Chicago: Rand McNally.

Hurd, P., Bybee, R., Kahle, J., & Yager, R. (1980). Biology education in secondary schools of the United States. *The American Biology Teacher, 42* (7): 388-410.

Huxley, T. (1899). *Science and education*. New York: Appleton.

Kromhout, R. & Good, R. (1983). Beware of societal issues as organizers for science education. *School Science and Mathematics, 83*, 647-650.

National Education Association (1893). *Report of the committee on secondary school studies*. Washington, D.C.: U.S. Government Printing Office.

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, D.C.: U.S. Government Printing Office.

National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council (2000). *Inquiry and the 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: Thirty-first yearbook of the NSSE*. Chicago: University of Chicago Press.

Ramsey, J. (1997). STS issue instruction: Meeting the goal of social responsibility in a context of scientific literacy. In W. Graber & C. Bolte (Eds.), *Scientific literacy* (pp. 305-330). Kiel, Germany: Institute for Science Education.

St. John, M. (1999). The value of knowing what you do not know. In *Foundations (Volume 2) Inquiry: thoughts, views, and strategies for the K-5 classroom* (pp. 109-111). Arlington, VA: The National Science Foundation.

Schwab, J. (1962). The teaching of science as enquiry. In *The teaching of science* (pp. 1-103). Cambridge, MA: Harvard University Press.

Smith, A. & Hall, E. (1902). *The teaching of chemistry and physics in the secondary school*. New York: Longmans, Green.

Spencer, H. (1864). *Education: Intellectual, moral, and physical*. New York: Appleton.

Spencer, H. (1864, 1867). *Principles of biology*, 2 vols. London: Williams and Norgate.

University of the State of New York (1900). *Report of the committee of nine* (High School Report, Bulletin No. 7). Albany: University of the State of New York Press.

Welch, W., Klopfer, L., Aikenhead, G., & Robinson, J. (1981). The role of inquiry in science education: Analysis and recommendations. *Science Education, 65*, 33-50.