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A Brief History of Inquiry: From Dewey to Standards

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This paper describes how interpretations of inquiry have changed during the 20th Century. These multiple meanings have resulted in (a) confusion among K–12 teachers of science and (b) various interpretations by science teacher educators. Suggestions are provided for preservice programs (both science and methods courses), professional development for new and veteran teachers of science, and science education community to reach consensus about what is inquiry.

Introduction

According to *Webster's Third International Dictionary* (1986), *inquiry* is an "act or an instance of seeking for truth, information, or knowledge; investigation; research; or a question or query" (p. 1167), while the root word *inquire* means "to ask for information about, to make an investigation or search, to seek information or questioning" (p. 1167). Sometimes inquiry is spelled with an *I*, other times an *E*, reflecting a difference in the American and English spelling; either way, they mean the same thing—based upon question(s) asked by the learner or investigator. However, there is a lack of agreement on the meaning of inquiry in the field of science education (Martin-Hauser, 2002; Minstrell & van Zee, 2000). Barman (2002) presented his interpretation about inquiry as a teaching strategy and a set of student skills (i.e., individual process skills). Two subsequent responses (Editorial, 2002; Lederman, 2003) identified a third component of inquiry, that of knowledge about inquiry. Minstrell (2000) listed several different definitions of inquiry: encouraging inquisitiveness (habit of the mind), teaching strategy for motivating learning, hands-on and minds-on, manipulating materials to study particular phenomena, and stimulating questions by students. Minstrell considered an inquiry to complete when "we should know something we did not know before we started. Even when our investigation fails to find the answer, at least the inquiry should have yielded a greater understanding of factors that are involved in the solution" (p. 473). There is a need for science teacher educators to reach consensus about what is inquiry, in both preservice and inservice situations. The purpose of this paper is to provide a historical timeline that illustrates how the concept of inquiry has evolved.

Early Historical Perspective

The inclusion of inquiry into K–12 science curriculum was recommended by John Dewey (1910), a former science teacher. Dewey considered that there was too much emphasis on facts without enough emphasis on science for thinking and an attitude of the mind. Dewey encouraged K–12 teachers of science to use inquiry as a teaching strategy where the scientific method was rigid and consisted of the six steps: sensing perplexing situations, clarifying the problem, formulating a tentative hypothesis, testing the hypothesis, revising with rigorous tests, and acting on the solution. In Dewey's model, the student is actively involved, and the teacher has a role as facilitator and guide. In 1916, Dewey had encouraged that students be taught so that the students could be adding to their personal knowledge of science. To accomplish that, students must address problems that they want to know and apply it to the observable phenomena. Dewey's model was the basis for the Commission on Secondary School Curriculum (1937) entitled *Science in Secondary Education*. Subsequently, Dewey (1944) modified his earlier interpretation of the scientific method to accomplish his goal of reflective thinking: presentation of the problem, formation of a hypothesis, collecting data during the experiment, and formulation of a conclusion. According to Dewey (1938), problems to be studied must be related to students' experiences and within their intellectual capability; therefore, the students are to be active learners in their searching for answers.

Sputnik and Inquiry

The launching of Sputnik I on October 4, 1957, caused the Nation to question the quality of the science teachers and the science curriculum used in schools. Earlier, the National Science Foundation (NSF) had funded the development of an innovative physics curriculum (Physics Science Curriculum Study in 1956; DeBoer, 1991). The subsequent physics curriculum (Physical Science Study Committee, 1960) and other science curricula (biology, chemistry, physics, earth science, and elementary), with funding from NSF, provided for the development of curriculum and professional development for implementing the curriculum, with an emphasis on "thinking like a scientist" (DeBoer, 1991). There was also an emphasis on science processes as individual skills (i.e., observing, classifying, inferring, controlling variables, etc.).

Joseph Schwab (1966) believed that students should view science as a series of conceptual structures that should be continually revised when new information or evidence is discovered. Earlier, Schwab (1960) had described two types of inquiry: stable (growing body of knowledge) and fluid (invention of new conceptual structures that revolutionize science). Schwab considered that science should be taught in a way that was to be consistent with the way modern science operates. He also encouraged science teachers to use the laboratory to assist students in their study of science concepts. He recommended that science be taught in an inquiry format. Besides using laboratory investigation to study science concepts, students could use and read reports or books about research and have discussions about problems, data, the role of technology, the interpretation of data, and any conclusions reached by scientists. Schwab called this "enquiry into enquiry" (Duschl & Hamilton, 1998, p. 1060). Rutherford (1964) considered inquiry as both content and concepts that are to be understood in the context of how they were discovered so that future inquiries could occur. He recommended that all science teachers have a background in the history and philosophy of science.

Project Synthesis (Harms & Yager, 1981) was a compilation of three major NSF sponsored projects—a review of 1955–1975 literature (Helgeson, Blosser, & Howe, 1997), case studies by Stake and Easley (1978), and the 1977 national survey (Weiss, 1978). In addition, other sources, such as Third Science National Assessment of Educational Progress results, were also used in developing a discrepancy model. There were four different goal clusters developed: personal needs, societal issues, academic preparation, and career education and awareness. The greatest emphasis (95%) was on academic preparation. Inquiry (Welch, Klopfer, Aikenhead, & Robinson, 1981) was one of the five areas of Project Synthesis. Inquiry was studied from two dimensions: a content for teachers and their students and the strategy used by science teachers to help their students learn science. The Project Synthesis report divided student outcomes for inquiry into three categories (science process skills, nature of scientific inquiry, and general inquiry process). Welch et al. recognized reasons that teachers do not use inquiry and identified limited teacher preparation, including management; lack of time, limited available materials; lack of support; emphasis only on content; and difficult to teach. Subsequently, Eltinge and Roberts (1993) identified three reasons for avoiding inquiry (state documents emphasizing content, easier to access content, and textbooks' emphasis of science as a body of knowledge).

Influence of Policy Documents

Project 2061, the long-term efforts by the American Association for the Advancement of Science (AAAS) to reform K–12 science, identified what all students should know and be able to do when they graduate at the end of 12th grade. Their first document, *Science for All Americans* (SFAA; Rutherford & Ahlgren, 1989), has a broad view in defining scientific literacy. Subsequently, *Benchmarks for Scientific Literacy* (AAAS, 1993) organized the topics into K–2, 3–4, 5–8, and 9–12 grade-level groupings. Project 2061 established goals for the teaching of inquiry in the SFAA chapter entitled "Habits of the Mind," and inquiry was considered as a science content topic using the following recommendations: start with questions about nature, engage students actively, concentrate on the collection and use of evidence, provide historical perspective, insist on clear expression, use a team approach, do not separate knowledge from finding out, and deemphasize the memorization of technical vocabulary.

More recently, the *Atlas of Scientific Literacy* (AAAS, 2001) has a series of strand maps to illustrate several concepts of the Benchmarks (AAAS, 1993). They developed three strand maps on their interpretation of scientific inquiry. First, evidence and reasoning in inquiry includes two categories- lines of reasoning and observations and evidence. The second includes four categories of scientific investigations: control and condition, reliability of results, record keeping, and kinds of investigations. The third category states that scientific theories consist of six categories: making sense of evidence, alternative explanations, theory modifications, reliability of results, safeguards, and expectations and explanations. The overlapping categories illustrate how inquiry is treated as content.

A second policy document, the *National Science Education Standards* (NSES; National Research Council [NRC], 1996) considers inquiry as the overarching goal of scientific literacy. According to Abd-El-Kalick (2002), NSES does not operationally define inquiry. The NSES provide guidance on what science students are to know, how teachers are to teach science, and how teachers are to assess students. According to Atkin and Black (2003), the NSES "...was intended as an inspiration and guide for state and local education authorities" (p. 15). The NSES goes beyond Project 2061 in describing inquiry. First, inquiry is the first science content area that is viewed from two perspectives: what students should understand about scientific inquiry and the abilities students develop based on their experiences with scientific inquiry. Second, inquiry also includes the teaching strategies associated with inquiry-oriented science activities. Bybee (1997) argued that K–12 teachers of science should not separate science content from the processes of science. He encouraged the combining of science processes with scientific knowledge, reasoning, and critical thinking so students can develop a richer, deeper understanding of science. This inquiry in context has also been encouraged by the NSES (NRC, 1996), Howe (1997), and Project 2061 (AAAS, 1993; Rutherford & Ahlgren, 1989).

Frequently, K–12 teachers of science have viewpoints about inquiry from the post-Sputnik era curriculum and original teacher preparation program, especially if they are veteran teachers of 10 or more years. Additional clarifications about what the NSES (NRC, 1996) meant when inquiry was discussed (content, process skills, or teaching strategies). To provide clarification, the NRC (2000) published *Inquiry and the National Science Education Standards* and identified five essential features of inquiry, regardless of grade level:

1. scientifically oriented questions that will engage the students;
2. evidence collected by students that allows them to develop and evaluate their explanations to the scientifically oriented questions;
3. explanations developed by students from their evidence to address the scientifically oriented questions;
4. evaluation of their explanations, which can include alternative explanations that reflect scientific understanding; and
5. communication and justification of their proposed explanations.

"...These essential features introduce students to many important aspects of science while helping them develop a clearer and deeper knowledge of ... science concepts and processes." (p. 27). According to the NRC (1996, 2000), K–12 teachers of science must know that inquiry involves (a) the cognitive abilities that their students must develop; (b) an understanding of methods used by scientists to search for answers for their research questions; and (c) a variety of teaching strategies that help students to learn about scientific inquiry, develop their abilities of inquiry, and understand science concepts (Bybee, 2000; NRC, 1996, 2000). The NRC (1996) included a list of increased emphasis and decreased emphasis regarding inquiry (see

Table 1). These statements allow teachers of science to see whether their perspectives about the three domains of inquiry are compatible with the reform movement in K–12 science. Also, the NRC (1996, 2000) acknowledged that not all science concepts can or should be taught using inquiry. The following three paragraphs summarize interpretations about inquiry from the NRC in 1996, and each of these domains was clarified by the NRC in 2000.

The fundamental abilities of inquiry specified by the NRC (1996) are to

1. identify questions and concepts that guide investigations (students formulate a testable hypothesis and an appropriate design to be used);
2. design and conduct scientific investigations (using major concepts, proper equipment, safety precautions, use of technologies, etc., where students must use evidence, apply logic, and construct an argument for their proposed explanations);
3. use appropriate technologies and mathematics to improve investigations and communications;
4. formulate and revise scientific explanations and models using logic and evidence (the students' inquiry should result in an explanation or a model);
5. recognize and analyze alternative explanations and models (reviewing current scientific understanding and evidence to determine which explanation of the model is best); and
6. communicate and defend a scientific argument (students should refine their skills by presenting written and oral presentations that involve responding appropriately to critical comments from peers).

Accomplishing these six abilities requires K–12 teachers of science to provide multiinvestigation opportunities for students. This type of investigation would not be a verification laboratory experience. When students practice inquiry, it helps them develop their critical thinking abilities and scientific reasoning, while developing a deeper understanding of science (NRC, 2000).

The second domain of inquiry is the understanding about inquiry so students will develop meaning about science and how scientists work. The six categories identified by the NRC (1996) are as follows:

1. conceptual principles and knowledge that guide scientific inquiries;
2. investigations undertaken for a wide variety of reasons—to discover new aspects, explain new phenomena, test conclusions of previous investigations, or test predictions of theories;
3. use of technology to enhance the gathering and analysis of data to result in greater accuracy and precision of the data;
4. use of mathematics and its tools and models for improving the questions, gathering data, constructing explanations, and communicating results;
5. scientific explanations that follow accepted criteria of logically consistent explanation, follow rules of evidence, are open to question and modification, and are based upon historical and current science knowledge; and

Table 1
Changing Emphasis to Promote Inquiry

Less emphasis on	More emphasis on
Activities that demonstrate and verify science content	Activities that investigate and analyze science questions
Investigations confined to one class period	Investigations over extended periods of time
Process skills out of context	Process skills in context
Emphasis on individual process skills as observation or inference.	Understanding multiple process skills—manipulation, cognitive, procedural
Getting an answer	Using evidence and strategies for developing or revising an explanation
Science as exploration and experiment	Science as argument and explanation
Providing answers to questions about science content	Communicating science explanations
Individuals and groups of students analyzing and synthesizing data without defending a conclusion	Groups of students often analyzing and synthesizing data after defending conclusions
Doing few investigations in order to leave time to cover large amounts of content	Doing more investigations in order to develop under standing, ability, values of inquiry and knowledge of science content
Concluding inquiries with the result of the experiment	Applying the results of experiments to scientific arguments and explanations
Management of materials and equipment	Management of ideas and information
Private communication of student ideas and conclusions to teacher	Public communication of student ideas and work to classmates

(National Research Council, 1996, p. 113).

6. different types of investigations and results involving public communication within the science community. (To defend their results, scientists use logical arguments that identify connections between phenomena, previous investigations, and historical scientific knowledge; these reports must include clearly described procedures so other scientists can replicate or lead to future research).

This domain of inquiry concentrates on the how and why scientific knowledge changes when new evidence, methods, or explanations occur among members of the scientific community. Therefore, they will vary by grade level, but will be very similar, except with increasing complexity (NRC, 2000). Science methods courses need to provide future science teachers with exemplary examples of inquiry as a content area. The vast majority of their K–12 and college science laboratory experiences have not modeled inquiry as content. Teachers need to have inquiry modeled for them because they need to see the benefit for their future students. For the vast majority of future science teachers, this is not their personal experience. Providing a model of quality instruction could enhance their view of scientific literacy.

The third domain of inquiry of the NSES is found in the teaching standards. There are several teaching strategies that facilitate students' developing a better understanding of science. Science teacher educators need to provide experiences and information so that future K–12 teachers of science can provide high-quality inquiry science lessons. Aspects of inquiry teaching include strategy to assess students' prior knowledge and ways to utilize this information in their teaching; effective questioning strategies, including open-ended questions; long-term investigations, rather than single-period verification-type investigations, and so forth. To accomplish high-quality instruction, preservice students need to participate in collaborative learning opportunities. By pairing with similar observations in their field experiences with master teachers of science, they will develop a better personal model of how inquiry teaching facilitates students learning of science.

According to Anderson (2002), the last half of the 20th Century associated inquiry with "good science teaching and learning." His synthesis of the research about inquiry identified that both teachers and students must be considered. Anderson considered that science teacher's beliefs and values about students, teaching, and the purpose of education influence their adoption and implementing of inquiry. Specifically, he described three barriers or dilemmas that influence the implementation of inquiry as envisioned by the NSES (NRC, 1996):

1. *Technical dilemmas* include the ability to teach constructively; the degree of commitment to the textbook; the challenges presented by state assessments; the difficulties of implementing group work; the challenge of the new teacher role as a facilitator; the challenge of the new student role as an active, rather than a passive, learner; and inadequate professional development.
2. *Political dilemmas* (short-term or limited professional development programs, parental resistance that science is taught differently than they experienced, unresolved conflicts among science teachers about what and how to teach, lack of

available resources, and differing views about failures) must be addressed at local and state levels because of funding ramifications.
3. *Cultural dilemmas* include quality of textbooks and support materials, views about purposes of assessment, and view of preparation for the next science class.

According to Anderson, these dimensions must be addressed systematically.

Using Anderson's (2002) dilemmas, there are a number of reasons that inquiry will not be enacted as recommended by such the policy documents as Project 2061 and the NSES (NRC, 1996), although, the NSES have a section on attributes of professional development where inquiry has long-term professional development recommendations addressing all three domains of inquiry. Also, some teachers could still have the belief that inquiry focuses upon single process skills (Lederman, 2004). Therefore, they will need to understand the current view of the meaning of inquiry. This will require a significant amount of time for K–12 teachers, as well as higher education faculty to become competent in a standards-based approach for inquiry. According to Caprio (2001), the supervisor must also be comfortable with inquiry to be able to help their staff. According to McIntosh (2001), science faculty will need to modify their planning so that the science class has true course goals of content and inquiry. This will be labor intensive because it also requires students to modify their role (e.g., design their own experiments, report their findings to peers, etc.); and, because it will probably be different from their previous course work, teaching assistants will need to have extensive preparation.

New K–12 teachers of science need to have had experiences where inquiry plays a dominant role in preservice science courses. Siebert (2001) recommended that laboratory experience should foster inquiry, rather than being confirmation. This can be accomplished when the research-oriented laboratory experiences involve group work and are open ended and long term, rather than single period. These experiences are more closely aligned with scientists' research projects. It is hoped that, in their science methods course(s), inquiry is a critical component. These future teachers need to experience inquiry as a learner and observe it happening in their field experience settings. All teachers of science (K–16+) must value inquiry, rather than "talk about it, but don't practice it."

Chinn and Malhotra (2002) constructed a theoretical framework to compare authentic inquiry done by research scientists with K–12 school-based inquiry. They contend that school-based inquiry results in students' viewing reasoning as simple, certain, and algorithmic, with surface-level observation being emphasized, thereby resulting in K–12 students having a distorted belief about science. They focused upon elementary and junior high science textbook activities in their analysis. They reported that only 2% of the textbook activities allowed students to select their variables, fewer allowed students to plan how they would control variables, and only 17% had multiple observations. Their findings complemented Germann, Haskins, and Auls' (1996) research about laboratory investigations in high school biology laboratory manuals. The essential features will vary by the amount of structure a science teacher establishes for the investigation or students' ability to design and conduct an investigation. Therefore, science methods faculty must provide in-depth study so future teachers of science are comfortable with abilities, understandings, and effective teaching strategies for inquiry. Because of limited available inquiry laboratories in textbooks, Volkmann and Abell's (2003) suggestions for modifying a "cookbook" investigation into an inquiry investigation should be considered. Specifically, they recommend 10 adaptation principles focusing upon changing the purpose to a relevant question; replacing procedures or recipes where a class or groups of students identify variables and develop operational procedures; giving explanations after the laboratory, rather than before, so students are looking for patterns to develop explanations; and presenting explanations to others through a variety of communication formats (oral, poster, or written).

Reources by Cothron, Giese, and Rezba (1996) can be used to help future teachers of science develop an understanding about inquiry via of experimental design. To accomplish this task, Cothron et al. utilized a four-question strategy. Their four questions are as follows:

1. What materials are readily available for conducting experiments on ____________ (general topic)?
2. How can I change the set of ____________________________ (general topic) materials to affect action?
3. How does _______________________________ (general topic) act?
4. How can I measure or describe the response of _________________________ (general topic) to change?

This general format allows students to then generate their experimental design to address the question being studied.

Lee and Fradd (2001) developed an inquiry matrix consisting of questioning, planning, implementation (carrying out the plan and recording), concluding (analyzing data and drawing conclusions), repeating, and applying. As students develop greater confidence in conducting a scientific inquiry (using the four-question strategy), they will become more responsible for conducting their own inquiry. Therefore, the role of a teacher will be to provide assistance for individuals or teams of students to improve their inquiry competency. The use of the four-question strategy (Cothron et al., 1996), with the resultant experimental design, addresses some of the weaknesses of textbook investigations noted by Chinn and Malhorta (2002). Textbook investigations are frequently called "cookbook" because the students just follow the recipe to complete a science activity. In this model, a scientific question can be provided by the teacher or left to the team of students to formulate before sharing with the science teacher. The four questions help students identify what materials, variables, and measurement strategies should be used. When students list all the different ways that things can be changed, they become aware that multiple measurements help students to be aware that a single trial does not "prove" things. The four-question model provides students with a consistent plan as they move from partial to full inquiry as recommended by the NSES (NRC, 1996, 2000).

Closing

Over the past century, science educators have provided multiple interpretations of inquiry. Consequently, K–12 teachers of science, students, and parents are confused. To help clarify, the NRC (2000) released *Inquiry and the National Science Education Standards*. This was done because many readers of the NSES were unclear about what inquiry means. Every inquiry must engage students in a scientifically oriented question. These questions must be of interest to the student; otherwise, they will not establish ownership.

Siebert and McIntosh (2001) separated the responsibilities for preparing teachers of science to science faculty and education faculty. They specified that science faculty are primarily responsible for students' science knowledge, understanding the nature of science, understanding and using scientific ways of thinking, and making connections with applications to their world beyond the classroom, while the responsibilities of the education faculty are to provide future teachers of science information related to teaching and learning; mentor to assist their study and reflection; and use their own research to make informed decisions about the quality of curriculum, instruction, and assessment in their classrooms. What if the responsibilities of the science faculty are not stressed? Should education faculty add that responsibility to their syllabi? What about education faculty who lack the background or experience of a science educator? There needs to be a shared understanding about inquiry by both science and education faculty. Otherwise, these future teachers of science are not going to be prepared to implement inquiry as recommended by the NSES (NRC, 1996, 2000). Rather than providing improved understanding about inquiry and how to implement it, teachers of science will only internalize a partial understanding. Anderson's (2002) dilemmas will need to be addressed for total implementation to occur. In addition, all three aspects of inquiry—ability, understanding, and teaching—must be modeled so teachers of science will be able to do, know, and instruct, thereby promoting scientific literacy as viewed by the NSES (NRC, 1996).

Weiss, Pasley, Smith, Banilower, and Heck (2003), in their study of science education in classrooms, noted that inquiry as content for observed classes ranked from 15% in grades K–5 to 2% in grades 9–12. By looking at these samples, we must realize that there is a problem. Science educators are recommending the use of inquiry, but there is little impact in the K–12 schools. Based upon the definitions currently used for inquiry (Minstrell, 2000; Barman, 2002; Lederman, 2003), there is no uniform agreement among the science education community about what is the meaning of inquiry as recommended by the NRC (1996). This results in new K–12 teachers' feeling confused when interacting with others from different degree programs. Veteran K–12 teachers of science possibly are retaining their definition of inquiry from their teacher preparation program. Are the common science education practitioner journals implementing the NSES recommendations in their publications? If not, this adds to the confusion.

As recommended by the NSES (NRC, 1996), professional development programs for K–12 teachers of science need to model inquiry in their offerings. It should be assumed in planning for these sessions that there is no uniform agreement about what is inquiry. These sessions need to provide the opportunity for participants to become comfortable in doing inquiry themselves before expecting them to implement inquiry in their classroom. Model inquiry units and lessons should be demonstrated. This could include classroom visitations, video, and vignettes, with a debriefing afterwards. Consultative assistance should be available as teachers implement inquiry lessons.

Unless science teacher preparation programs provide an inquiry orientation to both their education and science courses, there will not be a major impact on seeing inquiry in K–12 classrooms. This must be addressed at both the preservice and inservice levels. In their preservice program, future K–12 teachers of science must personally experience inquiry in their science content courses as recommended by Siebert (2001). Their science methods courses must include early field experience where they are observing master teachers' practicing inquiry in their classrooms. Many times these preservice students have been very successful in noninquiry classrooms, so there will be a need for debriefing and analysis of teaching experiments. Both the methods and science courses must model where science is a verb, rather than a noun.

Based upon Smith and Gess-Newsome's (2004) review of a national sample of elementary science methods syllabi, there is not universal incorporation of the teaching standards from the NSES (NRC, 1996). It is possible that the same pattern could exist for inquiry in science methods courses. A future study should be conducted to determine if a similar pattern exists.

Science teachers who implement inquiry as described in this paper must be aware that students will requirea longer learning time because students bring to each investigation their current explanations and abilities (prior knowledge). However, research studies (Bransford, Brown, & Cocking, 1999) have shown that students will develop a deeper understanding of the science concepts when their prior knowledge is considered as they integrate new knowledge. Over the past century, inquiry had multiple meanings. I hope that, in the first decade of the 21st Century, we can reach consensus about what is inquiry by using the three domains of inquiry (abilities, understandings, and teaching strategies) as described by the NSES (NRC, 1996).

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