WHITE PAPER

Inquiry in Science Classrooms

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Recent reforms in the teaching of science have emphasized the importance of inquiry-based teaching strategies. Built on the premise that students learn best through direct experience and through the incorporation of new and existing knowledge, inquiry-based instruction is considered the "primary vehicle for students to develop meaningful understandings of key science concepts as well as learn about the nature and process of science" (Dunkhase, 2003, p 10). The teaching of science through inquiry is vital for U.S. students to become not only knowledgeable consumers of scientific products and technologies, but also to achieve on par with their international counterparts.

In an attempt to determine levels of student performance and student trends in science achievement, the U.S. Department of Education Institute of Education Sciences: National Center for Education Statistics released a report entitled the *Trends in International Mathematics and Science Study* (TIMMS). This study, conducted in 1995 and again in 2007, examined the science achievement of fourth and eighth grade U.S. and international students in various countries around the globe. The 2007 study revealed that at grade four, only two countries (Singapore and Chinese Taipei) exhibited higher percentages of students performing at or above the advanced international science benchmark than U.S. fourth-grade students. However, as students advanced to the eighth grade, the United States slipped in achievement rankings. At grade eight, six countries (Singapore, Chinese Taipei, England, Japan, Republic of Korea, and Hungary) exhibited higher percentages of students performing at or above the advanced science benchmark, than U.S. eighth grade students. Perhaps just as concerning is the trend in performance of U.S. students, which revealed no significant improvement or increase in science achievement scores from 1995 to 2007 (http://nces.ed.gov/pubs2009/2009001_2.pdf)

Traditionally, science instruction has relied heavily on teacher-lead, direct instructional strategies with particular emphasis on student acquisition of content knowledge. In contrast, inquiry-based instruction places the student in the driver's seat; designed to actively engage students' pursuit of knowledge, inquiry-based teaching methods permit students to search for answers to their own questions, and by doing so, take ownership of the process. Inquiry-based science instruction has demonstrated promise for fostering student interest in science and increasing levels of achievement (Geier, Blemenfeld, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008; Haury, 1993; Palmer, 2009), critical if students are to compete globally.

What Is Inquiry?

Inquiry is a "broadly defined construct in science education" (Windschitl, 2003, p 113), and there are various conceptualizations of inquiry-based teaching. The National Research Council's (NRC) *National Science Education Standards* (1996) is the impetus behind the reforming of science education instruction, and provides within the standards a rather vague conceptualization of inquiry:

Inquiry 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 answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries. (National Science Education Standards, 1996, p. 23).

The critical piece in a definition of scientific inquiry is the notion that inquiry is generated from students' experiences; that is, inquiry should be student-centered and student-driven. "Students need to personally construct their own knowledge by posing questions, planning investigations, conducting their own experiments, and analyzing and communicating their findings" (Jarrett, 1997, p 2). When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills (National Science Education Standards, 1996). It is the ownership of the experience that generates deeper understanding.

One of the benefits of using inquiry-based practices is the bridging of *content* and *process*. *Content* refers to the actual material that is to be learned after completing an activity, consists of facts, definitions, and formulas. *Process* refers to those activities that foster the acquisition and mastery of content. Within the context of science instruction, *process* often involves such activities as planning, hypothesizing, observing and reporting. (Gunstone, Loughran, Berry, & Mulhall, 1999 p.4). Inquiry provides a way to forge content and process, since it "focuses on content knowledge in the context of the process of developing scientific understanding" (Dunkhase, 2003, p. 11). This blending is critical, if students are to acquire not only the products of science, but also the process.

While there are various conceptualizations regarding what, exactly, constitutes scientific inquiry, there are general points of agreement among researchers concerning what inquiry is *not*. Inquiry is not represented by a fixed, standardized set of procedures, or "cook-book" methods of instruction. Inquiry is not completely synonymous with the "scientific method," which itself takes many forms and contains no universally-agreed upon procedures (Windschitl, 2003). Rather, inquiry is a more subtle, flexible process that is highly demanding on both student and teacher (Jarrett, 1997) and requires highly levels of active participation and student engagement.

Inquiry in practice generally ranges among a continuum, characterized by the degree of independence students possess in formulating questions and generating the plan for answering them. Windschitl (2003) describes four levels of inquiry, ranging from the lowest amount of student independence to the highest. The first level of inquiry is known as *confirmation experiences,* where students follow a specified laboratory procedure to verify a known scientific claim. At this level, the question under investigation, answer, and method for replicating the findings are provided to the students. This level contains the lowest level of student independence, and the most teacher direction. The second level, *structured inquiry*, occurs when the instructor presents a question to which the answer is unknown to the students. The instructor then provides a method or procedure to the students, who follow the method and answer the question. This level serves as the beginning stage in familiarizing students with inquiry-based practices. The third level, *guided inquiry*, occurs when specific questions for investigation are posed by the teacher, but the students are free to develop their own plan for answering the question. This level requires more student engagement and higher levels of critical thinking skills. The final stage of inquiry, *open* or *independent inquiry*, occurs when teachers permit students to generate their own questions for investigation and allow them to independently design a method of analysis, thus fully engaging the student in the inquiry process (Windschitl, 2003, p 114).

iSCIENCE For examples of inquiry see the Inquiry Labs and the Guided Inquiry in the Integrated iScience (Owl), Vol. 1, Chapter 6, Lesson 3, pp. 224-225.

Teachers who implement scientific inquiry are "actually practicing the art, rather than the act, of teaching" (Gooding & Metz, 2008, p 12), and while inquiry is a dynamic, fluid process, teachers and students each play specific roles during inquiry-based learning. Leonard and Penick (2009) provide a list of behaviors in which teachers and students typically engage during authentic inquiry:

Students typically:

Make initial observations;

Pose (or respond to) researchable questions;

Formulate predictions or cause and effect hypotheses to test these research questions;

Plan procedures that identify relevant variables and produce data to test these research questions;

Collect, organize, and display data

Analyze data and craft tentative inferences to evaluate predictions or hypotheses;

Share ideas, results, and inferences with a group that provides feedback on potential validity and utility;

Revise, if necessary, the evaluation of the data; and

Reach a formal consensus on answers to the research questions (p 41)

Teachers typically:

Create a safe, stimulating environment where students feel free to explore, question, digress, and communicate;

Ask questions that require thinking and thoughtful responses or action on the part of the students;

Listen to what students say and respond in ways that encourage students to examine and investigate ideas, questions, and suppositions;

Promote multiple and creative ideas for researchable questions as well as ways to conduct investigations; and

Develop classroom characteristics that place value on student communication, diversity; individuality, and intellectual freedom (p 41).

Inquiry in Early Elementary

One method used successfully in early elementary classrooms is an *inquiry path*. Described by Villavicencio (2000), the inquiry path consists of an organized structure that guides students as they explore scientific phenomena. Essentially, the inquiry path consists of five parts:

1. Form a question

2. Make a plan

3. Do the investigation

4. Record and report

5. Reflect, revisit, and plan again

Students are expected to be accountable for each stage of the process, with the teacher providing support by observing and providing feedback. Another procedure, utilized by Bresnick (2000) with her first-grade students, begins by having students participate in an unstructured free- exploration with science materials. Students share observations and design their own experiments based on their experience with the science materials. These mini-investigations are completed using a template containing three parts: "I wonder...," "the plan..." and "I found out...". Through teacher modeling and questioning, students begin to engage in inquiries that are more focused and meaningful and develop their skill in taking ownership of the scientific process.

Inquiry in Middle and High School

Marrero (2000) describes four stages of inquiry that may be used with middle and high school students. Not explicitly labeled, but perhaps best described by the term, *exposure*, students are provided multiple experiences with the phenomenon under investigation. This provides concrete experiences on which students can draw in formulating their own research questions. After exposure to the topic of interest, students move onto the second stage of inquiry: *planning and predictions*. In this stage, students formalize their research questions, create a research plan, and make predictions about the results. Teacher monitoring and feedback are critical for the procedure to be successful. Marrero states that it is "extremely important for students to be given feedback on their plan before they begin their investigation. I like to conference with each student or group of students before they begin their plan. If the investigation is not clear, the investigation won't work" (p 2). The third stage, *investigation*, represents student engagement as they perform their analysis. At this point, the students act independently and observe and record their findings. The final stage, *summary*, represents the summarization of student findings. The summaries may be delivered in a written form or presented orally, but must contain a restatement of the question or topic, description of the investigation, and interpretation of the results.

iSCIENCE See MiniLab on p. 424 of Integrated iScience (Owl), Vol. 2, Lesson 2 for an example of inquiry.

Challenges in Using Inquiry-Based Teaching

Inquiry-based teaching is not without its challenges, and some teachers, accustomed to more traditional methods of science instruction, are hesitant to adopt such techniques. These teachers are often required to adjust preconceived notions about how science should be taught, and this can be a challenging undertaking (Lustick, 2009). Some teachers often view student-lead inquiry as too open, without enough teacher direction (Anderson, 1998). Implied in the teaching of science is that there exist "expected" answers, and the withholding of answers when they are sought by students is challenging for educators (Furtak, 2006; Windschitl, 2003). In primary classrooms, inquiry-based teaching strategies are not often used as they are considered by some teachers to be difficult to implement with younger learners who may not possess the content knowledge or developmental maturity to work as independently (Leonard, Boakes, Stokton, & Moore, 2009). The level of support teachers receive from their peers and mentors also impacts the degree to which teachers implement inquiry-based instruction in their science classes (Bianchini & Cavazos, 2007). If, however, teachers are equipped with the tools and education needed to implement inquiry-based strategies and receive support from peers and mentors, they are often successful in implementing inquiry-based practices in their classrooms (Wee, Fast, Shepardson, & Harbor, 2004).

Summary

The emphasis on increasing student achievement and fostering student interest in science has lead to the development of innovative methods of instruction. Inquiry-based teaching is a fluid, dynamic teaching method that blends scientific content knowledge and scientific process. Designed to capture the natural curiosity of students and engage them in the process of conducting scientific investigations, inquiry-based methods are quickly becoming a central component of science classrooms around the globe.

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