Effectiveness and Accountability of the Inquiry-Based Methodology in Middle School Science

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ABSTRACT

When teaching science, the time allowed for students to make discoveries on their own through the inquiry method directly conflicts with the mandated targets of a broad spectrum of curricula. Research shows that using an inquiry-based approach can encourage student motivation and increase academic achievement (Wolf & Fraser, 2008, Bryant, 2006, National Research Council (NRC), 2000). On the contrary, other research points out that students at the middle school level are unable to properly and effectively perform the necessary and relevant steps of inquiry (Krajcik, Blumenfeld, Marx, Bass, Fredricks, 1998, Jeong, Songer, Lee, 2006). One aim of this paper is to support the findings that, with age-appropriate subject matter and scaffolding, middle school students are capable of inquiry learning and benefit greatly through its usage. Another goal is to highlight that the underutilization of the inquiry method, though supported by national science standards, is due to a lack of accountability in high stakes testing. This lack of inquiry accountability is undermining the inquiry science curriculum movement.

CHAPTER 1: INTRODUCTION

I recall learning about the concepts of lift and drag and their effects on an object's motion as a student in my 7th grade science class. We flew model paper airplanes in order to deduce the best setting of the wing foils for appropriate lift-to-drag ratio. I remember that the entire class was interested and involved in the subject matter and I became inspired to further my learning in science at that time. The inquiry-based method of teaching science continues to intrigue me because it encourages student curiosity and promotes self-directed investigation and discovery. As a first year science teacher, I want to examine the methodologies that would best inform and guide my teaching methods in the classroom, as well as benefit the students.

Statement of Problem

The effectiveness of the inquiry-based model is supported in the literature, but the implementation of such methods has shown to be a challenge. In the age of standardized tests spanning a wide range of curriculum, the time available for and practice of inquiry are being minimized (Manley, 2008).

Purpose Statement

One purpose of this paper is to evaluate previous research and ascertain why various researchers have yielded divergent results. Multiple studies favor the inquiry-based method, in that acting on a student's curiosity and problem-solving abilities will intrigue the student and promote self-discovery. Considering increased student

engagement, one might assume that the usage of inquiry would be beneficial for both short-term and long-term student achievement in science. A goal of this paper is to point out the necessity to incorporate this highly recommended student-driven approach to teaching science.

Another purpose of this paper is to point out the lack of accountability of the inquiry-based methodology in science. International tests with high degrees of inquiry-based questions have highlighted the need to improve science achievement at both middle and high school levels. However, the response to these outcomes is a high stakes test that emphasizes the memorization of a wide range of curriculum instead of on skills necessary to conduct and approach science (i.e. the tests stress rote memorization over the demonstrably necessary skills of critical thinking). It is generally accepted that domestic science assessments have shown deficiencies in science education when compared against international test results; however our response to these identified deficiencies currently fails to adequately address underlying problems.

The overall objective of this paper is to add to the current knowledge base, and hopefully support the case for incorporating inquiry-based teaching and learning in the classroom, as well as including inquiry in national assessments.

Research Question

How does an inquiry-based teaching and learning activity compare to a non-inquiry activity in the area of science with regards to student achievement and attitudes among middle school-aged students? As the inquiry method is considered of key importance to the learning of science and mirrors how science is conducted (National

Science Teachers Association, 2005), what is being done to ensure the nationwide usage of inquiry in the middle school science classrooms?

Theoretical Rationale

Humans are inherently curious, and learn about the world around themselves through a variety of trial-and-error techniques (NRC, 2000). Children and adults alike, when trying to make sense of an unfamiliar situation, make observations, organize data, and synthesize information, as well as check and recheck the process and results (NRC, 2000). This innate style of learning and highly developed capacity is referred to as inquiry (NRC, 2000), and utilizing this approach is referred to as inquiry-based methodology.

Inquiry-based learning is a form of discovery learning, fostering problem solving and reasoning skills, and is therefore embedded in the theory of constructivism (Ornstein, Lasley, & Mindes, 2005). Constructivism is an approach to teaching based on the notion that students learn best when drawing upon their prior knowledge in conjunction with their own exploration, experimentation, and discovery (Brooks & Grennon, 1990). Jean Piaget was a pioneer in the theory of constructivism, as his studies deduce that children cannot be given information and automatically understand and use. They must be able to construct their knowledge, and continue to do so, through experience (Clark, 1999).

The focus of inquiry-based learning is a “hands-on” approach with the student in control of his/her learning and the teacher acting as a facilitator, unlike that of the traditional approach, which relies heavily on lecture, the use of a textbook, and the memorization of facts (Hebrank, 2000).

Assumptions

There are three major assumptions that promote the development of this research. The first is that students have a greater motivation, therefore higher overall achievement, when learning through an inquiry-based method. Wolf and Fraser (2007) conducted experiments and surveyed 71 middle school science classes. They found significant improvements in student attitudes and classroom environment perceptions when inquiry-based activities were conducted. Student attitudes must be positive for optimal improvement of knowledge (Brunkhorst, 1987; Jarrett, 1997).

A second assumption is that science teachers have adequate time available to both teach this type of model, and cover the scope of curriculum standards. Inquiry-based activities are a necessary component in the science classroom and are beneficial among aspiring student scientists (NRC, 2000). Also, inquiry-based activities can be completed in as few as one to two lessons (Wyatt, 2005). With this in mind, teachers can integrate inquiry into their teaching strategies and no longer rely on the excuse that there is not enough time available.

A third assumption is that currently, the focus in the science classroom is put too much upon standardized test taking knowledge and skills. Because of this focus, many teachers do not follow the principle of using inquiry in the classroom set forth by the National Science Education Standards (Manly, 2008). With the No Child Left Behind legislation, there is much pressure put upon teachers to cover all the facts within the curriculum. However, this fact-memorizing method of learning does not benefit the student as they fail to see how the information applies to their lives, and therefore lowers motivation (NRC, 2000).

Background and Need

Recent U.S. science test score results indicate that students are not competitive on an international level (4Choice, 2008). This is of great concern and merits research to find potential causes. Twelve years earlier, the National Research Council (NRC) put forth national science standards incorporating the teaching and learning approach of inquiry (NRC, 1996). Yet, the National Research Council (2000) still discovered that the majority of teachers were using traditional lecturing methods. Students are memorizing "disconnected" facts, but not developing critical-thinking skills, problem-solving skills, or the ability to relate these facts to real life.

Several opposing studies have been conducted regarding the effectiveness of the inquiry approach. Krajacik et al. (1998) and Jeong et al. (2004) came to similar conclusions that students at the middle school level had difficulties with inquiry-based activities, such as in asking questions based on scientific merit, deciphering between relevant and irrelevant evidence, and drawing conclusions based on data collected. Based on these observations alone, the conclusion that inquiry-based activities are not an effective practice at the middle school levels may be reasonable.

On the other hand, several studies have been performed and conclusions drawn in favor of the NRC standards. Wolf and Fraser (2007) found that through inquiry activities student attitudes and motivation toward science greatly improve, and inquiry activities contribute to a supportive classroom environment. Bryant (2006) found student achievement was higher in inquiry activities vs. non-inquiry activities. Based on these

studies, inquiry appears a paramount method as it increases achievement, attitude, and motivation.

CHAPTER 2: REVIEW OF THE LITERATURE

The review of the literature covers eight themes. The first theme, *Historical Perspectives* focuses on the theories that contributed to the development of the pedagogical approach of inquiry. The next section, *Student Achievement in Science*, draws attention to low science test scores in the United States and postulates that the methodological approach is the cause. *Inquiry Fundamentals* unveils the basic elements of the approach of inquiry learning and teaching, and *Reasons For Inquiry* explains the benefits of the teaching practice. *Difficulties of Inquiry-Based Methods* explains the reasons inquiry activities can be troublesome and therefore not utilized as often as recommended. The *Methods and Limitations of Literature* section explains the various approaches researchers have taken in order to study the effectiveness of inquiry-based methodology. *Findings From the Literature* discusses what was observed and the conclusions of these studies. *Other Sources of Information* provides context to a variety of viewpoints and outlooks associated with the literature.

Historical Perspectives

Until the 20th century, educators viewed science, as well as most content areas, as best learned through direct instruction (NRC, 2000). John Dewey (1897) was the first to challenge the sole use of this method by emphasizing the importance of stimulating a student's interest and connecting with the student's prior knowledge. Dewey (1910) declared that the subject matter of science is so vast that it is imperative for educators to focus on the methods and techniques of scientific inquisition to best prepare students for the future. Schwab (1960) expands upon and refines Dewey's emphasis of a "methods first" approach by stressing the authenticity of conducting experiments first, then looking

to explanations and scientific concepts afterwards to reinforce what was observed. Schwab agrees that this initial hands-on approach will provide greater scientific knowledge and understanding.

Mehan (2007) points out that the major developer of an inquiry-based teaching and learning method was Richard Suchman, as he put forth the Inquiry Training Model in 1962. In this model, students are actively engaged and responsible for constructing their own knowledge through a series of 5 phases (Mehan, 2007): (1) encounter the problem, (2) gather data, (3) experimentation, (4) formulate rules and explanations, and (5) analyze findings and processes that lead to long-term strategies. In this model, the teacher acts primarily as a facilitator and the student is responsible for his/her learning. Constructing knowledge by means of learning “how to learn” takes precedence over what is being learned (Youth Learn Initiative [YLI], 2003).

Student Achievement in Science

Data recently collected regarding science achievement compares students of the United States to those around the world. One 2003 comparison study, called the Trends in International Mathematics and Science Study (TIMSS) measures the degree to which students recall the curriculum knowledge (Brown & Brown, 2007). A second international test, called the Program for International Student Assessment (PISA) was given in 2003 and 2006 and assesses whether students can apply learned concepts to real-life problems (Brown & Brown, 2007). United States’ 15 year-old students ranked 19th out of 21 nations with regards to math and science literacy on the TIMMS in 2003, and 29th out of 34 nations in science on the PISA test in 2006 (Hodges, 2007). The scores

from PISA test, which are well below average in 2006, had similar results the previous time the test was given in 2003 (Glod, 2007).

A major factor for the low achievement scores is due to teachers relying too heavily upon textbook usage. Research indicates that over 90% of science teachers rely almost solely on their textbooks to direct their teaching (Park, 2006). In 2006, the National Research Council (NRC) produced the National Science Education Standards, which address a need to shift emphasis away from the textbook method and incorporate a component of inquiry into the standards. One of the eight categories of the content standards for grades K-12 is titled “science as inquiry” (NRC, 1996). The National Science Teachers Association (NSTA) had already recommended that K-16 teachers adopt scientific inquiry as a primary method used in the classroom two years earlier (NSTA, 2004).

Inquiry Fundamentals

Inquiry-based learning is the method of gaining knowledge through curiosity, developing questions, experimenting, and finding out the answers to those questions (Saskatchewan Education, 1991). Students take responsibility for their own learning by analyzing and organizing their discoveries, and communicating their findings (Jarrett, 1997). This type of learning is closely associated with the nature of scientific discovery, where learners must inquire using their background of knowledge and construct new knowledge using the inquiry process (NRC, 2000). The National Science Education Standards (NSES) states that inquiry requires reflective and divergent thinking, as the learner must identify his/her own assumptions, use critical and rational thinking, and

consider alternative interpretations of the results (NRC, 1996). Scientific inquiry can be defined as the complex manner in which scientists view and explain the natural world using their observations (NSTA, 2005).

Reasons For Inquiry

The process of inquiry, where learners experiment with and discover their own conclusions, provides context among the facts and processes used and learned. This context promotes the likelihood that students will understand and retain what they have learned (NRC, 2000). Inquiry lends itself to a variety of learning styles. It is flexible in the manner in which a conclusion is reached, and is particularly well suited for a collaborative-learning environment (Hebrank, 2000). Students are able to learn from their interactions with peers when the classroom is opened into a social setting (NRC, 2000).

The inquiry method is flexible in terms of whom it reaches, remaining effective with students of varying ages and abilities, as it relies on each student's own curiosity and pertinent questions (YLI, 2003). Due to this flexibility, inquiry-based methods can be cross-curricular, as there are no limitations to a student's curiosity and because scientific phenomena and research are embedded in multiple core subjects (Hebrank, 2000).

Of utmost significance, inquiry-based learning promotes student motivation (e.g. Jarrett, 1997, NRC, 2000, Hebrank, 2000). The content being taught relies on student curiosity, prior knowledge, and issues to which a student can relate. Research shows that students have better attitudes towards science when they are more actively involved in the learning process (Jarrett, 2000, Jorgenson, 2005). Many students who do not normally

do well under traditional “scope and sequence” methods, where the teacher decides what information is important, excel in an inquiry-based classroom when their curiosity, ownership of learning, and confidence are encouraged (YLI, 2003). With these considerations in mind, the inquiry-based method helps a student develop problem-solving and decision-making skills necessary throughout life (Hebrank, 2000) and promotes the chances that a student will pursue the study of science at a higher academic level.

Through historical perspective and current studies, the developers of the National Science Education Standards noticed that the majority of science teachers were using traditional, lecture-based teaching methods, leading to a wide range of disconnected facts (NRC, 1996). In response to these findings, a shift in science methodology was incorporated into the national science standards to utilize the teaching and learning methods of inquiry in order to promote cognitive skills, such as critical and rational thinking, in addition to content (NRC, 2000). Research reflects various opportunities for improving student achievement through the use of inquiry-based strategies. Multiple school districts across the United States have recorded higher standardized test scores, higher enrollment into higher level science classes, and better attitudes towards science as a result of multiple years of inquiry-based science classes (Jorgenson, 2005).

Difficulties of Inquiry-Based Methods

Due to the reasons listed above, the inquiry-based methodology is considered by many to be an imperative aspect of science curriculum and teaching. However, recent research also shows the difficulties teachers face in attempting to implement inquiry-

based learning strategies. Some teachers are afraid that they may lose control of learning. Teachers often require extra training in order to provide developmentally age-appropriate scaffolding, the basic foundations needed for the particular learning activity (Trautmann, Avery, Krasny, Cunningham, 2002) or methods for interpreting data (Krijcik et al., 1998). It is imperative that teachers learn how to effectively guide or expand student thought for optimum student achievement (Wolf & Fraser, 2008).

Students may also be intimidated and discouraged by the inquiry model as they may be accustomed to being told what to do and which processes and answers are correct (Trautmann et al., 2002). Students often have difficulty asking pertinent questions to guide the inquiry process (Wolf & Fraser, 2008). These initial difficulties, and/or potential teacher disappointment with student performance, can lead to a hasty dismissal of the method (Krajcik et al., 1998). Another critical aspect of the potential for the student to learn from the inquiry method is the need of a risk-free environment (Wolf & Fraser, 2008). A student needs to feel safe in the classroom and free to communicate his/her thoughts and ideas.

Time constraints are another problematic issue that many teachers feel deters them from inquiry-based activities. Standardized tests cover a broad spectrum of content and it is difficult for teachers to spend the required amount of time on a single process of inquiry (Wolf & Fraser, 2008) when they are required to cover so much content. Not enough time is also a challenge when it comes to teacher training of effective inquiry-based teaching methods (Trautmann et al., 2002). Within all of the time constraints, it is inevitable that not all students will achieve all of the goals put forward (Wolf & Fraser, 2008).

Methods and Limitations of Literature

In each of these studies that have been conducted to demonstrate the advantages and disadvantages of inquiry-based teaching and learning, different methods were utilized with corresponding limitations. Comparative research has been conducted using inquiry-based lessons and assessments compared against non-inquiry (traditional) lessons and assessments, such as those by Wolf & Fraser (2008), Kalia, (2005), and Bryant, (2006). Parallels are then drawn to student achievement between the two methods. Another type of research used to explore the effectiveness of the inquiry method is a case study, a longitudinal research method where an independent variable, in this case the teaching and learning method, is monitored over a period of time and its outcome analyzed, such as with Schneider, Krajcik, Marx, & Soloway, (2002) Krajcik et al. (1998), and Brunkhorst (1987). Interviews of members within the sample are another way to assess the effectiveness of inquiry-based methods for teaching science from the perspective of those actively involved.

The literature cited has some limitations. First, as a general rule, smaller sample sizes yield larger sampling errors, and the smaller and subtler the anticipated differences in the sample, the larger the sample needs to be (Pyrczak, 2006). Krajcik et al. (1998) used two classes taught by two teachers, Kalia (2005) used one class taught by one teacher, and Wolf and Fraser (2008) used a sample of eight classes. These relatively small sample sizes cannot provide conclusive evidence to support or contradict the effectiveness of the inquiry approach on all learners. Furthermore, the sample studied by

Wolf and Fraser (2008), as well as by Schneider et al. (2002) was primarily Caucasians, therefore limiting their findings to generalize only for other Caucasian groups.

Another limitation to consider is the method used for assessment. Wolf and Fraser (2008) were limited to measuring the level of student achievement to a relatively short test. This can provide for a margin or error. There were no student interviews given during the study by Krajcik et al. (1998), so they did not capture student considerations or thought processes along the way during the activities. This makes it difficult to assess whether the students were learning throughout the inquiry process, rather than based solely on the results of a summative assessment. In the comparative study performed by Bryant (2006), it is troublesome to assess whether the difficulty levels of each of the two comparative assessments was equal, as this could skew the results. Finally, the case study performed by Schneider et al. (2002) compared the results of the 1996 National Assessment of Educational Progress (NAEP) science test of students enrolled in a project-based science (PBS) program, which is based on the inquiry methodology and utilizes student-directed learning, versus students in traditional methods science class. In this case, the test was the control, however, the students are the independent variable, which can lead to skewed results.

Findings From the Literature

Conclusions have been drawn in favoring the inquiry-based methodology, though to varying degrees. Some findings have shown that student success was significantly greater when utilizing an inquiry-based activity (Bryant, 2006; Schneider et al., 2002). Another study showed that student achievement from an inquiry activity was only

slightly greater than from a traditional activity (Wolf & Fraser, 2008). In an additional study, student achievement from an inquiry-based model equaled that from a traditional model (Kalia, 2005).

The following studies evaluated learning environments and student attitudes comparing the two methods. One study showed that inquiry classrooms have significantly higher “student cohesiveness” and slightly higher “involvement, task orientation, and cooperation” than non-inquiry classrooms, while “student attitudes” were found to be similar (Wolf & Fraser, 2008). Positive student attitude and classroom environment traits are all necessary in exemplary science programs (Brunkhorst, 1987). When evaluating the variable of gender, Wolf and Fraser (2008) found that overall, the perception of environment was more positive for males in an inquiry-based classroom; they were more enthusiastic and experimental, though slightly more disruptive. Female perceptions of environment were more positive in a non-inquiry classroom. Females were often uncertain, and wanted reassurance whether the processes utilized and their findings were correct. Another study of importance showed significantly greater results from students participating in a program based in inquiry versus a closely matched student sample taught through traditional methods. Schneider et al. (2002) found that students from a PBS science program outscored the national sample on 44% of NAEP test questions.

Further findings showed that many students had difficulty with the process necessary for the inquiry model. Students struggled initially to design appropriate experiments, but soon became more efficient and required less teacher prompting (Wolf & Fraser, 2008). However, students were able to explore a wider range of materials (Wolf & Fraser, 2008) and broader issues (Krajcik et al., 1998). Other difficulties found

in middle grade students were their ability to form pertinent questions, to decipher relevant data from irrelevant data, and to draw conclusions that were linked to data collected (Krajcik et al., 1998, Jeong et al., 2006). On the other hand, evidence was collected claiming that, providing the age-appropriate scaffolding, 1st graders are capable of inquiry-based learning (Marshall, 2006) Also, Bryant (2006) concludes that gaining knowledge from an inquiry-based activity is not dependent upon success during the activity.

Other Sources of Information

Administrative Records: Standards/ Frameworks

"Benchmarks for Scientific Literacy, Part I: Achieving Science Literacy (1993)" by the American Association for the Advancement of Science (AAAS), consists of specific goals and objectives for science curriculum for each of the grade levels K-2, 3-5, 6-8, and 9-12. This report is based on AAAS previous research report, titled "Science for All Americans," (AAAS, 1989) emphasizing the need to avoid teaching more, but teach less and teach "better" in more depth. These "benchmarks" are not specific facts that need to be learned, but objectives that fit into the categories, The Scientific Worldview, Scientific Inquiry, and The Scientific Enterprise. Alongside the National Science Education Standards put forth by the National Research Council in 1996, Benchmarks emphasizes the importance of scientific inquiry, which stresses less focus on curriculum and more on scientific abilities.

Within the California state science curriculum, standard 7c states "Communicate the logical connection among hypotheses, science concepts, tests conducted, data

collected, and conclusions drawn from the scientific evidence.” Though this does not specifically state that students use inquiry, creating their own questions, experiments, and conclusions, the state standards do address the scientific ability to logically conduct an experiment without knowing the conclusions beforehand.

As standards drive curriculum, curriculum, in turn, influences teaching and learning. As noted earlier, there are not a significant amount of teachers utilizing inquiry teaching and learning methods. One reason for this is due to the accountability of inquiry. Assessment also drives teaching and learning when there are high stakes at hand. The report draft titled, “Science Framework for the 2009 National Assessment of Educational Progress,” (Framework) by the National Assessment of Educational Progress (NAEP) attempts to include inquiry in its assessment of science. The NAEP is a governmental organization that periodically collects academic information for grades 4, 8, and 12 in the U.S. The data is used as part of “The Nation’s Report Card,” a program of the U.S. Department of Education.

This NAEP report draft emphasizes the need for new assessments in relaying our national and international progress in the field of science. These reasons for updating the assessment include that the previous NAEP science assessments were developed over 15 years ago, and since then the Benchmarks and National Science Education Standards have been written. Also, advances in cognitive research have been conducted with new outlooks on how students of this age group learn science (Bradsford et al, 1999). Another reason for a modified assessment draft is the increased frequency and severity of science results nationally and internationally (NCLB, PISA, TIMSS).

As the NRC standards and Benchmarks both present science as inquiry, this "Framework" pays attention to this need by using open-ended items, multiple methods of delivery, and scientific inquiry performance tasks (not identified in previous assessment). Improving and developing curriculum and instruction would not prove vital if assessment did not attempt to measure these deemed important changes.

Historical Context

"No Child Left Behind and Science Education: Opportunities, Challenges and Risks," by Marx and Harris discusses historic events, such as the 1950s Russian launch of Sputnik and the release of "A Nation at Risk" in the 1980s, that justify the necessity of an immediate American improvement in science education. The two examples listed above, plus America's lack of economic competitiveness in STEM fields have been used to justify, according to Marx and Harris, the high-stakes No Child Left Behind (NCLB) legislation.

Recommended science standards from the AAAS and the NRC promote the importance of learning science through the methods of inquiry. However, the standards assessed by NCLB are left up to the individual state, as 'there are no national frameworks for developing science assessments' (Marx & Harris, 2006) and no specifications that NCLB assess for higher level thinking skills, as the national standards emphasize. To add to this, with a weighted focus on math and language arts, studies have indicated that time for science in the classroom is pushed aside and that many elementary teachers feel obliged to do so, as only 25% of elementary teachers consider themselves well qualified to teach science (according to the 2000 National Survey of the State of Science and

Mathematics Education, Weiss et al., 2001). The survey also found that only 6% of class time was devoted to science, and that approximately two thirds of teachers are unfamiliar with the science standards.

"International Test Scores: Poor U.S. Test Results Tied to Weak Curriculum," by an organization called '4Choice,' compares test scores from the Trends in International Mathematics and Science Study (TIMMS) among 41 countries by assessing a half-million students. Of 26 countries assessed, U.S. science scores in 4^{th} grade were ranked 3^{rd}, 17^{th} of 41 countries in 8^{th} grade, and 16^{th} of 21 in grade 12. This article goes on to fault the American education system's curriculum, teachers, and textbooks, and that America needs to look to textbooks and teaching methods of higher ranked countries.

Looking at the issue with historical context helps to explain the current situation. It helps to see that there is an ongoing movement concerning the necessity for inquiry methodology to be placed within national standards and how these standards can be held accountable.

Biases

It is quite possible that the information from the 2000 National Survey of the Sate of Science and Mathematics Education is not entirely accurate. This report does not state the sample size used for the survey. Therefore, a relatively small population is speaking for all of elementary teachers across the United States.

Furthermore, biases of the authors might stem from the positions in their professional careers (Marx & Harris, 2006). Marx, an educational psychologist at University of Arizona's College of Education, teaches the practices of learning and

instruction, and psychology and school reform. Harris is a teacher of both theory and research of inquiry-based instruction. These authors have their careers based in the reform of educational practices, and specifically in promoting the practices of inquiry-based instruction. Therefore, the authors are biased towards the need for reform in science education, branching from teaching practices all the way to national standards and assessment.

Biases in “International Test Scores: Poor U.S. Test Results Tied To Weak Curriculum” can be seen after investigating the organization ‘4Choice.’ This organization promotes parental choice of schools for their children as it claims the government has too much control in education’s current state. With this position, it is clear that the author is attempting to assign fault to America’s education system. Though it cannot be argued that the U.S. did not rank highly in this assessment, it is recommended that authors look further at issues such as: which student populations were assessed and what material the assessment covered.

It is useful to look at articles through a critical lens. While it is convenient to cherry-pick statements simply because they align with one’s research, it is equally important to be able to show a balanced view of all opinions concerning a particular topic. The articles, “No Child Left Behind and Science Education: Opportunities, Challenges and Risks,” and “International Test Scores: Poor U.S. Test Results Tied To Weak Curriculum” had a common theme: the need for incorporating new methodological practices in the teaching of science. However, these views came about from different perspectives and for different reasons. The latter of the articles, written by an

organization, had specific motives for its statements. This article confusingly muddled opinion with fact and it negated the article's credibility for me.

When an article is presented as research findings, a reader must still view that article with a critical eye. It is nearly impossible to write an article absent of personal opinion or inclination and therefore readers must work to present a balanced view from a variety of sources.

Special Collections

A unique compilation of scientific inquiry-based information and tools can be found at the Exploratorium, located in San Francisco. The San Francisco Exploratorium is a museum of science, art, nature and technology that fosters curiosity and interaction with its exhibits, based on the philosophy that questioning and curiosity are critical means by which to explain the world around us.

The Exploratorium has a website, www.exploratorium.edu, which contains activities (examples of subjects include the chemistry of cooking, physics of sports, vision and illusions, etc.), and a digital library with access to explanations of scientific phenomena, images, videos, history; the library also has an audio component for those who cannot read the text. The library contains links to other scientific web sites, other libraries, and access to over 25 years of Exploratorium Magazine. The website offers convenient tools for educators, scientists, and any curious mind.

Beyond the museum and website information are ways to access a network of scientific inquiry-based outreach programs. One such program is called the Institute For Inquiry. Based on the principles of inquiry pedagogy, this Exploratorium program provides an array of workshops, conferences, and resources to encourage and support educators to incorporate inquiry successfully into science education. For 25 years the

Institute For Inquiry worked locally with San Francisco Bay Area school districts and teachers. In 1995, upon receiving a grant from the National Science Foundation, the Institute For Inquiry was able to broaden its outreach. Since then, over 4,500 educators have participated, representing 862 school districts in 39 states. This program is one of five national centers committed to elementary science education reform.

In 2006, the Institute For Inquiry created a professional-development curriculum based on their workshops. This program, among many more the Exploratorium has to offer (such as its partnership in the Center for Informal Learning and Schools [CILS], which supports research and promotes local outreach programs, and the Teacher Institute program that provides training for new teachers and stipends for summer educational programs), is designed to support high-quality science education locally in San Francisco and on a nationwide scale. Engaging outreach programs offered by the Exploratorium furthers the movement for sustainable change in science education.

Researching the expeditious inquiry lessons and the long-term outreach programs and training the Exploratorium has to offer provides a means by which educators can become inquiry-pedagogy literate. A major drawback to the use of inquiry-based teaching and learning in the classroom is the lack of teacher training. The Exploratorium offers accessible methods to overcome this major obstacle in science education. This new information leads me in a direction in my research to continue looking for methods that allow for and support effective incorporation of inquiry in the science classroom.

Statistical Research

Low national science test scores on the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA)

are indicative of the fact that the United States needs major improvements in education with regards to science. Wanting to discern whether it was specific areas where American students were deficient, I looked further into the studies to see specifically what content and skills they assess. One report titled, *Problem Solving in the PISA and TIMMS 2003: Technical Report*, conducted by the National Center for Educational Statistics (NCES), part of the Institute of Educational Sciences in the U.S. Department of Education, was especially helpful in illuminating the skills assessed by PISA and TIMMS.

This report analyzes the two assessments; given to students in grades 4 and 8, the TIMMS measures curricular knowledge and conceptual understanding in mathematics and science. The 2003 version included a new subset of questions categorized as "problem-solving and inquiry, or PSI, questions" (Dossey, Gonzales, & O'Sullivan, 2006). The PISA is a comprehensive assessment of mathematic and scientific literacy administered to 15 year olds. The PISA 2003 added a new category of questions referred to as "cross-disciplinary (C-D) problems" that emphasize problem-solving abilities beyond standard curricular content (Dossey et al., 2006).

By breaking the tests down and looking at individual questions, one can see the extent to which each assessment emphasizes scientific inquiry and problem-solving abilities. Problem-solving questions are categorized as questions that require a resolution that was not explicitly or likely studied, and that the student would not have a ready procedure (Dossey et al., 2006) Within the TIMSS, 49 of the 189 science-related questions (26%) were categorized as problem-solving items (PSI). Of the PSI questions, 39 of 49 required factual knowledge (80%), 35% of the questions required reading

comprehension and interpretation skills, 24 questions were open short constructed responses (49%), and 3 questions were open extended constructed responses (6%).

The PISA contained 17 of 35 science-related questions (49 percent) categorized as problem-solving items. Factual knowledge was required for 6 of the 17 PISA problem-solving questions (35%), reading comprehension and interpretation skills was contained within 87% of the questions, open short constructed responses were contained within 12 of the 35 questions (71%), and there were no open extended constructed response questions.

Investigating the types of questions helps reflect the objectives of each assessment. The TIMSS portion categorized as “problem solving” tend to focus on students’ knowledge and skills commonly explored in school curricula, whereas the PISA problem-solving questions concentrate on wide-ranging interpretive and contextual outcomes related to scientific literacy.

Example from TIMMS	Example from PISA
Item 4: Problem-solving item from science (TIMSS)  The diagram above shows a community consisting of mice, snakes and wheat plants. What would happen to this community if people killed the snakes? SOURCE: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS), 2003.	<u>Flies</u> A farmer was working with dairy cattle at an agricultural experiment station. The population of flies in the barn where the cattle lived was so large that the animals' health was affected. So the farmer sprayed the barn and the cattle with a solution of insecticide A. The insecticide killed nearly all the flies. Some time later, however, the number of flies was again large. The farmer again sprayed witht the insecticide. The result was similar to that of the first spraying. Most, but not all, of the flies were killed. Again, within a short time the population of flies increased, and they were again sprayed with the insecticide. The sequence of events was repeated five times, then it became apparent that insecticide A was becoming less and less effective in killing the flies. The farmer noted that one large batch of the insecticide solution had been made and used in all the sprayings. Therefore he suggested the possibility that the insecticide solution decomposed with age. Source: *Teaching About Evolution and the Nature of Science,* National Academy Press, Washington DC, 1998, p.75 ____ Question 1: Flies The farmer's suggestion is that the insecticide decomposed with age. Briefly explain how this suggestion could be tested. ____ ____ ____ ____ ____

The results of the TIMSS and PISA for the United States can help identify areas for improvement within science education. In 2003, United States' 4th graders averaged 6th out of 25 (scoring higher than 76% of the group) nations on the TIMSS, and 8th graders' averaged 9th out of 45 (higher than 80%). In 2007, United States 4th graders averaged 9th out of 36 countries (scoring higher than 75% of the group), and 8th graders averaged 11th out of 48 (above 77%) (NCES, http://nces.ed.gov). The 2003 PISA results show the United States' 15 year olds ranked 22nd out of 38 (falling under the international average), and in 2006, ranking 29th out of 57 participating countries, again falling below the international average (PISA, http://pisacountry.acer.edu.au).

CHAPTER 3: INTERVIEW

Sample and Site

A friend of mine is a science teacher at a school whose science program is based on the inquiry method. I had the good fortune of being introduced to Ms. Alice Moore, one of the school's leading science teachers, through this friend. This teacher told me that Ms. Moore is her mentor teacher and was responsible for building the school's program over the past twenty years. I contacted Ms. Moore by telephone and asked her about her experiences with the inquiry method.

Ethical Standards

This study conforms to all ethical standards of research as determined by the American Psychological Association. This project was reviewed by the Dominican University of California Institutional Review Board and assigned IRB Approval Number 7091.

Interview Questions

- Please tell me your position, responsibilities, how many years of teaching experience you have, and what grade levels you teach/taught.
- Can you explain to me your definition of the *inquiry method*?
- How did you become interested in the inquiry method?
- Have you observed a difference in the engagement level of your students when you taught through the inquiry method verses the non-inquiry method? If so, in what ways do you assess their engagement?
- Do you encounter difficulties with the inquiry method? If so, what are they?

- What strategies do you use to guide students through a lesson without taking away from the inquiry method?
- How do you assess that students have learned the desired results or utilized higher-level thinking?

The following account incorporates Alice Moore's responses:

Summary

Alice Moore is a knowledgeable educator with much experience in the inquiry methodology in the subject of science. She has been teaching for 20 years, 18 of which have been at Marin Country Day School (MCDS) in Corte Madera, California. Ms. Moore is currently the Director of Environmental Sustainability, and was the Science Coordinator for the 10 years prior to her current position. She has taught science utilizing the inquiry method for all grades Kindergarten through 6th grade.

Ms. Moore recollects that in her first teaching position as an elementary school teacher, her knowledge and ability to teach science was poor. Though her school was heavily focused on reading, writing, and math, by her second year she felt it important to pursue additional teacher training. Ms. Moore decided to attend a three and a half-week summer course for non-credit at The Workshop Center at the City College of New York in Harlem. These workshops taught about the inquiry methodology, which resonated with her and helped her to become "the teacher I wanted to be." Two years later, she worked half time and spent the other half time researching science education. She traveled to other schools with inquiry science programs. She went back to The Workshop Center and worked as staff. She also brought the program back to the Bay Area and performed a summer institute for teacher training on inquiry.

Ms. Moore learned strategies necessary to teach the inquiry method, which she described as “a cycle of teacher-guided/ student-directed experiences driven by student-generated questions”. After this switch in methodologies and noting the differences in the students, Ms. Moore has never gone back. Throughout many years of utilizing and practicing the inquiry method, she found that her students were more engaged in the subject matter. Ms. Moore noted that science became more engaging to students designing their own experiments based on their own questions, by demonstrating to students that their ideas matter and are valid. By recognizing the validity of their own questions, students are encouraged to participate and take more ownership over their learning experience.

When asked about the difficulties of inquiry, Ms. Moore responded, “it is all in how you set it up. The experience is going to be as good as the question.” As many teachers state that preteen students have difficulty asking relevant questions, Ms. Moore emphasized the need to practice this skill with students and not be afraid to tell the student if their question needs revision. She stressed that this portion of inquiry should not be rushed, that the time it takes to get good student questions provides reward throughout the rest of the process. Practice, or trial and error, is one way for teachers to be able to recognize good questions when no professional development is available.

Another highlighted difficulty with the inquiry method points to preteen students having difficulty drawing logical conclusions from their experiments and data. Ms. Moore drew attention to the importance of examining conclusions with students. She said, “It’s O.K. if the student did not prove something. Show them what they missed”. Obtaining accurate results is not the only way to learn, Ms. Moore explained that

revisiting the conclusion and pointing out what was missed is a powerful tool upon which students can build knowledge. Also, in cases where accurate conclusions are drawn, it is still important to revisit and emphasize that the student's conclusions are accurate, as they may be unsure.

When asked for strategies to help students through a lesson without taking away from the inquiry method, Ms. Moore responded with an analogy: "The inquiry method is like a highly choreographed dance, where the teacher is the choreographer and knows the dance, and leads the students through the learning process". This requires patience and time, another difficulty with the inquiry method. Ms. Moore followed up by saying, "Not every unit can be purely inquiry. You need to sneak it in to provide opportunities for more depth learning".

Ms. Moore explained a few common ways to assess that learning has taken place after an inquiry-based activity or unit: quizzes with questions that offer opportunities for open-ended short answers, as well as demonstrating knowledge through drawings. Another form is assessment for curiosity. This occurs in the form of notes taken during the activities that describe the types of questions students ask, as well as their enthusiasm and engagement during the process. This is a quality of the learning process not commonly assessed.

Ms. Moore has some flexibility at her school that enables her common usage of the inquiry method that most teachers do not. MCDS is a private school, and therefore does not have a strict set of standards that her program must adhere to. Therefore, she has adequate time to dedicate to the process of inquiry.

After the interview with Alice Moore, I felt that I had learned some strategies that I can utilize immediately in my own class. However, I was left with several questions as well: *Which framework is more successful: an in-depth or wide span of curriculum? Is it possible for a public school to incorporate ample inquiry-based activities and still meet the wide range of curriculum in the available time?*

CHAPTER 4: DISCUSSION

The literature provides arguments both for and against an inquiry-based approach to teaching and learning. Theoretically, a model that yields hands-on, inquisitiveness, self-discovery, building on prior knowledge, and real life applicability is an approach of sound rationale. But if students cannot make the connections themselves or receive the appropriate guidance, the inquiry method does not prove effective in the science classroom.

The most effective teaching methods should be implemented in middle school science classes nationally to best suit the success of all students and the future of science. Including students' perspective along with inquiry studies performed on student achievement will help formulate which practices are most effective. Student attitude and engagement leads to motivation within a subject, ultimately yielding achievement as well as potential further pursuit in science. The majority of the studies reviewed that do not support inquiry-based methods do not take the perspectives of the students into consideration. When student perspectives were taken into consideration, the surveys agree with the supporting research that inquiry-based approaches provide more effective methods for delivering instruction and learning. Engagement and attitude towards science are of critical importance for increasing sustainable achievement.

Educators and parents alike generally agree that rote memorization is not an effective way to comprehensively teach science; however given increasing curriculum demands, larger classroom size, and standards tests heavily reliant on rote memorization, American students are being forced into a curriculum that is generally seen as lacking. The TIMMS and the PISA international tests provide insight into the types of questions on which the US is being outperformed. The drastic fallback appears to be on the PISA,

which has a high degree of focus on concepts, skills, and scientific literacy required to meet “real-life challenges” (Dossey et al., 2006). This agrees with the NRC and AAAS’ recommended science standards to promote the learning of science through the method of inquiry.

With low scores on international tests that focus strongly on inquiry and problem-solving abilities, what exactly was/is the United States’ response? What is the US doing to remedy these low-test scores? How is our nation working to improve in these domains? The current focal point of the US’s accountability is NCLB. Under NCLB, are science programs/ teachers being held accountable to promote scientific literacy and inquiry? The answer is “no.”

Improving and developing curriculum would not be essential if assessments do not attempt to measure these changes. If inquiry standards were not being addressed in these assessments, then the movement for inquiry would be undermined. The recommended standards of inquiry are not being incorporated into the Standardized Testing and Reporting (STAR) test, NCLB’s accountability test given by the California Department of Education.

The STAR test for grade 8 has a total of 60 questions and six pertain to the state standard of “Investigation and Experimentation” (IE), though only three sample questions are offered on the website. The IE standard does not specifically address the recommended standard of inquiry, but emphasizes the need for students to ask pertinent questions, be able to logically conduct an experiment, and draw conclusions. Unfortunately, the three sample questions that fall under this category do not require all of these abilities from the student. They draw upon recalled knowledge of remembering

formulas, being able to see a pattern in data, and understanding a graph. Though these are useful skills in science, they do not draw upon inquiry-related skills. From this available sample, it appears that the STAR test has inadequately addressed the standard of inquiry, therefore not stressing its importance, and leading teachers to neglect its method of teaching and learning.

CHAPTER 5: SUMMARY, CONCLUSIONS AND IMPLICATIONS

"The challenge for all of us who want to improve education is to create an educational system that exploits the natural curiosity of children, so that they maintain their motivation for learning not only during their school years but throughout life" (NRC, 2000). This common-sense approach to science education utilizes the inquiry-based methodology, promoting student curiosity and ownership of one's learning. This method stresses the importance of building a foundation of knowledge based on practicing essential scientific skills, rather than solely on the memorization of facts. The style, knowledge, and ability practiced through the usage of inquiry are likely to remain throughout the students' lives.

Teaching with the inquiry method can be difficult if not properly executed. Newly credentialed science teachers are unlikely to take the risk of a relatively "unscripted" approach. The movement for improving science achievement in the US requires the use of the most effective teaching methods. For this implementation, it is imperative to offer numerous teacher-training opportunities, such as those offered by the Exploratorium. The inquiry method requires knowledge of essential strategies that cannot be relied solely upon through experience. Science teachers require exposure to this method of teaching, and must be provided with necessary tactics for implementation.

Training alone cannot solve the difficulty faced by science teachers needing to cover a wide range of curriculum within the academic year. For the success of regular implementation of the inquiry method, relatively short inquiry activities must be accessible. There is need for a universal curriculum that offers multiple inquiry activities

for a wide range of topics. This would address the concerns of inaccessibility and time constraints often associated with the inquiry method.

The lack of accountability for the usage of the inquiry method also begs amendment. If the emphasis of science reform is put on teaching fewer concepts in greater depth, but assessments continue to test for numerous facts, the reform effort will be weakened. NCLB's STAR test, with the most to gain or lose for schools and teachers, does not do an adequate job measuring the scientific skills that are addressed through the inquiry method. This assessment piece needs to be improved and updated in order to focus upon a domestic lack of competitiveness in relation to international science achievement scores, as well as address the recommended national science standards.

This necessary adaptation to the STAR test will encourage the usage of the inquiry method, not only by holding teachers accountable, but also by allowing teachers the flexibility to actually "teach" a subject rather than simply try to hammer several into a students' memory. Previous studies have shown increased student engagement when utilizing the inquiry method, and this enhanced engagement will naturally lead to greater achievement in the science fields – far beyond standardized tests. It is this shift in direction that US science education needs to take in order to become internationally competitive in middle school, high school, and professional levels in the science field.

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