4

Teaching Science as Inquiry

The goal of teaching science as inquiry has a long history in American education. Although terms used to describe this aim have varied, the goal has been a priority since the 1800s. The way inquiry has been interpreted by policy makers, included in programs, and implemented by teachers has an equally long and varied history. The emphasis on inquiry as a goal of science education programs has included teaching strategies and learning outcomes, the former being the dominant interpretation by policy makers, curriculum developers, and classroom teachers.

Now, in the early years of the 21st century, the science education community must support science teachers as they respond to contemporary scientific, social, and economic challenges that require a new emphasis on teaching science as inquiry.

A Brief History to 1957

In the United States, science itself had little recognition prior to the mid-19th century: "[F]aith was at least as important as empirical data and in many instances it dominated the practices of science. This faith was often a complex mixture of Christian theology, idealism, and entrenched traditions" (Stedman 1987, p. 657). So it is no surprise that discussions of science education, including scientific inquiry and laboratory work, were absent as well (Bybee and DeBoer 1993; DeBoer 1991).

The public's interest in science and the scientific method increased in the late 19th century. Most likely because of scientific progress in physics, chemistry, and biology and technological advances associated with the industrial revolution, some Americans proposed that scientific thinking was needed to help the public address everyday problems. As reported by historian John Rudolph

(2005), "One eminent scientist in 1884 argued for a thorough reorganization of higher education around the teaching of the scientific method" (p. 346).

During this period, several individuals brought science into discussions of school and college curricula. Louis Agassiz at Harvard University provided an early example of teaching science as inquiry "when he invited students to visit his lab, study specimens firsthand, and thereby gain direct knowledge. He directed field trips to the countryside and seashore, encouraged students to make their own collections, and conducted instruction by correspondence with specimen collectors around the country" (Stedman 1987, p. 660).

The Harvard List of Experiments

Charles W. Eliot, a chemist and president of Harvard, articulated the need for science and established the laboratory as an essential part of science instruction in American high schools (Stedman 1987). Eliot asked the physics department at Harvard to develop an entrance requirement that emphasized the laboratory as part of high school physics courses. The prestige of Harvard all but assured the list of experiments would become a part of high school science programs. By 1889, the list was published as "Harvard University Descriptive List of Elementary Physical Experiments" and covered a wide range of physics topics.

The "Harvard List of Experiments" became more than a laboratory notebook and entrance requirement. It first became the basis for a physics course and later for a national course in physics that was part of the newly formed College Entrance Examination Board's requirement. The use of this descriptive list of experiments and influences of scientists was furthered by the National Education Association's Committee of Ten report. The widespread acceptance of this report became the defacto first voluntary national standards for science, and the roles of laboratory experiences and inquiry as teaching methods were clearly part of the standards.

The Committee of Ten

In the United States, the laboratory method moved from broad goal statements, particularly for high school education, to the recommendations of policy in the 1893 NEA "Report of the Committee of Ten on Secondary School Studies." The report underscored the importance of science for all students, whether they intended to go to college or enter the workforce. Of significance to this chapter is that the report underscored the "absolute necessity of laboratory work" (NEA 1894, p. 27).

The prominent role of science in the Committee of Ten report undoubtedly was influenced generally by the industrial revolution and specifically by two scientists, both college presidents, Charles W. Eliot (Harvard) and Ira Remsen (Johns Hopkins).

The degree to which the laboratory became a part of high school science programs no doubt varied. Those schools that fed prominent universities tried to meet the standards; those without resources maintained the historic and cost-effective lecture-recitation approach. The significant increase in student enrollment beginning in the late 1800s (circa 1886–1900) contributed to the reluctance of school administrators and science teachers to embrace the laboratory approach to science. This lack of support for the laboratory, in particular the Harvard list of experiments, was aided by scientists such as C. R. Mann and organizations such as the Central Association for Science Mathematics Teaching (CASMT). The plea was for greater personal and social relevance of physics by revising the Harvard list to include greater emphasis on qualitative laboratory work (Rudolph 2005).

This shift represented the emergence of two perspectives on the goals of science education in general and the role of the laboratory in particular. These ideologies are evident and still in conflict in contemporary forms. The conflict and apparent opposition is between utility and inquiry. The apparent view that these goals are incompatible continues to this day.

The Influence of John Dewey

In 1910, John Dewey published a small book titled *How We Think*. In this book, Dewey introduced what he called a *complete act of thought*. According to Dewey, a complete act of thought consisted of five logically distinct steps: (i) a felt difficulty; (ii) its location and definition; (iii) suggestions of possible solutions; (iv) development by reasoning of the bearings of the suggestion; and (v) further observation and experiment, leading to its acceptance or rejection—that is, the conclusion of belief or disbelief (Dewey 2005, p. 60).

There are several reasons for mentioning Dewey's book and logical phases based on his conception of a complete act of thought. First, the book title, *How People Learn* (Bransford, Brown, and Cocking 1999), anticipates a contemporary synthesis of research on learning. Second, the steps Dewey described established what became the five steps of the scientific method that has influenced science teachers' conception of scientific inquiry. Finally, the five phases also anticipate the role of instructional models such as the BSCS 5Es.

The fact that Dewey's five phases became a rigid sequence introduced in science textbooks and classrooms is unfortunate. John Dewey did not perceive the methods of science as a lockstep process. Just the year before publishing *How We Think*, Dewey addressed the American Association for the Advancement of Science meeting on the topic "Science as Subject-Matter and As Method" (Dewey 1910). In his address and published article, he argued for the importance of using the scientific method in school science programs and presented a dynamic view of inquiry.

Early in the 1910 publication of Dewey's address, he states his position by saying, "I mean that science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after a pattern of which mental habits are to be transformed" (Dewey 1910, p. 121). Dewey elaborated on scientific method as a habit of mind. One should also notice that in the following excerpts, Dewey refers to aims that include the abilities of inquiry, the nature of science, and an understanding of subject matter.

> *Surely if there is any knowledge which is of most worth it is knowledge of the ways by which anything is entitled to be called knowledge instead of being mere opinion or guess work or dogma.*
>
> *Such knowledge never can be learned by itself; it is not information, but a mode of intelligent practice, and habitual disposition of mind. Only by taking a hand in the making of knowledge, by transferring guess and opinion into belief authorized by inquiry, does one ever get a knowledge of the method of knowing.* (p. 125)
>
> *But that the great majority of those who leave school have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable. Nor is it absurd to expect that they should go forth with a lively interest in the ways in which knowledge is improved by a marked distaste for all conclusions reached in disharmony with the methods of scientific inquiry.* (p. 127)

Later Dewey again states his position. "Thus we again come to the primary contention of the paper: That science teaching has suffered because a science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject matter" (p. 127).

In a later section of his address, Dewey makes his position clear for the third time. The perspective expressed by Dewey in 1909 is even applicable now, more than 100 years later.

> *I do not mean that our schools should be expected to send forth their students equipped as judges of truth and falsity in specialized scientific matters. But that the great majority of those who leave school should have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable. Not is it absurd to expect that they should go forth with a lively interest in the ways in which knowledge is improved and a marked distaste for all conclusions reached in disharmony with the methods of scientific inquiry.* (Dewey 1910, p. 127)

Dewey concludes with this powerful statement:

> *One of the only two articles that remain in my creed of life is that the future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind; and that the problem of problems in our education is therefore to discover how to mature and make effective this scientific habit.* (p. 127)

I have quoted John Dewey at length because 100 years ago he articulated the need for teaching science as inquiry, for which he included several important outcomes: developing thinking and reasoning, formulating habits of mind, learning science subject matter, and understanding the processes of science. Dewey later wrote *Logic: The Theory of Inquiry* (1938), in which he presented his "steps" in the scientific method (induction, deduction, mathematical logic, and empiricism). This book no doubt influenced the many science textbooks that treat the scientific method as a fixed sequence as opposed to a variety of strategies whose use depends on the question being investigated and on the researchers. Discussions about the role of the scientific method in science classrooms and textbooks continue in the science education community. I think it is clear that John Dewey did not support teaching the scientific method as a formal step-by-step sequence. He likely did support phases of instruction based on the psychology of learning.

The historian John Rudolph (2005) has proposed that educators quickly embraced the five steps for the following reasons: (1) the steps' alignment with the trends toward the psychology of students as applied in problems from actual life situations, (2) increasing levels of enrollment in schools, and (3) the ease of applying scientific approaches without attending to the nuances of individual and contextual differences. In the end, a complex set of social, educational, and scientific trends led educators to equate Dewey's idea of reflective thought with the scientific method. Soon the scientific method was included in textbooks, thus becoming part of the knowledge that students had to memorize.

The Harvard Red Book

In 1945, a Harvard committee published *General Education in a Free Society*. The report included a section on science and mathematics in the secondary schools. After a fairly extensive discussion of what science is, what science is not, what scientists do, and the ways scientists adapt the modes of inquiry, the committee summarized their view of scientific inquiry:

> *The working scientist brings to bear upon these problems everything at his command—previous knowledge, intuition, trial and error, imagination, formal logic, and mathematics—and these may appear in almost any order in the course*

> *of working through a problem. ... The nub of the matter is that the problem be solved.* (Harvard Committee 1945, p. 158)

From a historical point of view, these criteria by a prestigious committee came shortly after the education community embraced the scientific method and *solidified* its place in science education by placing the five steps in textbooks, often in the first chapters of science textbooks.

The Influence of James B. Conant

James B. Conant was president at Harvard and by nature of his position had appointed the committee and attended to the report's conclusions. Conant had a particular interest in science because he was a chemist. The view expressed later by Conant in *Science and Common Sense* (1951) should not come as a surprise. I refer to Chapter 3, titled "Concerning the Alleged Scientific Method." After an introduction, Conant states his view in no uncertain terms.

> *There is no such thing as* the *scientific method. If there were, surely an examination of the history of physics, chemistry, and biology would reveal it ... few would deny it is the progress in physics, chemistry, and experimental biology which give everyone confidence in the procedures of the scientist. Yet a careful examination of those subjects fails to reveal any* one *method by means of which the matters in these fields broke new ground.* (Conant 1951, p. 45; emphasis in original)

Expressions of the scientific method have continued, especially in opening chapters of science textbooks (Lederman 1992). As we enter the 21st century, it is time for science teachers to introduce accurate and appropriate perspectives of scientific inquiry.

The Recent Past, 1957 to Present

I selected 1957—in fact, October 4, 1957—as the place to begin this discussion because the science education community continually refers to Sputnik as initiating a major era of reform. Although Sputnik-era reform implemented any number of innovations on science education, teaching science as inquiry would have to be among those that have been sustained for more than 50 years since that reform.

The Influence of Joseph Schwab

One of the intellectual leaders of the Sputnik reform was Joseph Schwab, whose extensive writing established teaching science as inquiry as a prominent theme for the era. In 1960, Schwab published "Enquiry, the Science Teacher, and the Educator" (*enquiry* was Schwab's preferred spelling of the term) in *The Science*

Teacher. In the following discussion, the reader should note the parallel between the concepts of normal and revolutionary science as described by Thomas Kuhn in *The Structure of Scientific Revolutions* (Kuhn 1970) and Schwab's use of stable and fluid enquiry.

In this article for science teachers, Schwab presented a distinction between what he called stable scientific enquiry and fluid enquiry. Stable enquiry is the pursuit of scientific investigations centered on answering questions that fill in knowledge at places where there is incomplete understanding of particular scientific principles. Those principles are the origins and guiding ideas of enquiry, and the result is greater understanding of that particular principle.

Fluid enquiries have the intention of testing, revising, or ultimately inventing new principles. According to Schwab, both approaches have value as stable enquiry completes and fills in knowledge of a particular principle and fluid enquiry invents new principles. Both types of enquiry advance scientific knowledge, but Schwab argued that fluid enquiry was essential to the long-term advancement of scientific knowledge.

Closely related to our contemporary situation, Schwab stated that England, France, Germany, and Scandinavia trained their potential scientists with an emphasis on fluid inquiry. Schwab brings his views on enquiry to education when he states the following:

> *We are asked to discover, select, motivate, and launch an increasingly large group of fluid enquirers and original engineers—and a non science public which understands the nature and consequences of the work these scientists do.* (Schwab 1960, p. 8)

In the late 1950s and 1960s, Joseph Schwab published other articles on inquiry. Schwab laid the foundation for the emergence of inquiry as a prominent theme in the curriculum reform of that era (Schwab 1958, 1960, 1966). Schwab grounded his argument to teach science as inquiry in science itself: "The formal reason for a change in present methods of teaching the sciences lies in the fact that science itself has changed. A new view concerning the nature of scientific inquiry now controls research" (1958, p. 374).

When Schwab discussed the implication of these changes for education, he quickly pointed out that science textbooks and science teachers were presenting science in a way that was inconsistent with modern science. According to Schwab (1966, p. 24), science was taught " … as a nearly unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths." Schwab goes on to clarify his assertion: "A rhetoric of conclusions, then, is a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts, as if to say, 'this, everyone of importance knows to be true'" (1966, p. 24).

The implications of Schwab's ideas were, for their time, profound. He suggested first that science should be presented as inquiry, and second that students should undertake inquiries as the means to learn science. To achieve these changes, Schwab (1960) recommended that science teachers first look to the laboratory and use these experiences to lead rather than lag the classroom phase of science teaching. That is, the laboratory experience should precede rather than follow the formal explanation of scientific concepts and principles. He also suggested that science teachers consider three levels of openness in their laboratories. First, the materials can be used to pose questions and describe methods to investigate the questions that allow students to discover relationships they do not already know. Second, the laboratory manual or textbook can pose questions, but the methods and answers are left open. Finally, in the most open approach, students confront phenomena without textbook- or laboratory-based questions. They are left to ask questions, gather evidence, and propose explanations based on their evidence.

Schwab also proposed a second approach, which he referred to as *enquiry into enquiry*. In this approach, teachers provide students with readings, reports, or books about research. They engage in discussions about the problems, data, role of technology, interpretation of data, and conclusions reached by scientists. Where possible, students should read about alternative explanations, experiments, debates about assumptions, use of evidence, and other issues of scientific inquiry.

Joseph Schwab had a tremendous influence on the original design of instructional materials—the laboratories and invitations of inquiry—for the Biological Sciences Curriculum Study (BSCS). Schwab's recommendation paid off in the late 1970s and early 1980s when education researchers asked questions about the effectiveness of these programs. Shymansky (1984) reported evidence supporting his conclusion that "BSCS biology is the most successful of the new high school science curricula" (p. 57).

Curriculum reform was a centerpiece of the Sputnik era, and Joseph Schwab was among the intellectual leaders supporting the idea of teaching science as inquiry as a fundamental part of the reform. The founding of BSCS in 1958 brought together Joseph Schwab and curriculum reform in a fruitful union. Indeed, inquiry has been recognized as one of the significant education legacies of the BSCS project (Rudolph 2008). The period leading up to the founding of BSCS had witnessed the Cold War and a "red scare," with the subsequent threat to intellectual freedom. This atmosphere contributed to the linking of scientific inquiry and intellectual freedom as scientists appealed to policy makers, members of the business and industry communities, and citizens to maintain the integrity of science. As BSCS took form, the founders and initial staff and steering committee—including Bentley Glass, Arnold Grobman, H. J. Muller, Paul Brandwein, John A. Moore, and Joseph Schwab established scientific inquiry as a central learning outcome and guiding principle for future curriculum materials.

Did the Science Education Community Meet the Challenge of Teaching Science as Inquiry?

When this question centers on teaching science as inquiry, the answer has to be no. As early as the mid-1960s, insightful criticism emerged. For example, in 1964, F. James Rutherford addressed the role of inquiry in science teaching. He began the article by pointing out that when it comes to the teaching of science, we are unalterably opposed to rote memorization, and we are all for the teaching of scientific processes, critical thinking, and the inquiry method. Rutherford also noted that the practice of science teaching does not represent science as inquiry; in fact, the idea of "teaching science as inquiry" needs clarification. He shows how the terms are sometimes used in a way that emphasizes that inquiry is really part of the science content itself. Science teaching can help students learn about inquiry. At other times, educators refer to a particular technique or strategy for teaching science content. That is, students can conduct an inquiry to learn science concepts and principles.

Rutherford presented these observations:

1. It is possible to gain a worthwhile understanding of science as inquiry once we recognize the necessity of considering inquiry as content and operate on the premise that the concepts of science are properly understood only in the context of how they were arrived at and what further inquiry they initiated.
2. As a corollary, it follows that it is possible to learn something of science as inquiry without the learning process itself having to follow precisely any one of the methods of inquiry used in science. That is, inquiry as technique is not absolutely necessary to understanding inquiry as content.
3. Although the laboratory can be used to provide the student experience with and knowledge of some aspects or components of the investigative techniques employed in a given science, it can effectively do so only after content of the experiments has been carefully analyzed for usefulness in this regard.

Rutherford connected teaching science as inquiry and the knowledge base for doing so. He concluded that until science teachers acquire "a rather thorough grounding in the history and philosophy of the sciences they teach, this kind of understanding will elude them, in which event not much progress toward the teaching of science as inquiry can be expected" (Rutherford 1964, pp. 80–84).

In the late 1970s and early 1980s, the National Science Foundation (NSF) supported a project that synthesized a number of national surveys, assessments, and case studies about the status of science education in the United States (Harms and Kohl 1980; Harms and Yager 1981). One major portion of this review centered on the role of inquiry in science teaching and was completed by Wayne Welch, Leo Klopfer, Glen Aikenhead, and James Robinson (1981). Their analysis revealed that the science education community used the term *inquiry* in a variety of ways, including the general categories identified in this review—inquiry as content and inquiry as instructional technique—and generally science educators and science teachers were unclear about the term's meaning. The researchers identified several discrepancies that presented doubts about the implementation of inquiry in either use of the term. The greatest discrepancy was between teachers' espoused belief in the importance of teaching science as inquiry and their actual practice. The evidence indicated that "although teachers made positive statements about the value of inquiry, they often felt more responsible for teaching facts, 'things which show up on tests,' 'basics' and structure and the work ethic" (Welch et al. 1981).

Teachers expressed a number of reasons for not teaching science as inquiry, introducing the content (knowledge and abilities), or using inquiry-oriented experiences. Among the reasons cited were problems with classroom management, difficulty meeting state requirements and obtaining supplies and equipment, dangers for students, and concerns about whether inquiry really worked. Notice that the justification centers on inquiry as instructional technique. In conclusion, the authors (Welch et al. 1981) reported,

> *The widespread espoused support of inquiry is more simulated than real in practice. The greatest set of barriers to the teacher support of inquiry seems to be its perceived difficulty. There is legitimate confusion over the meaning of inquiry in the classroom. There is concern over discipline. There is worry about adequately preparing children for the next level of education. There are problems associated with the teachers' allegiance to teaching facts and to following the role models of the college professors.* (p. 40)

I participated on the analysis of biology for Project Synthesis, and that team concluded, "In short, little evidence exists that inquiry is being used" (Hurd et al. 1980, p. 391).

In 1986, Kenneth Costenson and Anton Lawson pursued answers about the lack of inquiry by surveying a group of biology teachers. Teachers gave the following reasons for not teaching biology as inquiry: (1) lack of time and energy (e.g., it takes too much time to develop inquiry materials), (2) too slow (e.g., using inquiry takes too much time, so the district curriculum will not be covered) , (3) reading too difficult (e.g., students cannot read the inquiry book), (4) risk too high (e.g., administration will be critical of teaching), (5) tracking (e.g., level of thinking is too high for students in regular biology), (6) student immaturity (e.g., students waste too much time in inquiry experiences), (7) teaching habits (e.g., I cannot change my style of teaching), (8) sequential material (e.g., I cannot skip chapters and labs in inquiry textbooks), (9) discomfort (e.g., inquiry teaching makes me feel uncomfortable, not in control), and (10) too expensive (e.g., it will cost too much to equip the lab for inquiry) (Costenson and Lawson 1986, p. 151). Their survey responses were similar to those reported by Welch et al. in 1981. Although the context for the Costenson and Lawson study was biology, similar results would likely be obtained for other disciplines, particularly at the secondary level. I list all 10 reasons because they form the substantial barriers between policies—for example, the *National Science Education Standards* (NRC 1996) that recommend science as inquiry and science programs that incorporate teaching science as inquiry and the actual practices in science classrooms.

Costenson and Lawson (1986) conclude their article by saying,

> *In our opinion, all ten of the previous reasons for not using inquiry are not sufficient to prevent its use. However, to implement inquiry in the classroom we see three crucial ingredients: (1) teachers must understand precisely what scientific inquiry is; (2) they must have sufficient understanding of the structure of biology itself, and (3) they must become skilled in inquiry teaching techniques.* (p. 158)

In this quotation, we again see the differentiation of inquiry as *content* to be understood first by teachers and then by students and inquiry as a *technique* to be used by teachers to help students learn biology.

Project 2061

In 1985, F. James Rutherford inaugurated Project 2061, a long-term initiative of the American Association for the Advancement of Science (AAAS) to reform K–12 education. Project 2061 materials such as *Science for All Americans* (AAAS 1989) and *Benchmarks for Science Literacy* (AAAS 1993) have made significant statements about teaching science as inquiry.

In *Science for All Americans* (AAAS 1989), the lead chapter discusses the nature of science, and another chapter discusses "Historical Perspective." These chapters provide the basis for recommendations for including scientific inquiry in school programs. Rutherford and Project 2061 made concrete recommendations consistent with his 1964 critique. The chapter "Habits of Mind" includes categories of values and attitudes, manipulation and observation, communication, and, very important, critical-response skills.

In a separate chapter, "Effective Learning and Teaching," *Science for All Americans* (AAAS 1989, pp. 147–149) has a general recommendation: "Teaching Should Be Consistent With the Nature of Scientific Inquiry," followed by specific recommendations:

- Start with questions about nature
- Engage students actively
- Concentrate on the collection and use of evidence
- Provide historical perspectives
- Insist on clear expression
- Use a team approach
- Do not separate knowing from finding out
- Deemphasize the memorization of technical vocabulary

Benchmarks for Science Literacy (AAAS 1993) provides actual learning outcomes for the aforementioned chapters on the nature of science, historical perspectives, and habits of mind. In addition, there is an excellent research base that indicates what students should know and be able to do relative to various benchmarks. Project 2061 also set in place goals and specific benchmarks for the teaching aspect of scientific inquiry as content and made recommendations for using teaching techniques associated with inquiry. The work of this project clearly set the stage and influenced the *National Science Education Standards* (NRC 1996).

National Science Education Standards

More than a decade ago, the *National Science Education Standards* (NRC 1996) presented national policies that included teaching science as inquiry. Release of the standards again brought the issue of teaching science as inquiry to the forefront in the education community. In the *National Science Education Standards* (NRC 1996), scientific inquiry refers to several related but different aspects of teaching and learning: the ways scientists study the natural world, activities of students, strategies of teaching, and outcomes that students should learn. The *National Science Education Standards* provides the following statement on scientific inquiry:

> *[I]nquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.* (NRC 1996, p. 23)

The Standards use the term *inquiry* in two ways. First, inquiry is *content*, which is divided between what students should *understand* about scientific inquiry and the *abilities* students should develop based on their experiences with scientific inquiry. Second, the term *inquiry* refers to teaching strategies and the processes of learning associated with inquiry-oriented activities. In this section, I address the content, beginning with the following statement of the content standard for Science as Inquiry for grades 9–12 (see Figure 4.1).

Figure 4.1

Content Standard for Science as Inquiry

General Standards for Inquiry
All students should develop

- abilities necessary to do scientific inquiry.
- understandings about scientific inquiry.

Science as Inquiry: The Abilities

Figure 4.2 presents the key abilities from the standard. Based on the original discussion in the Standards, this discussion provides details about the fundamental abilities. As you read the descriptions, note the distinct emphasis on *cognitive* abilities and critical thinking by students. This emphasis differentiates the Standards from the traditional emphasis on processes without eliminating activities such as students' observing, inferring, and hypothesizing. In this sense, the Standards advance our understanding of inquiry beyond processes (Millar and Driver 1987).

Figure 4.2

Science as Inquiry: Fundamental Abilities for Grades 9–12

Fundamental Abilities Necessary to Do Scientific Inquiry

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

Science as Inquiry: The Understandings

Figure 4.3 summarizes the fundamental understandings that students should develop as a result of their science education.

Figure 4.3

Science as Inquiry: Fundamental Concepts for Grades 9–12

Fundamental Understanding About Scientific Inquiry

- Scientists usually inquire about how physical, living, or designed systems function.
- Scientists conduct investigations for a wide variety of reasons.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Mathematics is essential in scientific inquiry.
- Scientific explanations must adhere to criteria such as the following: A proposed explanation must be logically consistent; abide by the rules of evidence; be open to questions on possible modification; and be based on historical and current scientific knowledge.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists.

I turn to questions that emerge from the discussion of inquiry as content: "How do science teachers help students attain the abilities and understanding described in the Science as Inquiry Standards?" and "What do the Standards say about teaching?"

Science Teaching Standards

The science teaching standards (see Table 4.1) provide a comprehensive perspective for science teachers who wish to implement strategies that will provide students with the opportunities to experience science as inquiry. The national standards advocate the use of diverse teaching strategies to achieve varied outcomes. The *National Science Education Standards* state,

> *Although the standards emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and ability described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry. Attaining the understanding and abilities described in [the prior section] cannot be achieved by any single teaching strategy or learning experience.* (NRC 1996, pp. 23–24)

Table 4.1

Science Teaching Standards

Teaching Standard A Teachers of science plan an inquiry-based science program for their students.	In doing this, teachers • develop a framework of yearlong and short-term goals for students. • select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students. • select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners. • work together as colleagues within and across disciplines and grade levels.
Teaching Standard B Teachers of science guide and facilitate learning.	In doing this, teachers • focus and support inquiries while interacting with students. • orchestrate discourse among students about scientific ideas. • challenge students to accept and share responsibility for their own learning. • recognize and respond to student diversity and encourage all students to participate fully in science learning. • encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.
Teaching Standard C Teachers of science engage in ongoing assessment of their teaching and of student learning.	In doing this, teachers • use multiple methods and systematically gather data about student understanding and ability. • analyze assessment data to guide teaching. • guide students in self-assessment. • use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice. • use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.
Teaching Standard D Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.	In doing this, teachers • structure the time available so that students are able to engage in extended investigations. • create a setting for student work that is flexible and supportive of science inquiry. • ensure a safe working environment. • make the available science tools, materials, media, and technological resources accessible to students. • identify and use resources outside the school. • engage students in designing the learning environment.

Table 4.1 *(continued)*

Science Teaching Standards

Teaching Standard E Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.	In doing this, teachers • display and demand respect for the diverse ideas, skills, and experiences of all students. • enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community. • nurture collaboration among students. • structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. • model and emphasize the skills, attitudes, and values of scientific inquiry.
Teaching Standard F Teachers of science actively participate in the ongoing planning and development of the school science program.	In doing this, teachers • plan and develop the school science program. • participate in decisions concerning the allocation of time and other resources to the science program. • participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.

The Essential Features of Inquiry in Science Classrooms

After publication of the *National Science Education Standards* (NRC 1996), we realized the need for an addendum that elaborated on inquiry, as it was a prominent feature of the standards. Work began on *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning,* and the addendum was published in 2000. A key theme in this document was a description of the essential features of inquiry in the specific context of science classroom and science teaching. Following are the five essential features of inquiry.

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations.

The next sections describe the essential features in greater detail. These descriptions are adapted from the aforementioned addendum (NRC 2000).

Essential Feature 1: Learners Are Engaged by Scientifically Oriented Questions.

Scientifically oriented questions center on objects, organisms, and events in the natural world; they connect to the science concepts described in the content standards. These questions lend themselves to empirical investigation and lead to gathering and using data to develop explanations for scientific phenomena. Scientists recognize two primary kinds of scientific questions. Existence questions probe origins and include many "why" questions. Why do objects fall toward Earth? Why do some rocks contain crystals? Why do humans have chambered hearts? There also are causal and functional questions, which probe mechanisms and include *how* questions. How does sunlight contribute to plant growth? How are rocks formed?

In the classroom, a question can drive an inquiry and generate a need to know in students, stimulating additional questions about natural phenomenon. The initial question may originate from the learner, teacher, curriculum materials, internet, or other sources. The science teacher may play a critical role in guiding the identification of questions, particularly when they come from students. Fruitful inquiries develop from questions that are meaningful and relevant to students, but they also must be able to be answered by students' observations and the scientific knowledge they can obtain from reliable sources. The knowledge and procedures students use to answer the questions must be accessible and manageable, as well as appropriate to the students' developmental levels.

Essential Feature 2: Learners Give Priority to Evidence That Allows Them to Develop and Evaluate Explanations That Address Scientifically Oriented Questions.

Science distinguishes itself from other ways of knowing through the use of empirical evidence as the basis for explanations about the natural world. Scientists concentrate on getting accurate data from observations and experiments. They obtain evidence from getting accurate data from observations and experiments. They obtain evidence from observations and measurements taken in natural settings or in settings such as laboratories. They use their senses; instruments such as telescopes and microscopes to enhance their senses; and instruments that measure characteristics that humans cannot sense, such as magnetic fields. In some instances, scientists can control conditions to obtain their evidence; in other instances, they cannot control the conditions or control would distort the phenomena, so they gather data over a wide range of naturally occurring conditions and over a long enough period of time that they can infer the influence of different factors. The accuracy of the evidence gathered is verified by checking measurements, repeating the observations, or gathering different kinds of data related to the same phenomena. The evidence is subject to questioning and further investigation.

The above paragraph explains what counts as evidence in science. In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. They observe plants, animals, and rocks and carefully describe their characteristics. They can take measurements of temperatures, distances, and time and carefully record them. They can observe chemical reactions, predator and prey relationships, and moon phases and chart their results and interactions. They also may obtain facts and information from their teacher, curriculum materials, or the internet to facilitate their inquiries.

Essential Feature 3: Learners Formulate Explanations From Evidence to Address Scientifically Oriented Questions.

This aspect of inquiry emphasizes the connection between evidence and explanation rather than the criteria for and characteristics of the evidence. Scientific explanations should be formulated using logic and reason. They provide causes for effects and establish relationships based on evidence and logical argument. They must be consistent with observational and experimental evidence about nature. Scientific explanations respect rules of evidence, are open to criticism, and require the use of various processes generally associated with science—for example, classification, analysis, inference, and prediction—and cognitive processes such as critical reasoning and logic.

Proposed explanations extend what is known to what is unknown, so explanations go beyond current knowledge and propose some new understanding. For science, this means building on extant knowledge. For students, this means expressing new ideas based on their current understandings. In both cases, the result is a proposed explanation.

Essential Feature 4: Learners Evaluate Their Explanations in Light of Alternative Explanations, Particularly Those Reflecting Scientific Understanding.

Evaluation, and possible elimination or revision of explanations, is one feature that distinguished scientific inquiry from other ways of knowing. Science teachers can ask questions such as, "Does the evidence support the proposed explanation?" "Does the explanation adequately answer the questions?" "Are there any apparent biases or flaws in the reasoning connecting evidence and explanation?" "Can other reasonable explanations be derived from the same evidence?"

Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by others. This characteristic ensures that students make the connection between their results and appropriate scientific knowledge. That is, given their age and stage of development, students' explanations should ultimately be consistent with currently accepted scientific knowledge.

Essential Feature 5: Learners Communicate and Justify Their Proposed Explanations.

Scientists communicate their explanations in such a way that their results can be reproduced. This requires clear articulation of the question, procedures, evidence, and proposed explanation, as well as a review of alternative explanations. It provides for further skeptical review and the opportunity for other scientists to use the explanation in working on new questions.

Having students share their explanations provides other students and teachers the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument.

Variations of Inquiry in Science Classrooms

One of the unfortunate misconceptions about teaching science as inquiry is that all inquiry must originate with a student's question. In the extreme, this position does not allow for other origins for questions, such as the science teacher asking a question, conducting a demonstration, or engaging students in an activity. *Inquiry and the National Science Education Standards* (NRC 2000) presents a view of classroom inquiry that is not this either/or position. Rather, the view is one of a continuum and variations that may range from less to more self-direction by students and more to less direction by teachers, materials, or other sources. Table 4.2 (p. 86) uses the essential features of inquiry and presents this continuum.

Table 4.2

Essential Features of Classroom Inquiry and Their Variations Along a Continuum

More<--------------------------------Amount of Learner Self-Direction---------------------------------->Less Less<---------------------Amount of Direction From Teacher or Written Material-------------------->More				
Learner ENGAGES in scientifically oriented questions.	Learner poses a question.	Learner selects among questions, poses new questions.	Learner sharpens or clarifies question provided by teachers, materials, or other source.	Learner engages in question provided by teacher, materials, or other source.
Learner gives priority to EVIDENCE in responding to questions.	Learner determines what constitutes evidence and collects it.	Learner directed to collect certain data.	Learner given data and asked to analyze.	Learner given data and told how to analyze.
Learner formulates EXPLANATIONS from evidence.	Learner formulates explanation after summarizing evidence.	Learner guided in process of formulating explanations from evidence.	Learner given possible ways to use evidence to formulate explanation.	Learner provided with evidence.
Learner connects explanations to scientific KNOWLEDGE.	Learner independently examines other resources and forms the links to explanations.	Learner directed toward areas and sources of scientific knowledge.	Learner given possible connections.	Learner given connections to scientific knowledge.
Learner COMMUNICATES AND JUSTIFIES explanations.	Learner forms reasonable and logical argument to communicate explanations.	Learner coached in development of communication.	Learner provided broad guidelines to use to sharpen communication.	Learner given steps and procedures for communication.

Source: National Research Council (NRC). 2000. *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academies Press. p. 29.

Some Research Worth Noting

This section presents some research supporting the proposal to teach science as inquiry. I criticize a contemporary view supporting direct instruction and establish a linkage among research, instruction, and inquiry.

A Definition of Inquiry

Inquiry as presented in science education has several different and quite distinctive meanings. Beginning with a definition that I developed using a common dictionary form will help set the parameters for further discussion.

> *In.quir.y In´ kwir´ ē) n., pl. ies. 1. An outcome of science teaching that is characterized by* **knowledge** *and* **understanding** *of the processes and methods of science. 2. Outcomes of science teaching that refer to specific* **skills** *and* **abilities** *integral to the processes and methods of science. 3. The instructional strategies used to achieve students' knowledge and understanding of science* **concepts, principles,** *and* **facts** *and/or the outcomes described in the aforementioned definitions 1 and 2.*

This short statement differentiates between inquiry as teaching strategies and inquiry as the learning outcomes of a science teacher. The distinction between teaching strategy and learning outcome is not as clear as the headings indicate because teaching science as inquiry requires some use of inquiry-oriented strategies and inevitable results in learning outcomes associated with knowledge and understanding or skills and abilities.

Historically, there always have been individuals and groups advocating different strategies for teaching science. On one end of a continuum is direct instruction. Lecture serves as the example of this teaching method. At the other end of this continuum is full, unguided inquiry. The extreme position in this view is that students must discover scientific knowledge themselves without any guidance from the teacher. In reality, most science teaching is somewhere in the middle of the continuum. Effective science teaching embodies a variety of strategies and methods. One difficulty, however, is that terms such as *direct instruction* and *inquiry learning* often are argued from either/or positions.

The Inquiry Synthesis Project

The Education Development Center (EDC) in Boston completed an extensive review of qualitative and quantitative research on inquiry. Known as the "Inquiry Synthesis Project," the research team reviewed research between 1984 and 2002 to answer the central question of the project: What is the impact of inquiry science instruction on student outcomes?

Methodology for the project consisted of three phases: report collection, coding, and analysis. An initial review identified 443 research reports, of which

138 met the criteria for inclusion in the final analysis. The review and inclusion or exclusion of studies in the final analysis was among the most rigorous I have seen. The team established five components of inquiry science instruction. Those components included

- developing investigation questions,
- designing experiments,
- collecting data,
- drawing conclusions, and
- communicating results.

The dependent variable was retention of knowledge or understanding (i.e., facts, concepts, principles, theories) in the physical, life, and Earth sciences.

Several conclusions are worth noting. First, a majority (51%) of the studies showed positive results for inquiry-based science instruction on learning outcomes. Second, the research team completed a further analysis of comparative studies (i.e., quasi-experimental and experimental designs with comparison groups) and found that 63% of these studies demonstrated a statistically significant increase in students' understanding of science concepts for those who received higher levels of inquiry-based instructional experiences (EDC 2007; Minner, Levy, and Century 2010).

The EDC research team gave appropriate cautions about the conclusions of this synthesis and use of the results to declare a winner or loser in debates about inquiry instruction versus direct instruction. This said, I would give a slight advantage to inquiry-based instruction based on the rigorous methodology employed by the EDC team, the number of studies included, and the positive results. Considering the relationship to the definition described at the beginning of the section, I would note that the primary emphasis was on instructional strategies used to achieve knowledge and understanding of science concepts, principles, and facts in the physical, life, and Earth sciences.

Inquiry Strategies Versus Direct Instruction

Research headed by David Klahr has stimulated review and discussion of the relative importance of direct instruction and inquiry learning (Klahr has used the term *discovery learning*) as instructional approaches to science teaching (Chen and Klahr 1999; Klahr, Chen, and Toth 2001; Klahr and Li 2005; Klahr and Nigam 2004). In a 1999 study, Chen and Klahr investigated one important aspect of scientific reasoning. They asked the question, "What is the effectiveness of different instructional strategies in children's acquisition of the domain-general strategy—Control of Variables Strategy (CVS)?" They had children ages 7 to 10 years old design and evaluate experiments after direct instruction about CVS and without direct instruction—that is, inquiry learning in the extreme, unguided form. They reported that with direct instruction children did learn and could transfer the basic strategy for designing unconfounded experiments—that is, they could apply CVS (Chen and Klahr 1999). Before continuing this discussion of Klahr's research, I will introduce a report on the use of the laboratory in high school science. The report includes an important perspective on instruction that directly relates to this discussion. I will return later to Klahr's research.

In 2006, the National Research Council published *America's Lab Report: Investigations in High School Science* (NRC 2006). The NRC proposed the *phrase integrated instructional units* to describe the design of instructional units that carefully combine laboratory experiences with other types of teaching strategies, including lectures, reading, and discussion. Research indicates that integrated instructional units increase students' mastery of subject matter compared with other modes of instruction, and, very important, these units aid the development of more sophisticated aspects of scientific reasoning, increase students' interest in science, and somewhat improve students' understanding of the nature of science when this goal is explicitly targeted (NRC 2006, p. 100). All of these are valued goals of science education. Upon reading this research, I immediately made several connections. First, integrated instructional units had the design features of the BSCS 5E Instructional Model. Second, integrated instructional units were not exclusively "direct instruction" but may include direct instruction; they were not unguided inquiry but could include activities and strategies embodying the essential features of guided inquiry (NRC 2000). Third, both the NRC report and David Klahr's research claimed support for their respective strategies as being effective for the development of some aspects of scientific reasoning, which is a critical outcome of inquiry-based instruction.

The research methodology used by Klahr and his colleagues actually paralleled that of an instructional model or an integrated instructional unit. Although the varied teaching methods were evident in the articles, Klahr and colleagues concluded that direct instruction was the critical strategy. The following quotes are from the methodological section of one of the key articles cited in the direct instruction versus inquiry learning debate (Chen and Klahr 1999). In my view, the entire methodology could be described as an integrated instructional unit that centers on students learning the key concepts of the Control of Variables Strategy.

> *The present study consisted of two parts. Part I included hands-on design of experiments. Children were asked to set up experimental apparatus so as to test the possible effects of different variables. The hands-on study was further divided into four phases. In Phase 1, children were presented with materials in a source domain in which they performed an initial exploration followed by (for some groups) training. Then they were assessed in the same domain in Phase 2. In phases 3 and 4, children were presented with problems in two*

additional domains (Transfer-1 and Transfer-2). Part II was a paper-and-pencil posttest given two months after Part I. The posttest examined children's ability to transfer the strategy to remote situations. (Chen and Klahr 1999, p. 4)

David Klahr and his colleagues present a well-designed study that, I would argue, used an integrated instructional approach that closely resembles the BSCS 5E Instructional Model. With an engagement based on the orientation and hands-on introduction to materials, the researchers had the students continue with an exploration, proceed to an explanation and demonstration of CVS, then apply or elaborate CVS to new situations for which they used the terms *assessment*, *Transfer-1*, and *Transfer-2*.

One could reasonably argue that the research methods employed by Klahr and his colleagues used instructional sequences that integrated different strategies but then isolated one strategy, direct instruction, as the key factor in learning. Others have generalized these results to claim that direct instruction is the best way to teach the processes and methods of science and, in the extreme, all of science (Adelson 2004; Cavanagh 2004; Begley 2004a, 2004b). In my view, such extreme generalizations based on the methodology and data of the Klahr studies extend beyond the reasonable limits of the studies. However, the research does provide insights that may help answer questions about effective instructional strategies that could be identified as inquiry oriented.

"How does inquiry-based instruction contribute to the development of knowledge and skills for the 21st century?" This, it seems to me, is a reasonable and appropriate question. Answering the question may advance our understanding of the form and function of inquiry in science education. Based on recent reports from the National Research Council (Bransford, Brown, and Cocking 1999; Donovan and Bransford 2005; NRC 2006), I argue that using an integrated instructional sequence that incorporates varied teaching methods holds the key to a reasonable and appropriate approach to teaching science as inquiry.

The design of integrated instructional units requires the careful selection of activities on the basis of research-based ideas likely to enhance learning. Laboratory and other experiences are explicitly linked. As I mentioned earlier, the BSCS 5E Instructional Model meets the design criteria for integrated instructional units. The strategies used in such units may include direct instruction, discrepant events, laboratories, discussions, demonstrations, readings, debates, virtual field trips, and other activities and methods common to curriculum and instruction in science.

PISA 2006 and Instruction in Science

PISA 2006 emphasized science and included a test of scientific competencies and a student questionnaire that included different opportunities to learn, specifically questions about science lessons. Based on data from PISA 2006, colleagues in Germany completed an analysis and report on instruction in science (Seidel et al. 2008). The German research team analyzed PISA data for variables that were considered relevant for attaining scientific literacy. These variables include learning time, teacher-student interactions, experimenting with student-conducted research, and scientific modeling and applications. In addition, and important in this discussion, the German team analyzed lesson patterns rather than individual lesson characteristics. Here, I make the connection to "integrated instructional unit" (NRC 2006), guided inquiry (NRC 2000), and a specific example of these that has special meaning for me, the BSCS 5E Instructional Model.

The questions asked in this analysis were:

1. In which countries is the complex process of scientific thinking and scientific methods consistently and also frequently considered in everyday lessons?

The specific elements of this question should by now be familiar to the reader: In almost all lessons, students have the opportunities to (1) plan their own experiments; (2) carry out practical experiments; (3) draw conclusions from experiments; (4) discuss their own ideas and basis for explanations; and (5) recognize contributions that science makes to society (see summary in Figure 4.4).

Figure 4.4

Five Basic Elements Used as a Basis for Lesson Patterns

1. Students can develop their own experiments.
2. Students carry out practical experiments in the laboratory.
3. Students should draw conclusions from an experiment that they have carried out.
4. Students are given the opportunity to explain "their own" ideas.
5. Teacher uses science lessons to make the world outside of school comprehensible for students.

2. This question centers on "dosage," how much time and emphasis were given to different activities, methods, and learning approaches. To answer these questions, the research team combined five questions (listed in Figure 4.4) from the international questionnaire. These five questions represent a comprehensive lesson pattern that centers on scientific methods and scientific ways of thinking and the degree to which teachers provide structure and guidance in lessons. Analysis revealed three patterns of lessons that OECD countries have implemented.

The first pattern of lessons (referred to as Type 1) involves all five of the aforementioned methods of scientific experimenting and research in all or most lessons. I would characterize this lesson pattern as the extreme form of open or free inquiry. In OECD countries, 21% of students reported this pattern of lessons. The U.S. percentage for Type 1 was 29%.

The second pattern (Type 2) is characterized by less frequent opportunities to plan and carry out their own experiments. However, they regularly draw conclusions from experiments, explain their ideas, and apply science to the world outside of school. I suggest this is guided inquiry. In OECD countries, 45% of 15-year-olds reported this pattern. The U.S. percentage for Type 2 was 55%.

The third lesson pattern (Type 3) is characterized by the fact that the five characteristics of scientific experimenting and research are rarely encountered in lessons. In OECD countries, 34% of students report this pattern of lessons. The U.S. percentage for Type 3 was 16%.

Following are some conclusions of the German research team.

- Students who reported a lesson time of at least four hours per week achieve significantly higher levels of scientific literacy than students who have a weekly lesson time of less than two hours. This finding is true for all OECD countries. A difference in the U.S. level of scientific literacy is evident—a difference of 69 points on the assessment, which is above the OECD average of 62 points.
- Students who experience Type 2 patterns of lessons—less frequent opportunities to plan and carry out their own experiments but draw conclusions, explain ideas, and apply science to the world outside of school—clearly demonstrate higher levels of scientific literacy. Type 1 patterns of lessons result in the lowest performance scores. The score for Type 2 in the United States is 52 points above the average performance score for Type 1. Type 3 scores are above Type 1 but lower than Type 2.
- Students' interest in science varies with the patterns of lessons. Not surprisingly, Type 1 patterns result in the highest interest in science. On average for OECD countries, Type 2 is slightly below Type 1. This difference in the United States is greater than average.

This analysis suggests that students should have four hours or more of science per week, and from the view of multiple learning outcomes (i.e., scientific literacy and interest in science), the use of a Type 2 pattern of lessons would be ideal.

In the context of this chapter, secondary school science should include four hours or more per week and use integrated instructional units that are characterized as guided inquiry.

Table 4.3 presents linkages among the research of Klahr, the BSCS 5E Instructional Model, and the essential features of inquiry as described in the National Research Council report *Inquiry and the National Science Education Standards* (NRC 2000).

Table 4.3

Linking Research, Instruction, and Inquiry

Chen and Klahr (1999)	**An Integrated Instruction Sequence** (NRC 2006): **The BSCS 5E Instructional Model**	**Essential Features of Inquiry** (NRC 2000)
"Children were presented materials in a source domain in which they performed an initial exploration."	**Engagement** initiates the learning process and exposes students' current conceptions.	Teachers can engage learners with demonstrations, activities, and field trips to form the basis for scientifically oriented questions.
"Children were asked to set up experimental apparatus so as to test the possible effects of different variables."	In the **Explore** phase, students gain experience with phenomena or events.	Learners can use the results of laboratory investigations to give priority to evidence and to allow them to address scientific questions.
"… included an explanation of the rationale behind controlling variables as well as examples of how to make unconfounded comparisons."	In the **Explain** phase, the teacher may give an explanation to guide students toward a deeper understanding.	Learners formulate explanations and teachers can provide direct instruction about scientific concepts, principles, and facts.
"… children were presented with problems in two additional domains."	In the **Elaborate** phase, students apply their understanding in a new situation or context.	Learners evaluate scientific explanations as they apply them to new situations.
"Part II was a pencil-and-paper posttest given two months after Part I."	In the **Evaluate** phase, student understanding and transfer are assessed.	Learners communicate and justify their proposed scientific understanding.

Concluding Discussion

In conclusion, I have tried to bring some clarity to the term *inquiry* as it applies to school science programs and the preparation of young minds. First, teaching science as inquiry includes understanding scientific inquiry and developing the cognitive abilities associated with the processes and methods of science. Second, inquiry can refer to an integrated and linked instructional sequence designed with the intention of helping students learn science concepts, as well as understanding inquiry and developing cognitive abilities aligned with inquiry. It is past time to move beyond the old either/or arguments of inquiry versus direct instruction. Science teachers have always used multiple strategies, so we need not make a decision about the one best strategy for teaching science. There isn't one; there are many strategies that can be applied to achieve different outcomes. Science teachers should try to sequence the various strategies into coherent and focused ways. This is teaching science as inquiry.