Science As a Verb: The Effects of Teaching Science By Inquiry

by

Bailey C. Edgley

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Bailey C. Edgley

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Anita Lenges, Member of the Faculty

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ABSTRACT

This review of published, peer reviewed journal articles centered on the question: what are the effects of science by inquiry on students' knowledge and application of scientific principles? The question is first examined in light of the debate between inquiry-based science instruction, the *National Science Education Standards*, and the No Child Left Behind Act. Inquiry is a central component of the *National Science Education Standards* and the passing of the No Child Left Behind Act made establishing standards a required part of state and federal accountability systems. Science by inquiry was a subject of debate long before the establishment of the *National Science Education Standards.* In the progressive era, Dewey pushed for science education to be similar to the investigative processes of practicing scientists. In the post Sputnik era, inquiry was a central component of the NSF sponsored "alphabet soup" curriculum projects. Inquiry is again a central point of focus in the standards-based education era. The current movement differs from past movements in that it places emphasis on all citizens becoming scientifically literate, not a select few. The critical review of the literature examined the effects of inquiry on students' understanding of the nature of science, epistemological understanding, conceptual understanding, and development of inquiry culture. The implications of emergent themes across the effects of inquiry such as argument supported with evidence, context, cultural practice, discourse, discrepant events, explicit reflective metacognition, hands-on vs. inquiry, teacher role, and writing are discussed in relation to the practice in the classroom.

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This project is dedicated in loving memory to

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CHAPTER ONE: INTRODUCTION

Rationale

The No Child Left Behind Act of 2001 made content standards a required part of federal and state accountability systems. Prior to 2001, some states including Washington, developed science content standards. In response to No Child Left Behind mandates, all U.S. states have now written their own science content standards using the *National Science Education Standards* (NRC, 1996) as a guide. The Office of the Superintendent of Public Instruction in the State of Washington and the *National Science Education Standards* ask that students are able to engage in scientific inquiry. States are held accountable for deliverables (adequate yearly progress determinations, annual report cards, diagnostic assessments aligned with academic standards and linked to the states assessments (Glynn Ligon, 2004 as cited in Hovey, Hazelwood, & Svedkauskaite, 2007). Assessment is a central focus of the standards movement; yet many classroom teachers believe their primary goal is to develop science literacy, not test it (Hovey, Hazelwood, & Svedkauskaite, 2007). Often teachers believe assessment takes too much time from their instruction. They feel pressured to learn how to incorporate as much of the standards as they can into their instructional methods. Due to the pressure to teach to the standards, teachers often feel that they are teaching to the test.

Inquiry is the central goal of the science standards documents (Zemelman, Daniels, & Hyde, 2005). Many teachers do not teach science by inquiry because they did not learn science by inquiry (Hovey, Hazelwood, & Svedkauskaite, 2007). I learned science via the traditional method, mostly through lectures and memorization. We are being asked not only to teach science by inquiry but also to teach students in a way that helps them to pass high stakes tests such as the Washington Assessment of Student Learning. As I enter the teaching profession in the midst of the standards-based education reform movement, I ask: what are the effects of science by inquiry on students' knowledge and application of scientific principles?

Controversy

Inquiry is an approach to science teaching that is emphasized in the *National Science Education Standards*. There is much debate among educators between the tradeoffs of teaching science as inquiry and science through traditional teaching. Strategies for addressing standards-based science in the classroom place less emphasis on knowing scientific facts and information; studying subject disciplines (physical, life, earth sciences) individually; separating science knowledge and process; covering many science topics; and implementing inquiry as a set of processes (Krueger & Sutton (2001, p. 47, as cited in Hovey, Hazelwood, & Svedkauskaite, 2007). More emphasis is placed on understanding science concepts and developing abilities of inquiry; learning subject disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science; integrating all aspects of science content; studying a few fundamental science concepts; and implementing inquiry as instructional strategies, abilities, and ideas to be learned.

Critics of inquiry-based science teaching argue that inquiry cannot be used to teach students complicated theories and ideas, such as evolution, which were developed by scientists over many decades ("Inquiry-based science," 2006). Other critiques are that inquiry fails to teach students essential facts and knowledge and that many teachers are uncomfortable teaching via the technique of inquiry. Another debate is the depth vs.

breadth argument (Rop, 2003). Science educators argue whether it is better or worse to teach for fuller understanding of fewer concepts or to teach a wide range of concepts more superficially. Inquiry-based science teaching aims to teach fewer concepts more in depth. Some teachers feel that inquiry takes too much time that could otherwise be spent preparing students for tests such as the Washington Assessment of Student Learning (Hovey, Hazelwood, & Svedkauskaite, 2007).

Definitions

Conceptual understanding, the understanding of scientific concepts, is one goal of traditional science education and scientific inquiry. Constructivist theories say that conceptual understanding is the result of conceptual change. Conceptual change, based on Piagetian accommodation, focuses on knowledge acquisition in specific domains and describes learning as a process that requires the significant reorganization of existing knowledge structures and not just their enrichment (Vosniadou & Brewer, 1987 as cited in Vosniadou et al., 2001).

Inquiry is a method to learn science by which teachers help students build understanding of scientific concepts and theories through investigations (Zemelman, Daniels, & Hyde, 2005). Scientific inquiry has essential components, but there is not just one set method of approach. Some features of the method of learning science by inquiry are: learners generating investigable questions; learners planning and conducting investigations; learners gathering and analyzing data; learners explaining their findings; and learners sharing and justifying their findings with others (NRC, 2000 as cited in Wee, Fast, Shepardson, Harbor, & Boone, 2004). Inquiry and hands-on science are not synonymous; many teachers teach hands-on science but not inquiry (Zemelman et al., 2005). Inquiry is hands-on but also minds-on, engaging students in cognitively challenging tasks.

Metacognition is awareness of one's own thinking and epistemology; learning how to learn by thinking about thinking (Zion, Michalsky, & Mevarech, 2005). In classrooms, metacognition is specifically students' awareness of their own problem solving processes, monitoring their progress, and reflecting on their own thinking which can lead to developing more effective strategies for accomplishing tasks, making decisions, and reviewing their work (Zemelman, Daniels, & Hyde, 2005).

The nature of science, also known as the epistemology of science, or science as a way of knowing, refers to the social values and epistemological assumptions inherent to scientific knowledge (Spector & Lederman, 1990 as cited in Bell & Lederman, 2003). Aspects of these assumptions include: understanding that scientific knowledge is tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (influenced by scientists' background, experiences and biases); partly the product of human imagination and creativity (involves the invention of explanations); and socially and culturally embedded.

Limits

Successful science learning experiences are affected by many factors and I am not able to cover all of them in this study. In my examinations, I am not searching to differentiate based on groups. I am not choosing to disaggregate literature particular to race, gender, language, etc. However, I will critique studies based on whether or not the authors disaggregate data. I am studying the general effects of science by inquiry on students from early elementary school to early college in biology, chemistry, physics, astronomy, and general science classes. I will not limit my examinations to a particular content area or grade level.

Conclusion

In the following three chapters, I examine the question: what are the effects of science by inquiry on students' knowledge and application of scientific principles? In chapter two, I explore the history of science education in the United States as related to science as inquiry. The current standards-based education reform movement and the curriculum reform that followed the Soviet launch of Sputnik are the largest of many science curriculum movements. In chapter three, I critically review literature related to the effects of science by inquiry on students. My review is broken into four areas of focus as effects of science by inquiry: understanding of the nature of science, understanding of epistemology, conceptual understanding, and inquiry culture. In chapter four, synthesizing information from chapters one and two, I discuss the implications of the effects of inquiry and emergent themes across the areas of focus from chapter three. I explore how the effects of inquiry and emergent themes apply to my future classroom practice and discuss unanswered questions.

CHAPTER TWO: HISTORICAL BACKGROUND

U.S science education has gone through many changes and reform movements since science was adopted into the curriculum. The most recent is the standards-based education reform movement, which is based on the idea that high expectations and the setting of goals will lead to success of all students ("Standards-based education reform," 2006). The passing of the No Child Left Behind Act of 2001 made content standards a required part of federal and state accountability systems (Hovey, Hazelwood, & Svedkauskaite, 2007). States used the *National Science Education Standards* as guidelines for establishing state content standards. The content standards for the state of Washington are the *Essential Academic Learning Requirements*. Scientific inquiry, the central theme of the science standards documents, is viewed in two ways (Zemelman, Daniels, & Hyde, 2005). First, it is seen as a content standard, where students are to understand what inquiry is and develop the abilities needed to construct it. Second, it is viewed as a way to learn science, a method by which teachers help students build understanding of scientific concepts and theories through investigations. By making inquiry an element of content, there is a fusion between what is to be learned and how a student goes about learning it (Atkin & Black, 2003).

Before 1900, science education in the United States mostly consisted of memorizing a body of knowledge taught via lecture (DeBoer, 1991). John Dewey, in 1909, challenged the traditional view of science education in an address to the AAAS (American Association for the Advancement of Science) when he called for teaching science as a way of thinking and frame of mind. He said there was more than a body of knowledge to be learned; there was a process and method as well (DeBoer).

Led by Dewey, the progressive education movement emphasized the everyday activities and interests of youth with the hope that the educational system would prepare students for active participation in a changing society (Dow, 1991). The core of Dewey's pedagogy was progressive organization of knowledge based on the use of the scientific method. Students experimented, constructed hypotheses, recorded data, and reflected on their work. Dewey said that learning to think scientifically was the primary goal of good teaching. Progressive education's idea of tailoring education to the curiosity of the child was misinterpreted by some as anything goes. Many teachers geared lessons toward preparing lower socioeconomic status students for specific jobs and catering to the interests of middle class students. In *Experience and Education* Dewey said that people took direct experience in education and degenerated it into a formless curriculum in which any experience was seen has having significant educational value. In traditional education, plans and programs were handed down from the past. Dewey did not intend for progressive education to be implemented via directionless improvisation (DeBoer).

After World War II, attention shifted to life adjustment education. Dewey's critical thinking was replaced with the development of practical skills and "real life problems," such as finding a family dentist or developing hobbies (Dow, 1991). Life adjustment education was based on the idea that education did not related to the everyday needs of students and that intellectual training should be replaced with vocational instruction. The non-academic focus of life adjustment education received a great deal of criticism (DeBoer, 1991). Arthur Bestor, an Illinois historian, led the political academic attacks against the public schools (Rudolph, 2002). According to Bestor, professional educators were responsible for the anti-intellectual quality of schools in the United States.

He published his criticisms in *Educational Wastelands* in 1952. In 1949, Mortimer Smith, a former school board member and retired businessman, published *And Madly Teach* followed by *The Diminishing Mind* in 1954. In these books, Smith and Bestor emphasized the idea that schools were undemocratic and that current curricula didn't allow schools to prepare students equally for participation in the world (Dow, 1991). In 1956, the Council for Basic Education was formed with Arthur Bestor as its president and Mortimer Smith as the executive director and major force behind organizing operations. The Council publicized the debate between traditional academics, leading professional educators to call for new humanism in public education.

Bestor and Smith led the attacks on the U.S. educational system, criticizing it for its softness and neglect of intellectual heritage (Rudolph, 2002). Their answer was to strive for excellence and to provide more rigorous educational experiences for all students, especially those who had the intellectual capacity to do the work. In science and math, this meant getting the scientists and mathematicians themselves involved in the creation of courses for high school students. By the late 1950s, progressive education was dead (DeBoer, 1991). Shortages of technology personnel in World War II and competition during the Cold War and criticism of the education system moved U.S. education away from social relevance and toward the mastery of traditional disciplines.

In the 1950s, school performances declined. Post World War II schools had no money and few new schools had been built since 1941 (Dow, 1991). Inflation decreased teacher salaries and teachers were seeking higher paying professions (Spring, 2005). Educators tried to get federal legislation to build schools and pay teacher salaries. Federal involvement in education had not been supported historically. Americans distrusted centralized education planning as a character of totalitarian systems and looked to the school board as a protector of community values and administrator of democracy. Mounting public discussion of the "school crisis" increased pressure from teachers for federal aid. Congress continued to resist. After *Brown v. Board of Education* in 1954, the school aid debate became more complicated by its link to the issue of civil rights.

The National Science Foundation (NSF) was created after World War II to promote science education research and to stimulate curriculum and incorporate post World War II science modifications into classrooms (Dow, 1991; Rudolph, 2002). In 1955, the NSF was concerned that not enough high school students were entering science careers in midst of the Cold War era (Dow, 1991). Nixon said, "Our national security has a tremendous stake in our education system."

The 1957 Soviet launch of Sputnik broke the Congressional hold on federal school funding (Atkin & Black, 2003). Public schools were blamed for the lag in technological development and there was a demand for increased math and science in schools. For the first time since the Smith-Hughes legislation of 1917, the federal government gave serious attention to school reform (Dow, 1991). The National Defense Education Act was passed in 1958, giving one billion dollars toward education reforms (Spring, 2005). In an address to Congress, Eisenhower outline the program of education for national defense which included a five fold increase in appropriations for the educational activities of the NSF. It also allotted federal funds to improve the teaching of science and math through the hiring of more science teachers and by purchasing new equipment and materials. Cold War concerns also got the federal government involved in developing new curricula, particularly in areas of math and science.

The NSF backed many curriculum reform projects nicknamed “alphabet soup” for acronym titles such as BSCS, PSSC, CHEM study, SMSG, and CBA (Rudolph, 2002). For the first time, research scientists were involved in developing curricula. The new rigorous curricula required students to think and act like scientists by doing science instead of being told or reading about science (DeBoer, 1991). There was no emphasis on relevance to student lives or catering to student interest. The “alphabet soup” projects represented a unique collaborative effort by the U.S. Congress, NSF, and scientists of all sorts. Up to this point, science education had been shaped by professional organizations, publishers, national committees, task forces, and thousands of local school boards nationwide (Rudolph, 2002).

The NSF’s “alphabet soup” curricula had a significant and lasting impact on education (Rudolph, 2002). The new curricular projects succeeded in establishing enduring norms of content and instruction that continue to shape school science. Much of the language, practices, and expectations for science education have been derived from this movement. The rehabilitation of subject matter, elevation of the instructional role of the laboratory, utilization of innovative instruction media, and particularly the emphasis on discipline-centered inquiry and explicit attention to the nature of science (all common in the education literature today) can be traced to these early NSF curriculum projects. Though curriculum projects faded, they grew out of existing classroom practices, international and domestic political tensions, wartime technologies (hot and cold), disciplinary rivalries, and the professional desires of the American scientific community (Rudolph).

Soviet space competition calmed after the moonwalk of 1969 (Dow, 1991). In the 1960s and 1970s, curricula focused on student interest and social relevance. Due to the resemblance to the progressive era before World War II, this movement was dubbed the "new progressivism." The focus was more about equitable and humane education environments for all American youth (DeBoer, 1991). Out of the social atmosphere of the Vietnam War and the civil rights movement grew the term science literacy.

Scientific literacy was described as an education in science that was focused on socially relevant issues and relevant to the lives of all youth. In 1971, the National Science Teachers Association (NSTA) Board of Directors declared that the major goal of science education was to develop scientifically literate individuals (DeBoer, 1991). The NSTA said that a scientifically literate individual "uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and his environment" and "understands the interrelationships of science, technology, and other facets of society, including social and economic development" (National Science Teachers Association, 1971, pp. 47-48 as cited in DeBoer, 1991, p. 177). Science programs were evaluated for their student-centeredness and their ability to foster positive student attitudes towards science and independent investigations.

Building on the social relevance of the 1970s, science, technology, and society was the NSTA's science education theme for the 1980s (DeBoer, 1991). Science, technology, and society education was humanistic, value oriented, and relevant to a wide range of personal, societal, and environmental concerns. Science educators in the 1980s disagreed whether science education should be socially relevant or based around the disciplines of science and the process of scientific investigation.

The NSF sponsored curriculum projects until the 1980s, when the funding ran out (DeBoer, 1991; Dow, 1991). DeBoer describes the main goal of science educators from the 1950s to the 1980s as inquiry. Learning the processes and the products of science was viewed as valuable during that time period. Due to confusion whether inquiry was a method of instruction or a description of the nature of science, inquiry was not incorporated into as many science classrooms as educators had hoped (DeBoer).

In the 1980s, there was rising concern over trends in U.S. public education: low test scores, student avoidance of science and math, demoralized and weakening teaching staff in many schools, low learning expectations compared to other technologically advanced nations, and being ranked near the bottom in international studies of student knowledge of science and math ("Reforming Education," 1989). The 1983 publication of *A Nation at Risk: the Imperative for Educational Reform* by the National Commission on Excellence in Education called for reform of the U.S. education system.

The setting of academic standards for what students should learn and be able to do drove the present education reform movement that started in the 1980s ("Standards-based education reform," 2006). Standards-based education reform called for clear, measurable standards for all school students, raising expectations for all students' performance (Hovey, Hazelwood, & Svedkauskaite, 2007). Curriculum, assessments and professional development were aligned with the standards.

The 1989 report *Science For All Americans: A Project 2061 Report on Literacy Goals in Science, Math, and Technology* by the AAAS and the *Benchmarks for Science Literacy*, published by AAAS in 1993 set the foundation for the publication of the

National Science Education Standards by the National Research Council in 1996 (Zemelman, Daniels, & Hyde, 2005).

The National Research Council assembled the NCSESA (National Committee on Science Education Standards and Assessment) with advisors from the NSTA, AAAS, ACS, NSRS, and many discipline specific science teacher organizations to develop the *National Science Education Standards* ("Introduction," 2006). The NCSESA based its work in a historical and research perspective. Studies showed that most science teachers were using traditional methods and that students were memorizing disconnected facts. Many educators were using the newer curricula (BSCS, SCIS, ESS, etc) and their students were engaging in inquiry activities. Students taught via the newer curricula were developing critical thinking skills as well as learning science content through making observations, manipulating materials, and conducting laboratory investigations ("Introduction," 2006). The NCSESA decided to include inquiry as both science content and as a way to learn science. The NRC published the *National Science Education Standards* in 1996. Individual states started developing standards based on the *National Science Education Standards*. The passing of the No Child Left Behind Act in 2001 made content standards a required part of federal and state education accountability systems.

Scientific inquiry, the central theme and first goal of the science standards documents (the *National Science Education Standards* and the Washington State *EALRs*), is viewed in two ways (Zemelman, Daniels, & Hyde, 2005). First, it is seen as a content standard, where students are to understand what inquiry is and develop the abilities needed to construct it. Second, it is viewed as a way to learn science, a method by which teachers help students build understanding of scientific concepts and theories through investigations. Many studies have examined the effects of inquiry via the *National Science Education Standards*. Chapter three critically examines some of the body of literature in light of the question: what are the effects of science by inquiry on students' knowledge and application of scientific principles?

CHAPTER THREE: CRITICAL REVIEW OF THE LITERATURE

Inquiry is the central goal of the *National Science Education Standards,* yet there is debate among educators whether the educational goals of the standards can be achieved through inquiry. In this chapter, I will critically review the research on the effects of science by inquiry on students' knowledge and application of scientific principles. My review of the research includes the following four areas. First, I examine how teaching by inquiry shapes students' understanding of the nature of science. Understanding of the nature of science is touted as a key goal of developing scientific literacy in students and citizens (AAAS, 1989, 1993; Bybee, 1997; NRC, 1996; NSTA, 1982 as cited in Bell & Lederman, 2003). Several research studies examined how students conceptualize the nature of science after engaging in scientific inquiry. Second, I examine how teaching by inquiry shapes students' epistemological understanding of science. Along with conceptualizations of the nature of science, students have conceptualizations of themselves as science learners. Third, I examine how teaching science by inquiry shapes students' conceptual understanding. Student conceptual understanding is one goal of traditional science education and teaching science by inquiry. Several studies examined either student conceptual change as a result of participating in inquiry or compared changes in student conceptual understanding as a result of traditional education or science by inquiry. Fourth, I examine how teaching science by inquiry develops an inquiry culture. Science, as practiced by students and scientists, is embedded in a social and cultural context. Several studies examined the culture that developed as a result of inquiry and how it influences students' scientific abilities.

Understanding the Nature of Science

The nature of science, also known as the epistemology of science, or science as a way of knowing, refers to the social values and epistemological assumptions inherent to scientific knowledge (Spector & Lederman, 1990 as cited in Bell & Lederman, 2003). Aspects of these assumptions include: understanding that scientific knowledge is: tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (influenced by scientists' background, experiences and biases); partly the product of human imagination and creativity (involves the invention of explanations); and socially and culturally embedded. (Khishfe & Lederman, 2006). Understanding of the nature of science is a primary component of scientific literacy (AAAS, 1989, 1993; Bybee, 1997; NRC, 1996; NSTA, 1982 as cited in Bell & Lederman, 2003). According to Bell and Lederman, knowing the characteristics of scientific knowledge and the way it is constructed will allow citizens to apply scientific knowledge to their everyday lives. Nature of science instruction is linked to the ultimate goal of scientific literacy: to improve citizens' abilities to make reasoned decisions in a world increasingly impacted by the processes and products of science (Carey & Smith, 1993; Collins & Shapin, 1986; Cotham & Smith, 1981; Driver et al., 1996; Kuhn, Amsel, & O'Loughlin, 1989; Lederman, 1983, 1999; Millar & Wynne, 1988; Shamos, 1995 as cited in Bell & Lederman, 2003).

Students tend to hold inadequate conceptions of the nature of science such as the view that science is the accumulation of objective, isolated facts about the world, rather than an effort to explain the world (Carey & Smith, 1993; Driver et al., 1996; Lederman, 1992 as cited in Sandoval & Morrison, 2003). Students' beliefs about the nature of scientific knowledge and the ways in which that knowledge is produced and evaluated affect how they attempt to learn science (Hammer, 1994; Hogan, 1999; Roth & Roychoudhury, 1994; Songer & Linn, 1991 as cited in Sandoval & Morrison, 2003). Improved understanding of the nature of science is a suggested outcome of inquiry and part of the inquiry process.

Crawford et al. (2005), Khishfe and Abd-El-Khalick (2002), Khishfe and Lederman (2006), Lederman and Druger (1985), and Sandoval and Morrison (2003) conducted studies concerned with student conceptions of the nature of science as an effect of scientific inquiry. Sandoval and Morrison, (2003) were interested in finding whether inquiry experiences change students' beliefs about the nature of science. Lederman and Druger, (1985) investigated whether teacher understandings of the nature of science are related to changes in students' conceptions of the nature of science. Khishfe and Abd-El-Khalick, (2002) were interested in whether an explicit and reflective inquiry oriented approach would help sixth graders develop informed conceptions of targeted aspects regarding the nature of science. Khishfe and Lederman, (2006) compared the relative effectiveness of two approaches (integrated and non integrated) in developing informed conceptions of the nature of science. Crawford et al., (2005) studied what ways, if any, the Galapagos Finches (BGuILE) software based curriculum instruction enhanced students' understandings of the nature of scientific knowledge.

Sandoval and Morrison (2003) were interested in finding whether inquiry experiences changed students' beliefs about the nature of science. Student's ideas did not change as a result of their study, but Sandoval and Morrison did find that students' epistemological views of the nature of science were fragmented.

The study was conducted at a suburban high school of a major Midwestern city. Two teachers, each with two classes, and a total of 87 students (44 boys 43 girls) participated in a four-week inquiry unit. The main component of the unit was computer based investigations of complex problems of natural selection and evolution: Galápagos Finches followed by Tuberculosis Lab. The computer-based inquiry problems were not introduced as examples of natural selection and evolution. Students worked on the computer problems in groups of three to four for four to five hours of class time over the course of the unit.

Sandoval and Morrison interviewed students before and after the four-week inquiry unit. Teachers asked for volunteers and then selected five students each to be interviewed, giving ten students total. Two students dropped out of the interview process, leaving four boys and four girls who completed interviews. The interviews were conducted according to Carey and Smith's (1989, 1993, 2000) three level characterization of student epistemologies of science and the nature of science. There were 16 questions around several themes: the goals of science, the types of questions scientists ask, the nature of experiments, the nature of hypotheses and theories, the influence of theories and ideas on experiments, and processes of theory change.

The levels (1 being the lowest level of understanding aspects of the nature of science and 3 being the highest level of understanding aspects of the nature of science) of scores for different question clusters vary, which suggested to Sandoval and Morrison that different epistemological views were expressed in response to different questions. Student responses fluctuated between level 1 and level 2 ideas and a clear model epistemology did not emerge from the students. "Paired-sample t-tests yielded no significant differences between pre and post interview level scores for any cluster or question, or overall (Sandoval & Morrison, 2003, p. 377)." Students' ideas about science did not change as a result of the four-week inquiry unit, and inconsistencies in student responses indicated to Sandoval and Morrison that students' epistemological views of the nature of science were fragmented.

Student understanding did not significantly change as a result of this unit. Four weeks is a short period of time to expect changes in student views of the nature of science that have been developing over the course of years of science education. If the intervention unit were several months long, there might be more significance between pre and posttest scores. The students interviewed were chosen by their teachers from a pool of volunteers, which could have led to selection bias. Lack of significance between pre and posttest scores could be due to the fact that the teacher picked students that were not likely to change their views of the nature of science during the intervention unit. The reasoning for selecting students in this way was unclear and it would be interesting to compare the pre and posttest scores if students had been selected more randomly. There was a gender balance in the classroom but there was no indication of the ethnic demographics of the students in the classes or those interviewed.

Sandoval and Morrison (2003) studied whether student conceptions of the nature of science change as the result of a computer-based inquiry unit, Lederman and Druger (1985) quantitatively investigated whether teacher understandings of the nature of science were related to changes in students' conceptions of the nature of science. This study is important in examining the effects of science by inquiry on students' understanding of the nature of science because it examined which aspects of instruction influenced students' conceptions of the nature of science. Lederman and Druger (1985) found that teachers' conceptions of the nature of science did not significantly influence changes in student conceptions of the nature of science. However, they identified other characteristics of science classrooms that had great amounts of changes in student conceptions of the nature of science.

The participants were 18 high school biology teachers and students from 1 randomly selected New York State Regents biology class of each teacher, giving 409 students total. Classes were considered heterogeneous with regards to sex. Students were considered above average students because they were in the Regents program. The 18 classes were in nine different schools with a maximum of three classes per school. Six classes were in urban areas, one class was in a rural area, and 11 classes were in suburban areas.

All teachers and students were given the Nature of Scientific Knowledge Scale (NSKS) (Rubba, 1976) pretest which consisted of 48 statements and Likert responses to 5 choices. NSKS gives total score and six subscales: (1) amoral: scientific knowledge is amoral (2) creative: scientific knowledge is partially a product of human creativity (3) developmental: scientific knowledge is tentative (4) parsimonious: scientific knowledge is comprehensive as opposed to specific (5) testable: scientific knowledge must be capable of empirical test (6) unified: various specialized sciences contribute to a network of laws, theories, and concepts. NSKS scores are highest when they are consistent with a subscale. Twelve weeks after the pretest, all students and teachers were given the NSKS as a posttest. The difference between pre and posttest scores was used as a measure of change in students nature of science conceptions. The six teachers/classes with the greatest change toward the teacher's viewpoint (based on the test) were classified as "high," the six teachers/classes exhibiting the least change were classified "low," and the remaining six classes were classified as "medium." Teachers/classes were categorized for the NSKS Overall and the six subscales of the NSKS test.

For eight weeks, each classroom was qualitatively observed without observer knowledge of pretest data. In each classroom observers attempted to record every teacher and student verbalization, blackboard notes, handouts, assignments, teacher mannerisms, nonverbal cues and the physical plan of the classroom. Variables in classrooms that influence student conceptions of the nature of science came from these observations. The posttest was given 12 weeks after the pretest.

A quantitative analysis was performed to determine statistical differences between variables contributing to changing student conceptions of the nature of science in "high" and "low" classrooms. Sixteen raters went through the field notes for each classroom and compared whether a teacher/class exhibited "more" or "less" of each classroom variable. The raters were given training manuals and were experienced within the field of science education. Inter-rater agreement was calculated for each classroom variable, with 0.75 required for acceptance. Data that were below 0.75 inter-rater reliability were excluded from further analysis. The rater comparison data was analyzed as a series of binomial variables. The hypotheses produced from the analysis were set as grounds for future research.

The data from the changes in pre and posttest scores do not indicate that teacher conceptions of the nature of science influenced student conceptions of the nature of science ($p > 0.05$). However, changes in students' conceptions of science were observed in this study. Lederman and Druger emphasized the importance of the teacher's classroom behavior and the atmosphere she/he establishes to promoting changes in student conceptions of the nature of science.

By including qualitative and quantitative analyses in their study, Lederman and Druger's findings have greater implications than if they had focused on one or the other. In the qualitative observations between the pre and posttests, it was not clear whether the researchers made the observations in all 18 classrooms or whether they had help from a team of observers. Also the qualitative research was described as recorded which could mean audio, video, or writing and then later the 16 raters reviewed the observations which were referred to as pages. The ambiguity surrounding the collection of the qualitative observations causes the reader some confusion when reading the analysis. Also, the NSKS had six subscales and one Overall. Lederman and Druger stated that for the sake of time (their 16 raters were volunteers and the observations they rated averaged 180 pages) the Overall and development scales were analyzed. The Overall was chosen because it was all encompassing and the development was chosen because how crucial the tentative versus absolute view is to understanding the nature of science.

While Lederman and Druger's (1985) study examined implied teacher and classroom effect on students' views of the nature of science, Khishfe and Abd-El-Khalick (2002) were interested in whether an explicit and reflective inquiry oriented approach would help sixth graders develop informed conceptions of targeted nature of science aspects. They found that the explicit and reflective inquiry-oriented approach was more effective than an implicit inquiry-oriented approach in enhancing sixth graders views of target nature of science aspects.

Four aspects of the nature of science believed to be accessible to sixth graders and emphasized in AAAS benchmarks (AAAS, 1993) and NRC standards (NRC, 1996) were chosen for this study: (1) scientific knowledge is tentative (2) scientific knowledge is empirical (3) science knowledge is partly the product of human imagination and creativity (4) distinction between observation and inference. Khishfe and Abd-El-Khalick sought answers to two questions: (1) does an explicit and reflective inquiry-oriented approach help sixth graders develop informed conceptions of the target nature of science aspects? (2) is an explicit and reflective inquiry-oriented approach more effective than an implicit inquiry-oriented approach in enhancing sixth graders' nature of science understandings? The explicit group did a reflective nature of science component at the end of each inquiry activity, all or some target nature of science aspects were highlighted and the explicit group participated in guided discussion reflecting on the aspects in relation to the inquiry activity.

The participants were 62 sixth grade students at a private school in Beirut, Lebanon where English was the language of instruction. The explicit group was composed of 29 students, 12 girls and 17 boys. The implicit group was composed of 33 students, 16 girls and 17 boys. A six-item open-ended questionnaire was given at the beginning and end of the study. Sixteen students, eight from each group, were interviewed at the start of the study and a different group of 16 students, eight from each group, was interviewed at the conclusion of the ten-week unit. The interview questions were written based on previous research and reviewed by two science education professors, two sixth grade English teachers and was pilot tested and modified before being used in this study. The interviews were conducted to ensure that researcher and student interpretations of the survey were consistent.

The ten-week intervention unit was taught by Khishfe and all classroom sessions were videotaped. The camera was in place one week before the start of the unit to get students acclimatized. Khishfe, Abd-El-Khalick, and a science teacher monitored tapes of lessons for consistency between explicit and implicit classroom sessions. The implicit group and the explicit groups each had two 50 minute science classes per week for ten weeks. Students worked in groups during the six inquiry activities that took two to three class sessions each. Each activity started with Khishfe posing a problem or guiding question. Participant student groups made predictions and designed data collection procedures to answer their questions and then presented and defended data collection procedures to the entire class. Data from the different groups was pooled and the class discussed science content and process skills. Since only the explicit group discussed relevant nature of science aspects, their lessons were longer. In order to avoid engagement time as a conflating factor, the implicit group discussed content or process science skills to balance the engagement time.

Table 1

Percent of Pre and Post Instruction Explicit Group Students with Informed Nature of Science Views

Target nature of science area	Pre instruction	Post instruction
Tentative nature of science	6	52
Observation vs. inference	9	40
Empirical nature of science	6	48
Creative and imaginative nature	3	34

Table 2

Percent of Pre and Post Instruction Implicit Group Students with Informed Nature of Science Views

Target nature of science area	Pre instruction	Post instruction
Tenative nature of science	7	7
Observation vs. inference	4	18
Empirical nature of science	4	7
Creative and imaginative nature	7	4

The results of students' pre and post instruction views of the nature of science are presented in tables 1 and 2. Khishfe and Abd-El-Khalick compared student pre and post views of the nature of science. They found that pre instruction, 85% of all students in both groups had naïve nature of science views in all four target areas (tentative nature of science, observation vs. inference, empirical nature of science, creative and imaginative nature of science). Post instruction, 52% of the explicit group held informed views of the tentative nature of science, 40% in observation vs. inference, 48% in empirical nature of science, and 34% in creative and imaginative nature of science. Pre instruction the explicit group had informed views of: 6%, 9%, 6%, 3% respectively. The implicit group went from 7% informed views of observation vs. inference pre instruction to 18% informed views post instruction. Informed tentative nature of science views stayed at 7% for the implicit group. The implicit group went from 4% informed views about empirical nature of science to 7% and from 7% informed creative and imaginative nature of science to 4% post instruction. The results from the implicit group were not surprising to Khishfe and Abd-El-Khalick, who said "engaging in inquiry and learning about science process skills are not equivalent to learning about the nature of science (Khishfe & Abd-El-

Khalick, 2002, p. 573).” The finding that 24% of the explicit group’s views improved in all four target nature of science aspects and that there was no change in about half of the explicit group’s views suggested to Khishfe and Abd-El-Khalick that ten weeks is not enough to change the nature of science views the students had acquired in their five years of science education. Khishfe and Abd-El-Khalick stated that “attempts to teach the nature of science should be contextualized and woven into inquiry activities and teaching about science content and process skills. (Khishfe & Abd-El-Khalick, 2002, p. 573).”

Khishfe and Abd-El-Khalick stayed within the realm of their study and did not intend for their results to be reflective of the larger population. They supplemented student pre and posttests with interviews, to make sure that student and researcher interpretations were consistent. Khishfe and Abd-El-Khalick’s interview questions were planned and purposeful; they were reviewed by teachers, piloted in another study, and revised before they were put to use in this study. Khishfe and Abd-El-Khalick did not want abrupt changes in the learning environment to affect the results of the study and placed the video camera in the classroom well before the start of the intervention unit. Engagement time between the explicit and implicit groups was balanced so that longer engagement time in the explicit group would not be a conflating factor in the study.

Khishfe and Lederman (2006) compared the relative effectiveness of explicit and implicit approaches to developing informed conceptions of the nature of science when coupled with a controversial science topic. Explicit teaching of the nature of science was integrated within the context of a global warming unit for the integrated group and explicit teaching of the nature of science was taught separate from a global warming unit in the nonintegrated group. Comparison of differences between the two groups showed improvement in the informed views of the integrated group participants and greater improvement in the transitional views of the nonintegrated group participants. The overall results did not provide any conclusive evidence in favor of one approach over the other.

Khishfe and Lederman (2006) compared the relative effectiveness of two approaches (integrated and non integrated) when coupled with a controversial science topic in developing informed conceptions of the nature of science. Comparison of differences between the two groups showed improvement in the informed views of the integrated group participants and greater improvement in the transitional views of the nonintegrated group participants.

Two ninth grade environmental science classes taught by Khishfe at an urban public high school in Chicago participated in the study. Students that attended the school were low to middle socioeconomic status and 17.3% white, 18.6% black, 58.3% Hispanic, 5.3% Asian Pacific Islander, 0.5% Native American. The 29 year old male teacher had been teaching environmental science at the school for four years. The teacher had participated in one year of a five year NSF project promoting teacher and student understanding of the nature of science and scientific inquiry. The integrated and non-integrated groups were assigned to each class via a coin toss. The integrated class had 14 male and seven female students and the non-integrated class had eleven males and ten females.

Khishfe and Lederman (2006) used an explicit approach to teach the nature of science, which Khishfe and Abd-El-Khalick (2002) found to be more effective in improving student conceptions than an implicit approach. Explicit teaching of the nature of science was integrated within the context of a global warming unit for the integrated group and explicit teaching of the nature of science was taught separate from a global warming unit in the nonintegrated group. Khishfe and Lederman selected nature of science aspects on which to focus: (1) tentative nature of science (2) empirical nature of science (3) imaginative/creative nature of science (4) subjective nature of science (5) observation vs. inference. Each of the five nature of science aspects was targeted in more than one questionnaire item. All students were given a five item open-ended nature of science questionnaire. Ten students (five from each class) were randomly selected for interviews at the beginning of the six-week treatment. At the end of the treatment, another ten students were randomly selected for interviews. Each interview was 20-50 minutes long. The interviewee was given her/his questionnaire and asked to elaborate on her/his responses. The last two questions dealt with global warming: "does it surprise you that scientists disagree when they are looking at the same data?" and "if data supports both groups, will we ever determine who is right?"

The sample size (n=2 classes) was too small for inferential statistics. Due to the nature of their study they were also not able to use student number as the sample size. The interview transcripts and their corresponding questionnaires were analyzed separately to make two separate profiles of student nature of science views. The two profiles were then compared and lack of discrepancies confirmed the validity of the questionnaire. Then each questionnaire (pre and post) for each student was analyzed separately to generate a pre and post profile for each participating student. Student responses from their profiles were categorized as naïve, informed, or transitional for each nature of science aspect. Comparison of differences between the two groups showed improvement in the informed views of the integrated group participants and greater improvement in the transitional views of the nonintegrated group participants. The overall results did not provide any conclusive evidence in favor of one approach over the other. Khishfe and Lederman (2006) do not suggest that nature of science should be taught separate from content. The fact that both the integrated and non integrated groups improved their conceptions of the nature of science supports the explicit approach to teaching the nature of science. Khishfe and Lederman (2006) were not able to use statistics because of the small n of their sample. Due to the fact that this study was inconclusive in its findings, Khishfe and Lederman would need to study a larger number of classrooms to obtain quantitative data. The added dimension of quantitative data may have helped their results be more conclusive. Due to the close nature of the findings, the next study would need to be a time period longer than six weeks.

The BGuILE computer-based inquiry software has several reflective components. While Sandoval and Morrison (2003) found that after a four-week unit with BGuILE, students nature of science conceptions were fragmented, Crawford et al. (2005) found that students enhanced their nature of science understandings through BGuILE (Biology Guided Inquiry Learning Environments) computer software. "The scaffolds built into the software are designed to promote children's mental activities of grappling with data and building explanations for questions similar to those asked by scientists" (Crawford et al., 2005, p. 618). One of the main tools of the software is the ExplanationConstructor, an embedded electronic journal where students can build explanations by writing reasons for the claims they make and link the claims to evidence.

The study participants were prospective teachers so some of the goals of the study were aimed at how the prospective teachers connect their learning experience to how they would teach. The part of the study that is relevant to this analysis of the nature of science as an effect of scientific inquiry is the research question: in what ways, if any, did the Galápagos Finches (BGuILE) software-based curriculum instruction enhance prospective science teachers' understandings of the nature of scientific knowledge? It is important to distinguish that I am interested in how the participants in this study were able to enhance their understandings of the nature of science and am viewing the prospective teachers as students. The implications of their experiences to their teaching practice is beyond the scope of my masters question.

The participants were 21 prospective teachers in their senior year in a 15-week course taught by Crawford. All students agreed to have artifacts saved and analyzed and to be videotaped in class. The students spent 12 hours over three weeks on computer lab work with the Galápagos Finches and class instruction. Crawford et al. selected two focus pairs and videotaped them as they worked together on the Galápagos Finches computer inquiry. Data collected was audio taped conversation as students worked on software, written pre and posttests on concepts of natural selection and the nature of science and responses to email journal questions.

They found that even the two prospective teachers with the most research experience prior to the intervention unit failed to demonstrate a working knowledge of the diverse ways scientists use evidence and construct explanations. Post instruction 14 out of 18 participants holding initial alternative conceptions demonstrated movement toward enhancement of their understandings of evolutionary concepts and a shift in recognizing their own alternate conceptions.

Crawford et al.'s main focus was the prospective teachers' science education experiences and views of the nature of science and the implications on their abilities to teach adequate conceptions of the nature of science. While some of Crawford et al.'s implications will be explored in chapter 4, it is worth noting here that Crawford conducted a small qualitative study and generalized the results to the larger population, calling for changes in the way undergraduate college science courses are taught. There is a body of research suggesting changes in the undergraduate college system, but suggesting changes of such a magnitude is beyond the scope of Crawford et al.'s small qualitative study.

Literature in this section focused on informed views of the nature of science contextualized in scientific inquiry as characteristic of a scientifically literate individual. Lederman and Druger (1985) found that teacher conceptions of the nature of science did not influence student conceptions of the nature of science so much as the classroom atmosphere the teacher created. Lederman and Druger's findings also make sense in light of Khishfe and Abd-El-Khalick's (2002) finding that an explicit reflective inquiry oriented approach was more effective than an implicit inquiry oriented approach in enhancing sixth graders views of target nature of science aspects. Sandoval and Morrison (2003) found that student nature of science ideas did not change significantly in their study. They did find that students' epistemological views of the nature of science were fragmented, meaning students held more naive views in some nature of science areas and more informed views in other areas. Crawford et al. (2005) found that 14 out of 18 participants that held initial alternative conceptions demonstrated movement toward enhancement of understandings of evolutionary concepts and a shift in recognizing their own alternate conceptions. Khishfe and Lederman (2006) compared the relative effectiveness of explicit and implicit approaches to developing informed conceptions of the nature of science. Comparison of differences between the two groups showed improvement in the informed views of the integrated group participants and greater improvement in the transitional views of the nonintegrated group participants. The overall results did not provide any conclusive evidence in favor of one approach over the other.

Epistemological Understanding

Epistemology is a person's conscious or subconscious beliefs about knowledge and knowledge production (Sandoval, 2003). The nature of science is the social values and epistemological assumptions of science and science knowledge (Khishfe & Lederman, 2006). Students professed strategies for learning science seem generally consistent with their professed conceptions about the nature of science (Hammer, 1994; Songer & Linn, 1991 as cited in Sandoval, 2003). Thus, students' epistemological assumptions toward science directly influence their own goals during science instruction, the reasoning strategies they pursue, and their overall approach to science learning (Sandoval & Morrison, 2003). Greater student understanding of personal epistemologies toward learning science is a suggested effect of learning by scientific inquiry.

The following studies were concerned with student epistemological understanding as an effect of scientific inquiry. Hammer, (1994) wanted to show individual students can be characterized as having epistemological beliefs that are involved in learning introductory physics. Lawson (2005) studied whether students use enumerative induction in scientific inquiry. Leach et al. (2000) studied the consistency of science students' epistemological representations of the nature of science across different contexts. Sandoval (2003) used the BGuILE software project to uncover epistemic ideas students showed when explaining a complex event. Hogan (1999) was interested in how individual differences among middle school students' epistemological and motivational perspectives were associated with their approach to constructing knowledge with peers. Samarapungavan and Westby, (2006) wanted to compare the way research chemists and chemistry students conceptualized and evaluated their work. Hand, Wallace, and Yang, (2004) studied the effects of a science writing heuristic (SWH) on seventh grade students in science laboratory experiences. Hakkarainen (2004) analyzed whether elementary school students collaborating within a computer supported classroom would be able to participate in the research-like processes of inquiry that characterize practices of science research. Metz, (2004) wanted to know whether students could have more responsibility and control in inquiry when provided with an authentic context for elementary scientific knowledge.

When Hammer studied the epistemological beliefs of introductory physics students, he had two purposes: (1) to show individual students can be characterized as having epistemological beliefs that are involved in learning introductory physics and (2) to identify beliefs important to such characterizations. These goals were met by developing and using an analytic framework to characterize subjects' beliefs. This study is important in examining the effects of science by inquiry on students' epistemological understanding because it sought to uncover students' conscious or subconscious beliefs towards physics that affected their ability to learn physics. The subjects were college freshman in a calculus based introductory physics course. Four students were selected randomly and interviewed five times throughout the course; two students were selected for high scores on the first midterm and interviewed three times during the course. Each one hour interview session was audio taped and transcribed. Hammer also audio taped one third of lectures, observed several labs and followed reading problem sets and exams. In the interview sessions, students were engaged in open discussion ("how is class going?", directed tasks (going over graded tests or a lecture), and discussion regarding specific content (solving current homework problems). Hammer uncovered subject's beliefs through their statements, comments, or behaviors.

Hammer used three coding criteria (recognizability, evident involvement, and consistency) to analyze the interview sessions. From the coding, he was able to develop and apply the analytic framework:

Beliefs about structure of physics (a) pieces (b) weak coherence (c) coherence

Beliefs about the content of physics (a) formulas (b) apparent concepts and/or weak concepts (c) concepts

Beliefs about learning physics (a) by authority (b) independent

The subjects fell into two groups:

(1) the four randomly selected students were characterized by weak coherence, apparent concepts, and authority

(2) the two students selected based on midterm scores were characterized by concepts and independent

During the interviews, students were asked three questions to probe for common physics misconceptions. The two students selected for midterm scores did not demonstrate misconceptions.

Physics education research usually involves comparing novices and experts. Novices are usually characterized by having weak organization of knowledge, use of pure formula manipulation, and various misconceptions. Hammer's study showed differences among novice introductory level students. Hammer suggests that one implication of this study is that students have knowledge and abilities they don't use because of what they believe about physics. He suggests that if these beliefs were connected with physics content knowledge, students might be able to apply more knowledge and abilities to physics and that teachers use not have to anticipate and correct as many misconceptions.

Of the six participants, only one was female. A gender blind selection process was used and due to the imbalance, Hammer may change his selection method in future studies. Previous studies of introductory physics students give shared characteristics for novice physics students. Although this study found two groups of characteristics, he explored and considered alternative explanations for the results: content level knowledge, general cognitive resources, and goals in the course. This study stayed within the realm of a small qualitative study and did not try to over generalize the results. Also, although he gave implications for instruction, Hammer warned the reader to be cautious in drawing implications, that a narrow focus may be appropriate for research, not for instruction.

Lawson (2005) was looking at whether science students use enumerative induction. Lawson (2005) found that students reasoned with hypothetico-deductive reasoning, not enumerative induction. Lawson proposed that increasing student consciousness of hypothetico-deductive reasoning would lead to science literacy. Enumerative induction was defined as: "reasoning from observed particulars to general statements or 'laws' (Lawson, 2005, p. 720). Lawson (2005) describes hypothetico-deductive reasoning as "generating and testing increasingly complex and abstract hypotheses and theories," (Lawson, 2005, p. 716).

Six hundred and sixty nine college students in a non-major's biology course at a large university in the southwestern U.S. were randomly given one of two different reasoning tasks as part of a course exam. Students were told the initial item did not have a single correct answer and students were asked for their explanations, with responses being worth two points. It was predicted that students would have to use enumerative induction to identify the key features of fictional creatures called "Mellinarks." If students answered differently on both reasoning tasks, it would support the hypothesis that enumerative induction exists. If student answers were similar on both reasoning tasks, it would support Popper's hypothesis that enumerative induction "is a psychological and scientific myth," (Lawson, 2005, p. 734) and that people use hypothetico-deductive reasoning. Reasoning task A had a row of five identical creatures that were examples of "Mellinarks." Students were asked to identify "Mellinarks" in a second row of six different creatures. Reasoning task B had one "Mellinark" as an example and asked students to select which six creatures in a second row were "Mellinarks." The second row of creatures was identical in both reasoning tasks. Creatures in the second row had characteristics of "Mellinarks," one creature was "identical" to the examples, and a creature "identical" to the examples was upside down. Due to design of the reasoning tasks, enumerative induction could only be used on task

A, with multiple examples of "Mellinarks."

Student answers for each reasoning task were compared. Students had to select which creatures were "Mellinarks" and then explain why the creatures were "Mellinarks." Lawson (2005) analyzed student reasoning that led to the their answers and combinations of answers between the two reasoning tasks. Percentages on task A and task B were similar for most creatures except significantly less students selected creature 2 on task A than on task B ($p< 0.001$) and significantly less students selected creature 5 on form A than on form B ($p< 0.001$). Lawson's (2005) experimental results support Popper's hypothesis that enumerative induction is not used in scientific thought processes. Lawson (2005) suggests that inquiry proceeds in a hypothetico-deductive manner and that people, even scientists, aren't necessarily conscious of their hypothetico-deductive thought processes.

This study stays within the realm of its first question: whether or not enumerative induction exists. The results of the second question are a little more difficult to accept, given that the argument supporting them was not a quantitative or qualitative study but a literature review. Lawson (2005) drew from a large body of literature to connect the non-existence of enumerative induction with the existence of hypothetico-deductive reasoning via the subject of neural modeling. Since hypothetico-deductive reasoning is a controversial topic, Lawson's argument would have more weight if supported it with a study as well as a literature review. I take from Lawson (2005) that enumerative induction is not the reasoning method students use in scientific inquiry. According to Lawson, the AAAS (American Association for the Advancement of Science) states "teaching should be consistent with the nature of scientific inquiry," (AAAS 1989 as cited in Lawson, 2005 p. 716). Both Lawson (2005) reasoning tasks were decontextualized, which is inconsistent with the nature of scientific inquiry, yet Lawson identified a method of reasoning students use in scientific inquiry. The following studies Leach et al. (2000), Sandoval (2003) and Hogan (1999) examine the effect of context on student epistemology in science and science inquiry.

Leach et al. studied the consistency of science students' epistemological representations of the nature of science across different contexts and found that students use different epistemologies in different contexts. Seven hundred thirty one students in five countries were given a short answer survey. Three items gave detailed contextual information, one item gave limited contextual information, and one item was decontextualized. Survey responses were analyzed for three forms of epistemic reasoning determined in Leach (1999): focused reasoning, radical relativist reasoning, and knowledge and data reasoning. To analyze across contexts, Leach et al. hypothesized how students using the three forms of epistemological reasoning would respond to the survey items. One hundred twenty five participant responses were characteristic of theory and data reasoning on all five statement pairs vs. 81 predicted ($P<0.001$, significant). Sixty eight participants used theory and data reasoning characteristic responses on four of the statement pairs vs. a prediction of 57 ($P<0.13$, not significant). This implied that students in secondary and undergrad competitive science classes use different epistemological reasoning in different contexts and that students used theory and data reasoning in at least one context.

Leach et al. stated clear limitations of the study; there was not a focus on gender demographics. While findings were not different by gender, if the gender proportions are not “constructed to be representative of the proportion of male and female students studying science at this level in each country” (Leach et al., 1999, p. 502), it would be hard to generalize the findings of the study to the population of each country. The survey was given in five languages and in five countries and it was acknowledged that meaning could be slightly altered between translations. It was not clear whether survey responses in the five languages were translated into one language for analysis, which would also alter meaning of responses. Leach et al. called for future research to involve interviews to clarify meaning between researchers and subjects. It was also noted that lack of statistical significance in findings might have been to due to the possibility that students interpreted the fixed response statements differently from how the researchers intended. Although this was mainly a quantitative study, it would have benefited from qualitative interviews to clarify differing interpretations. There was not much consistency to suggest that students draw upon more than one form of reasoning when they answer questions. Leach et al. did clarify that when students use different forms of epistemological reasoning, they did not have to be aware that they have different epistemological reasoning in different contexts. Leach et al. was cautious about inferring individual epistemic reasoning based on short answer questions in the survey. Leach et al. suggests that students be taught to recognize contexts to use different forms of epistemological reasoning, as opposed to conceptual change, which involves replacement of one concept by another.

The BGuILE (Biology Guided Inquiry Learning Environments) project is computer software that guides students in scientific inquiry. Sandoval (2003) used the ExplanationConstructor component of the software to analyze student explanations of natural selection phenomena. Sandoval was not examining whether students learn from the software, he wanted to uncover epistemic ideas students show when explaining a complex event. Epistemology is defined as "beliefs about the nature of science and science knowledge." This study had three questions: (1) can students use the integrated conceptual and epistemic guidance of ExplanationConstructor to articulate explanations consistent with the theory of natural selection? (2) can students meet criteria for causal coherence and evidentiary support in their explanations? (3) how do conceptual and epistemic aspects of understanding interact?

The study participants were three introductory biology classes taught by the same teacher in an affluent suburb of a major Midwestern city. 85% of participants were white and less than 2% were on school lunch programs. During the four-week unit, students were asked to solve two interrelated questions via their work with Darwinian finches in the BGuILE software: (1) how did so many finches die? (2) why did some finches survive? Students analyzed data and were scaffolded via prompts in the ExplanationConstructor to make claims about why finches lived and died based on the data. At the end of the unit, student explanations were coded and analyzed for quality through two epistemic criteria: (1) causal coherence, coherence of cause and effect in student explanations and (2) evidentiary support, relation of data to claims.

Previous research had found that students did not understand the role of an individual variation in natural selection. In this study, 15/18 (over 80%) of student groups made claims that variations between individual finches led to survival. The most significant findings of Sandoval's study were that (1) students articulated explanations and attempted to find causal mechanisms to interpret data and (2) students viewed data as a part of science to be explained but not as a necessary component of an argument.

Sandoval's study was unique in that he focused on student epistemology during inquiry. Prior studies gave interviews and surveys after the inquiry activities, which according to Sandoval separates student epistemology from student inquiry performance. His interest was student perceptions of the nature of science as they are practicing inquiry. Sandoval hypothesized the relationship between conceptual and epistemic aspects of understanding, but major conclusions could not be drawn from this small study, this is an area for further research. Although Sandoval found positive impacts of computer supported inquiry, he stressed the importance of using computer-based inquiry in addition to reflective classroom discourse. Would this study produce the same results if conducted in an area with more diverse ethnic demographics?

Hogan (1999) was focused both on individuals and the social context of learning. Since science is also situated in a social context, it was important to understand the epistemology of the social context of learning. Hogan (1999) was interested in how individual differences among middle school students' epistemological and motivational perspectives were associated with their approach to constructing knowledge with peers. The two main goals of the study were to create qualitative profiles of a sample of 8^{th} graders' personal frameworks for science learning and to explore relationships between the frameworks and students' participation in collaborative knowledge-building tasks. Hogan (1999) found that student participants held a constructivist view of learning and the dimension of students' personal frameworks that most clearly mirrored their patterns of sociocognitive behaviors were their learning-referenced perspectives for constructing knowledge with peers.

Hogan (1999) gave three perspectives that compose personal frameworks: (1)

self-referenced perspectives: “What are my interests, capabilities and goals as a learner of science?” (2) learning-referenced perspectives: “What are the most effective ways for me to acquire science knowledge and skills in school?” (3) discipline-referenced perspectives: “What do I see as the nature of knowledge building in professional science?” The study participants were two eighth grade classes taught by the same teacher in suburban upstate New York. Twelve focal students were selected to represent diversity of achievement levels within the two classrooms. Six students were male, six were female, ten students were white, one was African-American, and one was Asian. The twelve students worked in four heterogeneous groups during the 12-week unit. Each of the 12 focal students was interviewed at the start of the unit. The interview was semi structured, questions were about self-referenced, learning-referenced, and discipline-referenced perspectives in science. Six students were interviewed a second time halfway through the unit where they watched and shared perspectives on videotaped group interactions.

Student discussions were analyzed by “identifying major episodes of interaction transcribing dialogue within peer knowledge building episodes, doing fine grained analyses of the transcripts, and recomposing the smaller analyses into patterns to create assertions about students’ roles in sociocognitive interchanges” (Hogan, 1999, p. 7). From the analysis, Hogan (1999) was able to build qualitative profiles of several major types of roles in student collaborative knowledge building, which yielded two major categories: high sociocognitive engagement/deep processing and low sociocognitive engagement/surface processing. High sociocognitive engagement/deep processing had three subcategories: (1) sociocognitively collaborative (2) sociocognitively curious and tenacious (3) sociocognitively stubborn and competitive. Low sociocognitive engagement/surface processing also had three subcategories: (1) sociocognitively sporadic (2) sociocognitively passive (3) non-sociocognitive/disruptive. All twelve focus students had constructivist views of learning ranging from exogenous (knowledge building is an external reality) to endogenous (knowledge is built internally through a person's activities) to dialectical (knowledge building is reciprocal and contextualized). There was a pattern between learning-referenced perspectives and student behaviors. Student discourse patterns matched their position on the learning-referenced continuum. Students who were less sociocognitively engaged were on the exogenous constructivism end of the continuum, students with mixed engagement patterns were endogenous constructivists, and the most sociocognitively engaged students were at the dialectical constructivist end of the continuum. In this sense, Hogan (1999) found that student participants held a constructivist view of learning and the dimension of students' personal frameworks that most clearly mirrored their patters of sociocognitive behaviors were their learning-referenced perspectives for constructing knowledge with peers.

Hogan made it clear that the purpose of the interviews was to uncover student perspectives on the nature of learning science and the nature of scientific knowledge acquired in school, not discovering student preferred learning styles or modalities of learning. The study structure was consistent with its goals; student interviews and video taped learning tasks were appropriate ways to measure students' collaborate knowledge building. The results were specific to the students studied, however Hogan (1999) suggested that while student's personal frameworks for science learning are not the sole influence on students' sociocognitive participation in collaborative-knowledge building tasks, they are an alternative lens that educators can use to understand their students and modify instructional practices.

While Hogan (1999) studied students' personal frameworks, Samarapungavan and Westby (2006) wanted to compare the way research chemists and chemistry students conceptualized and evaluated their work. They had three questions: (1) do epistemic beliefs vary as a function of chemistry expertise? (2) are there discipline-specific values and heuristics that guide chemistry research? (3) how does research experience influence participants' epistemic beliefs? They found that epistemic beliefs varied significantly with chemistry expertise and with exposure to authentic research in chemistry. This study is important in examining the effect of scientific inquiry on students' epistemological understanding because students' strategies for learning science tend to be consistent with their conceptions about the nature of science (Hammer, 1994; Songer & Linn, 1991 as cited in Sandoval).

The participants were 91 volunteers from five groups of varying levels of chemistry experience. The first group was 13 chemistry faculty involved in chemistry research. The second group was 22 doctoral candidate chemistry graduate students. The third group was 20 chemistry students participating in undergraduate research. The fourth group was 17 general chemistry undergraduate students in a general chemistry course with a laboratory. The fifth group was 19 high school students in a chemistry course with a laboratory. The college students and faculty were from a major Midwestern university and the high school was a large public Midwestern high school. Each participant was interviewed for one hour. The interviews were videotaped and later transcribed. The questions were adapted for different levels of chemistry experience and centered on five epistemic themes: (1) description of own work (2) choice of problems and methods (3) models for handling empirical anomalies (4) criteria for evaluating own work (5) what is science. Interview data was analyzed first with nominal coding, which tried to identify and code for common meaning, and then ordinal coding, where each theme was further broken into ordinal categories. Nonparametric Kruskal-Wallis tests (a nonparametric alternative to ANOVA) were given to each theme to determine if ordinal levels of responses varied significantly across the five groups of participants. The tests indicated there were significant differences between group responses for each theme. Post hoc pair wise comparisons were conducted to examine the differences further with an alpha value of 0.05.

In the first theme, description of own work, the scientists differed significantly from all other groups. Graduate students and research undergraduates were the same but differed significantly from undergraduates and high school students, which were the same. In the second theme, choice of problems and methods, and the third theme, models for handling empirical anomalies, graduate students and research undergraduates did not differ as well as undergraduate students and high school students. All other groups had significant differences. In regards to models for handling empirical anomalies, scientists said that anomalies were frequent in research in two ways. The first was commonly occurring anomalies from routine methodological errors. These were planned for with checks and controls built into the experiments such as replications and triangulation. The second type of anomaly was productive anomalies where in the process of trying to account for the problem, the scientist discovered new insights or venues for research. In contrast, undergraduate students and high school students attributed anomalies to lack of personal skill or careless mistakes. Strategies to account for anomalies included no strategy, copying correct answers from friends, and fixing the data to get the desired results. Fifty nine percent of undergraduate students and 90% of high school students reported never having lab problems. In theme four, criteria for evaluating own work, all groups differed significantly except graduate students and undergraduate research trainees and undergraduate students and high school students. The scientists evaluated their work based on pragmatic factors such as impact of the work, their peers, design criteria and cognitive factors such as novelty and difficulty. In contrast, all high school students and 82% of undergraduates evaluated themselves based on their ability to complete assignments, grades received, and feedback from the teacher. In the fifth theme, what is science?, scientists differed significantly from every other group. Most scientists defined science as trying to understand the natural world.

Samarapungavan and Westby (2006) found significant variation in epistemic beliefs as a function of chemistry expertise. Scientists, graduate students, and undergraduate research students had different epistemic conceptualizations of their work than undergraduates and high school students without authentic research experience. Undergraduate and high school students did not have epistemic criteria for knowledge evaluation, which Samarapungavan and Westby (2006) found to be congruent with other research. Scientists were the only group that saw empirical anomalies as productive, while graduate students and research undergraduate students had negative views of anomalies. The scientists had discipline specific pragmatic and epistemic criteria that guided their research. Samarapungavan and Westby (2006) also found that research experience influenced participants' views of what it meant to do science. While

Samarapungavan and Westby (2006) advocated for authentic research experience, they cautioned based on the undergraduate research students and graduate students in this study that apprenticeship in real research does not ensure that students will reflect on scientific inquiry or automatically enhance epistemic development.

The participants in this study were volunteers. Samarapungavan and Westby 2006 said that due to the fact that participants were volunteers, they had an interest in science. If this study was a random sample of high school and undergraduate students, the epistemological differences between groups might be greater. High school chemistry students might simply be fulfilling a requirement for the class and to some extent college students might as well. If the students in this study had an interest in science, a study with mixed student science interests would yield more drastic epistemological differences. Samarapungavan and Westby (2006) only included participants involved with chemistry in this study and when addressing their second question regarding discipline specific values and heuristics, they were aware that they did not observe other scientific disciplines. They alluded to Bell et al.'s 2003 finding that there is no single "scientific method." This informs the question of the effects of inquiry on student epistemological understanding because Samarapungavan and Westby (2006) suggested that there is not a single scientific method and thus different epistemologies are used when approaching different scientific disciplines.

Hand, Wallace, and Yang (2004) quantitatively and qualitatively studied the effects of a science writing heuristic (SWH) on seventh grade students in science laboratory experiences. Both treatment groups of students who used a science writing heuristic outperformed the control group on conceptual and multiple choice posttest questions. Students interviewed attributed their increased understanding of the cell unit to features of the science writing heuristic activities: framing their own questions, participating in peer group discussions, making connections between concepts, and the act of writing. The textbook explanations made students metacognitively aware of their knowledge and thus enriched their conceptual knowledge.

Hand, Wallace, and Yang (2004) had five research questions:

(1) Do students who use the SWH perform better on tests of conceptual understanding than students who use traditional laboratory reports?

(2) Do students who use the SWH and were also engaged in a second task of writing a textbook explanation perform better on tests of conceptual understanding than students who used SWH alone?

(3) Within the context of the SWH classroom, to what do students attribute their own increased science understandings?

(4) What are students' understandings of observations, claims, and evidence in science, and how do they assess their own understandings?

(5) What is the value of the additional textbook writing task from the students' perspective?

The study participants were 93 seventh grade students, in five class sections taught by the same teacher, in an introductory biology course at a Midwestern middle school. Ninety percent of students were Euro-American and ten percent were from "a variety of ethnic origins" (Hand et al., 2004, p. 135), and special needs students were excluded to avoid confounding effects like English fluency. Twelve Euro-American students (five boys seven girls) were selected for qualitative interviews based on gender mix and representation of high, middle, and low ability groups within the class. Abilities were based on students' test scores on the completion of the intervention unit. Hand, Wallace, and Yang developed a science writing heuristic (SWH), which adopts a more student-centered approach for teaching. One class section was the control group, in which students had very little input towards the direction or flow of the classroom and labs were traditional step-by-step "cookbook" experiments followed by questions from the textbook. Two class sections were treatment groups that used the SWH followed by questions from the textbook. Two class sections were treatment groups that used the SWH and composed a textbook explanation to the audience of a classmate instead of answering questions from the textbook. The intervention was an eight-week unit on cells in the fall of 2000. Students were given a pre and posttest, 34 multiple choice questions and three conceptual short answer questions. All seventh grade students in the school were given the Stanford Diagnostic Reading Test (SDRT) at the beginning of the school year and the results of that test were used to determine students' ability as high, medium, or low. Student interviews were transcribed and then coded by Hand, Wallace, and Yang to distinguish categories in student answers.

ANCOVA analysis showed the four treatment groups that used the SWH (SWH and SWH + textbook summary) outperformed the control groups on the conceptual and multiple choice posttest questions. There was no significant difference between the SWH group and the SWH with textbook summary group ($p < 0.00$). Hand, Wallace, and Yang took this as strong evidence that the SWH and textbook writing tasks were effective in developing student conceptual understanding about the cell. Students who were interviewed attributed their increased understanding of the cell unit to features of the science writing heuristic activities: framing their own questions, participating in peer group discussions, making connections between concepts, and the act of writing. Students saw the textbook writing task as a way to seek gaps in their knowledge and translating technical language into everyday language for their peer audience. One half of the students interviewed said the writing aspect of the SWH helped them learn and five of twelve students interviewed could articulate the need to coordinate a claim with evidence.

Through both quantitative and qualitative data, Hand, Wallace, and Yang (2004) were able to answer their five research questions and show that a science writing heuristic enhanced students' conceptual knowledge during the cell unit. There are great implications to their findings and their conclusions are valid for the scope of the study. The results would be even stronger if there was a wider ethnic demographic present in the study. Gender balance and ability were accounted for in the interview group, but all students interviewed were Euro-American even though other ethnicities were present.

Hakkarainen (2004) analyzed whether elementary school students, ages ten to eleven, collaborating within a computer-supported classroom would be able to successfully participate in the research-like processes of inquiry that characterize practices of scientific research. Hakkarainen was looking for higher cognitive levels of explanation instead of processing only factual and descriptive knowledge. The results of the study showed that some young students engaged in epistemic agency and genuinely pursued explanation driven inquiry.

Hakkarainen used the CSILE (Computer-supported Intentional Learning Environments)/Knowledge Forum, which is networked, inquiry-based software that engages students with setting up research questions, generating and improving their own intuitive explanations, and searching for science information. “Students were systematically guided by their teacher [while working with the software] to generate their own hypotheses, conjectures, and theories about the physical phenomena being investigated” (Hakkarainen, 2004, p. 981). The CSILE database allowed students to share cognitive achievements by giving each student access to all notes produced by fellow students.

Hakkarainen defined progressive inquiry as the sustained process of advancing and building knowledge characteristic of scientific inquiry. Hakkarainen analyzed students’ externalized conceptions posted to the CSILE database to determine whether CSILE students were able to profitably engage in an explanation-driven inquiry process. The interest was in the nature of student explanations posted to the CSILE database and whether students were able to progressively improve their ideas.

The participants were 28 students in a fifth and sixth grade science class over the course of one school year in an inner city public school in Toronto. A higher than normal percentage of students were middle class and upper middle class although there were also students from educationally disadvantaged homes. Each CSILE project took four to six weeks where students worked 40 minutes per day. The teacher was a male in his fifties who had worked with CSILE from its beginning. The teacher had a PhD in social anthropology but no degree in science and had developed a culture of knowledge building in his classroom. Since the class was a fifth grade sixth grade split, the teacher had each student for two years. Sixth graders helped the fifth graders acclimatize to the inquiry culture of the classroom quickly. Each day half the class worked independently on French, half worked on CSILE and then switched which allowed the teacher to work with a smaller group. Students spent four weeks studying force and added 77 pages in the CSILE database. The six-week electricity unit yielded 195 pages in the database and four weeks of cosmology produced 55 pages in the database. Students worked in small groups for the force and cosmology units and individually on the electricity unit.

The progressive inquiry student notes from the database were broken down into individual student ideas. There may have been several student ideas in one note. Two independent coders separated 200 notes into student ideas with a reliability of 0.94. The individual student ideas were then broken into five categories: object of inquiry (of communicative idea) with a reliability of 0.74, nature of research question with a reliability of 0.87, origin of research question with a reliability of 0.79, type of knowledge with a reliability of 0.91, and nature of explanation with a reliability of 0.76. Each student's process of inquiry was assessed by using the *degree of deepening explanation scale* based on guidelines of (1) no advancement, student was given a rating of 1 for not advancing in her/his inquiry (2) small advancement, student was given a rating of 2 if the student found new information but it did not help her/his research question and a slight chance that the new information would help the student's conceptual understanding (3) moderate advancement, student was given a rating of 3 if she/he found scientific information that clearly made progress in her/his inquiry and the pieces of information informed the research question and had potential to enhance her/his conceptual understanding (4) strong advancement, student was given a rating of 4 if new explanatory information was her/his new theoretical concept or theory that provided answers to her/his research question and the information had potential to contribute to the advancement of the whole group, not just the individual student. The correlation between the scores for the two coders was 0.85 for the deepening of explanation scale. Hakkarainen constructed inquiry structure graphs for each student to assess individual student strategies of inquiry. Two independent coders classified the graphs, with an agreement coefficient of 0.84.

CSILE's database had 1007 student produced intuitive or scientific explanations and 141 pieces of factual physics information. Fifty six percent of student explanations represented student's intuitive theories and 44% involved scientific theories founded by them. When students were working in small groups, the group solved research questions even if all individual members did not. Also if a student gave an advanced explanation to her/his group, all group members did not necessarily include the same information in their notes. It may have appeared, based on ideas in the database, that only the student who recorded the idea advanced conceptually but in actuality group members could have understood the same idea. Comparison between intuitive and scientific theories were one avenue of conceptual advancement for students. Another mechanism for conceptual advancement was peer interaction. Students displayed three main strategies for inquiry: (1) truncated inquiry: one main research question for one main relevant piece of information (2) extensive inquiry: several research questions without many in depth searches (3) intensive inquiry: student went deeply into a problem, created new specific research questions, and carried out several in depth searches. This study found that "under advantageous conditions, it is entirely possible for young children, collaborating within a computer-supported classroom, to engage in explanation-driven processes of inquiry" (Hakkarainen, 2004, p. 994).

Hakkarainen's findings have great implications but it is carefully pointed out that there were several contextual factors contributing to the success of the students in this study. A few of these factors include the experience of the teacher and his close involvement with the CSILE project, and the strong research base supporting the CSILE project. Hakkarainen wanted to show that young students are capable of engaging in inquiry and was successful in doing so. When the demographics of the study were described, it was said that a higher amount of students than "normal" were middle class. The reader is left to assume that Hakkarainen meant higher amount of middle class students than average for the inner city.

Metz (2004) was concerned with children's understanding of scientific inquiry. Metz (2004) noted that early elementary science is decomposed and decontextualized and that there is research supporting the idea that children can participate in more authentic forms of inquiry. The potential epistemological outcomes of young children participating in authentic inquiry are unclear and Metz (2004) proposed students could have more responsibility and control in inquiry, providing an authentic context for elementary scientific knowledge. Metz (2004) found that young students, under particular conditions, were able to conceptualize the grounds of uncertainty and strategic ways to understand their study, conveying their understanding of challenges in the knowledge building process.

The study took place in a kindergarten through eighth grade school in a rural area. Most students were middle socioeconomic status, with 34% of students on free or reduced lunch. Two classrooms participated: one second grade class with 21 students and one fourth and fifth grade class with 15 fourth grade students and 16 fifth grade students.

The teachers of both classrooms were considered expert by peers and had negligible science background. Data collected include: video of all class activities, easel pads of notes generated in class discussions, and copies of all student work. Metz (2004) developed prototype curricula in animal behavior and botany based on six interrelated instructional design principles: (1) maintain the integrity of the goal-focuses intellectual enterprise across the curriculum (2) teach science processes and methods as instruments in the context of their purpose and use (3) scaffold relatively rich knowledge of the domain within which the inquiry is embedded (4) gradually decrease the degree to which the investigation is structured (5) shift the unit of collaboration from whole class guided by the teacher to homogeneous dyads (6) build knowledge and responsibility to the point where pairs assume responsibility for an investigation of their own. The curriculum Metz (2004) developed was implemented in both classrooms in three phases. In the first phase, the whole class collaboratively studied the behavior of rodents. The curriculum scaffolded epistemic issues such as distinguishing between observation and inference. Students watched a video and read text about rodent behavior. In the second phase, pairs performed trails of common investigations. Student data collection for animal behavior was the same as the first phase but the organism was changed to crickets. Each pair of students received their own crickets and miniature lab, which increased student responsibility. Through whole class lessons and work in pairs, students learned about cricket behavior, developed questions, and developed more understanding and control over the inquiry process. In the third phase, student pairs designed and conducted their own cricket investigations. Each pair formed their own research question, designed a method to inform the question, and compiled their study into a research poster. The project built on conceptual, procedural, epistemological, and metacognitive knowledge developed in phases one and two of the unit. After students completed the inquiry unit, Metz (2004) interviewed each pair of students, asking seven questions and follow up probes. All 24 interviews were coded and analyzed for student conceptions of uncertainty in their inquiry research projects. Students conceptualized uncertainty in their investigations five ways: (1) how to produce the desired outcome as uncertain (2) data as uncertain (3) trend identified in the data as uncertain (4) generalizability of the trend as uncertain (5) theory that best accounts for the trend as uncertain.

Seventy one percent of second graders and 83% of fourth and fifth graders identified at least one sphere of uncertainty in their investigations. Fifty three percent of second graders and 52% of fourth and fifth graders conceptualized two or three spheres of uncertainty. Analysis also showed most students reflected some understanding of a "constructivist knowledge problematic epistemology of science including an emergent understanding of the complex relation between the knower and the known, which is a key issue in epistemological adequacy…Their conceptualizations of the grounds of the uncertainty and strategic ways to change their study conveyed their understanding of challenges in the knowledge building process" (Metz, 2004, p. 283). This study found that under certain conditions, even second graders could critically reflect on their investigation and view their investigation as a tool to try to address their question. Metz was not suggesting that elementary students make a universal general epistemic shift, but in the context of using research to address their question, they were able to think in advanced epistemological ways.

Metz (2004) did not over generalize the results. She gave implications to all of education at the end of this qualitative study, but also stated that this work will be repeated in 15 classes over the course of the next three to five years. The implemented curriculum was carefully designed, scaffolding students into conducting their own investigations. The qualitative data collected allowed the reader to follow the epistemological thinking of the student participants.

Literature reviewed in this section studied student epistemologies as an effect of scientific inquiry. Hammer (1994) and Sandoval (2003) found that students have epistemic resources to use in inquiry. Hammer (1994) also found that students did not necessarily use their epistemic resources because of what they believe about science. In Sandoval's study, students articulated explanations and attempted to find causal mechanisms to interpret data. Students understood the need to explain data but did not see data as a necessary component of supporting an argument. Although there was no statistical significance, Leach et al. (2000) found that students used different forms of epistemological reasoning (focused, radial relativist, knowledge and data) in different contexts. Lawson (2005) determined students use hypothetico-deductive reasoning, not enumerative induction, by testing students with decontextualized questions. Lawson (2005) proposed that increasing consciousness of hypothetico-deductive reasoning would lead to science literacy. The results of the study do not fully support Lawson's argument. Hogan (1999) found that student participants held a constructivist view of learning and the dimension of students' personal frameworks that most clearly mirrored their patterns of sociocognitive behaviors were their learning referenced perspectives for constructing knowledge with peers. Results were specific to students studied, however Hogan (1999) suggested that while student's personal frameworks for science learning are not the sole influence on students' sociocognitive participation in collaborative-knowledge building tasks, they are an alternative lens educators can use to understand their students and modify instructional practices. Samarapungavan and Westby (2006) found that epistemic beliefs varied significantly with chemistry expertise and with exposure to authentic research in chemistry. Both Metz (2004) and Hakkarainen (2004) found that young students were able to participate in inquiry and be aware of epistemological reasoning under certain conditions. Metz (2004) found that young students, under particular conditions, were able to conceptualize the grounds of uncertainty and strategic ways to understand their study, conveying their understanding of challenges in the knowledge building process. Hakkarainen (2004) found that some young students engaged in epistemic agency and genuinely pursued explanation driven inquiry. Hakkarainen (2004) analyzed students' externalized conceptions posted to the CSILE database to determine whether CSILE students were able to profitably engage in an explanation driven inquiry process. The interest was in the nature of student explanations posted to the CSILE database and whether students were able to progressively improve their ideas. Hand, Wallace, and Yang (2004) found that students became metacognitive and aware of their epistemologies through writing. Both treatment groups of students who used a science writing heuristic outperformed the control group on conceptual and multiple choice post questions. Students interviewed attributed their increased understanding of the cell unit to features of the science writing heuristic activities: framing their own questions, participating in peer group discussions, making connections between concepts, and the act of writing.

Conceptual Understanding

Conceptual understanding is one goal of traditional science education and scientific inquiry. Constructivist theories say that conceptual understanding is the result of conceptual change. Conceptual change, based on Piagetian accommodation, focuses on knowledge acquisition in specific domains and describes learning as a process that requires the significant reorganization of existing knowledge structures and not just their enrichment (Vosniadou & Brewer, 1987 as cited in Vosniadou et al., 2001). Posner et al. (1982) gave four criteria for conceptual change: (1) there must be dissatisfaction with existing conceptions (2) a new conception must be intelligible (3) a new conception must appear entirely plausible (4) a new concept should suggest the possibility of a fruitful research program, meaning a new concept should open up new areas of inquiry. It is important to find out what epistemological commitments students have if one wants to understand what they are likely to find initially plausible or implausible and more generally to understand their process of conceptual change (Posner et al., 1982).

The following studies were concerned with student conceptual understanding as an effect of scientific inquiry. Posner et al. (1982) sought to develop a well-articulated theory of conceptual change through their study. Dimitrov, McGee, and Howard (2002) studied whether students' science proficiency improved after participating in the Astronomy Village unit. Liang and Gabel (2005) wanted to know whether the PIPS curriculum improved students' understanding of science concepts and promoted positive attitudes towards science learning. Fellows (1994) studied whether student writing could be a tool to assess student conceptual change as a result of instruction. Hansen et al., (2004) studied the effects of the VSS (Virtual Solar System) project on students' conceptual understanding of astronomy. Vosniadou et al., (2001) studied why it is so difficult to understand concepts in science and how learning environments can be constructed to foster science learning. Niaz et al., (2002) studied whether classroom discussions based on students arguing and counter arguing the heuristic principles of Thomson, Rutherford, and Bohr's atomic models would facilitate students' conceptual understanding of atomic structure.

Posner et al. (1982) wanted "a well articulated theory explaining the process by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first" (p. 211). They proposed the theory of conceptual change, based on Piagetian accommodation.

Posner et al. conducted interviews with students in a non-calculus, self-study, self paced, introductory college physics course in which they just finished a unit on special relativity. They presented two problems to the interviewees who solved the problems and shared their thoughts out loud. Transcripts from the interviews were used to illustrate the four criteria for conceptual change and how they are influenced by the five features of a person's conceptual ecology. Posner et al. (1982) also identified five features of a person's conceptual ecology (her/his current concepts) which influence the conceptual change criteria. The five features of conceptual ecology are: (1) anomalies (2) analogies and metaphors (3) epistemological commitments (4) metaphysical beliefs and concepts (5) other knowledge both in other fields and competing concepts. Posner et al. (1982) is a seminal document to conceptual change and scientific inquiry.

Dimitrov, McGee, and Howard (2002) studied whether students' science proficiency improved after participating in the Astronomy Village unit. Astronomy

Village is computer-based inquiry software that teaches students concepts in life, earth, and physical sciences by investigating questions related to the solar system. Students are guided by a virtual mentor that scaffolds students in completing multiple investigation cycles that parallel the phases of scientific inquiry. Astronomy Village has two research paths: Mission to Pluto and Search for Life. Dimitrov, McGee, and Howard (2002) suggest that their findings indicate the Astronomy Village project can be used to promote interdisciplinary understanding and problem solving in a short period of time.

Participants were 837 students from schools around the United States. There were 590 students in the Astronomy Village groups, 117 students in alternative treatment groups, and 130 students in control groups. Dimitrov, McGee, and Howard (2002) drew from a wide range of demographics, which they proportionately balanced for all groups. Teachers were recruited to participate in the study through an application process. Participating Astronomy Village and alternative treatment teachers were trained for equal amounts of time during a summer workshop. Astronomy Village teachers used either Mission to Pluto or Search for Life. Control group teachers were recruited by participating teachers during the school year. The treatment period was four weeks. During that time, Astronomy Village groups used the software and the alternative treatment group learned content related activities. Pre and posttests were analyzed with the Linear Logistic Models for Change (LLMC). There were statistically significant treatment effects for the Mission to Pluto, Search for Life, and alternative treatment groups which according to Dimitrov, McGee, and Howard (2002) indicated learning gains in content and problem solving. Dimitrov, McGee, and Howard (2002) found that the knowledge students developed in the Search for Life research path transferred to their ability to solve Mission to Pluto problems as well. Their results supported the depth side of the controversial depth vs. breadth argument.

This was a large quantitative study, with participants in schools around the U.S. Participating Astronomy Village teachers and alternative treatment teachers were given instruction during summer training workshops. Teachers were asked to recruit teacher at their schools to be the control group. It was unclear what the control group teachers and students were studying in their classes. A control group does not receive treatment in an experiment, but the reader needs to know if the control group is studying astronomy as well. The Linear Logistic Model for Change (LLMC) was used to analyze results, which separated effects due to treatments from natural trend effects and eliminated the drawbacks of traditional pre and posttest comparisons.

Liang and Gabel (2005) implemented the constructivism-based PIPS (Powerful Ideas in Physical Science) curriculum in an introductory science course for elementary education majors at a large Midwestern university. They did not find that the PIPS approach was statistically significant in improving students' understanding of science concepts or in promoting positive attitudes toward science learning. The study focused on prospective teachers as students and as teachers. Since this paper is examining the effects of inquiry on students, the parts of this study concerning implications of participants as future teachers are not going to be discussed. Liang and Gabel's research question most relevant to this analysis is: when compared with the traditional lecture-laboratory approach, does the PIPS curriculum have differential effects upon the prospective elementary teachers' understanding of the target science concepts?

There were 121 participants, 103 female and 118 Caucasian. Three of the six class sections were given the PIPS curriculum and three sections were the control group, given the traditional lecture and laboratory approach. The three class instructors each taught one experimental section and one control section. The intervention unit lasted four weeks, toward the end of the semester. Quantitative data collected were past science grades, conceptual understanding measured by final course grade, and attitude according to the Chemistry Attitude Survey. Twelve participants were interviewed and eight class periods for each of the six class sections were videotaped. Statistically, the PIPS approach did not prove to be more significant in improving student understanding of science concepts or in promoting positive attitudes toward science learning and teaching. The researchers suggest this may be due to several factors: various abilities of instructors to effectively implemented the PIPS approach, disruption effects upon students, lack of effective assessment techniques to distinguish learning from conceptual understanding, lack of student internal motivation, and that the time period of study was toward the end of the term, close to final examinations, students were confused and concerned how they would be tested on the final. The data also showed that a more supportive classroom environment came out of the PIPS classrooms and that those students enjoyed class more and understood target science concepts better than the control lab-lecture group.

Liang and Gabel used a combination of quantitative and qualitative methods, which gave them a broader range of data types. However, the large Midwestern university where this study was conducted represented a very narrow demographic. Participants were mostly female and mostly Caucasian, which is the classic stereotype of a teacher. If this study were conducted at multiple universities with a broader range of demographics over a longer period of time, perhaps it would yield statistically significant results.

Fellows (1994) studied whether student writing could be a tool to assess student conceptual change as a result of instruction. It was found that students' conceptual structures (pictured by concept maps) showed differences in their schemas as a result of instruction. Fellows (1994) found that writing ideas, sharing them with peers, reflecting on ideas, and writing again was a mechanism for conceptual change.

This study was the second year of a three year study involving six classrooms under direction of two researchers from a Midwestern university. The participants in this study were a class of 25 urban middle school students of varying socioeconomic backgrounds, ethnicities, and abilities. Two small target groups of four students were selected for observation. Each group had one low achieving student, one high achieving student, and two students in between. Target students were selected based on diversity in ethnicity and gender among the groups of four to be interviewed. Interviewees were two African American boys, a Laotian American girl, a Hispanic boy, an Iranian American boy, and three Anglo American students (two boys and one girl).

All 25 students in the class were given a pretest and a posttest after the 12-week unit. Written answers to pre and posttest questions and written explanations from activities about matter and molecules were analyzed for each target student. Written and oral statements from each student were triangulated with what students said during science class to determine the validity of using student writing as data. The written ideas of the target students were analyzed for patterns of changes and concept maps were constructed from the written ideas. These maps were compared with patterns that emerged from the other 19 students' writing. Fellows (1994) found that the ideas interviewed students identified as central to their schema were also in written and oral statements, which might indicate what students understood about the concepts. There were more concepts given in instruction than students retained on the posttest. Retained ideas were those that were most prevalent in student observations and the focus of earlier student explanations. Based on the data, Fellows (1994) suggested that more opportunities for writing explanations during lessons produced better logical arguments and conceptual change. In interviews, students reported that writing helped them think and clear their minds. In this study, writing ideas, sharing them with peers, reflecting on ideas, and writing again was a mechanism for conceptual change.

Hansen et al. (2004) examined the effects of the VSS (Virtual Solar System) project on students' conceptual understanding of astronomy. The VSS project is learner-centered project-based computer software that allows students working in groups of two or three to build three-dimensional models of the solar system. Hansen et al. (2004) found that the VSS project facilitated student understanding of spatial astronomical concepts, such as distance, perspectives, and celestial bodies. Traditional instruction best facilitated student understandings of declarative (fact oriented) astronomical knowledge.

The experimental group used the VSS project in a 16-week semester long course that met three times a week for an hour. Twenty of the 26 students enrolled in the course participated in pre and post interviews, but all students used the VSS curriculum. The control group was a traditional college introductory astronomy course that met five days a week for an hour over 10 weeks during the summer. Thirteen of the 25 students enrolled in the course participated in the pre and post interviews. Students were encouraged to participate in the interviews, with an incentive of 5% extra credit in the course. The interview questions were based on one of two knowledge domains: declarative or spatial. Responses were coded as ordinal data, based on a pre-established rubric where a score of 0 was no conception and a score of 4 was sound conception. Two researchers coded 352 of 396 (89%) student responses with an inter-rater reliability of 0.82. Student conceptual development was based on the analysis of the interviews. SAS 8.1 statistical package was used as a split plot factorial design, SPF 2.2, for variance between the two classes, two knowledge domains (spatial and declarative), and pre and posttests.

The results indicate a significant interaction between the course and knowledge domain ($p=0.066$) which suggests participants in the different course groups performed differently on questions sampled from the two knowledge domains. VSS students performed better on spatial domain questions and traditional course students performed better on declarative domain questions. Hansen et al. (2004) attributed the difference to the context of the VSS course where students learned by interacting with their model, peers, and instructor. Due to the collaborative nature of the VSS course, student groups divided labor so that each student was responsible for certain concepts whereas in the traditional course each student was responsible for all concepts. Due to the nature of VSS, students could not explore and manipulate gravitational forces but were able to manipulate three-dimensional relationships. Hansen et al. (2004) identified the lack of attention to demographics or academic variables between groups and potential for different amounts of instructional time between the two courses of different lengths as limits of the study.

Hansen et al. (2004) did not take into account the possibility for differing student course loads during the academic year versus the summer. Students in the traditional summer course may have had a lighter course load than the VSS students and may have had more time to devote to the astronomy class, which may also have facilitated their understanding of declarative astronomy knowledge. Also, the extra credit incentive for participating in the sample may have skewed the sample in the sense that students who were doing well in the course or merely taking the course to pass may not have been interested or motivated by extra credit opportunities.

Vosniadou et al. (2001) studied why it is so difficult to understand concepts in science and how learning environments can be constructed to foster science learning. Their experimental learning environment was such that students took active control of their learning, expressed and supported their ideas, made predictions and hypotheses, tested them by conducting experiments, worked in small groups, presented work to the class for debate, and metaconceptual awareness was supported. Vosniadou et al. (2001) found that students had cognitive gains in the form of conceptual change as a result of the experimental learning environment.

Participants were two 5th grade classes (one was the control group and one the experimental group) from the same school in Athens, Greece. The control group was given the regular instruction in mechanics by their regular teacher: three weeks instruction, nine lesson units of 45 minutes each. The experimental group was taught by one of the researchers in the presence of the regular classroom teacher who also participated in the instruction. Students in the experimental class were divided into five groups of five students. Each group worked together on hands-on experiments related to mechanics. At the end of the class period, a representative from each group would present the group's work to the rest of the class after which the whole class engaged in discussion. The learning environment was structured so that students would engage in cognitive conflict, which created strong motivation to seek scientific answers. The sequence of introduced concepts was planned to overcome misconceptions and avoid making new ones. The cognitive effects of the learning environment were evaluated with pre and posttests for the experimental and the control groups. Interviews were conducted with a small number of students at the conclusion of the unit. A McNemar test showed that on 13 questions there was a significant increase from the pretest to the posttest in the number of experimental group students who gave scientifically accepted responses. There was no significant change in the control group on any question. A chi square test showed that in nine posttest questions, the experimental group performed better than the control group. There was no difference between the groups on the pretest. Classroom discourse was recorded as another source of information about the dynamics of conceptual change. The control class dialogue alternated simple main exchanges. In the experimental class the teacher used a variety of strategies to activate prior knowledge and elicit responses from students. The amount of main exchanges in each class was analyzed, 14 for the experimental class and 20 for the control. The ratio of complex to simple exchanges was 8:6 in the experimental class and 6:14 in the control group. The experimental class teacher shifted authority, presenting Newton's third law as the work of another student to make it possible for students to disagree. Vosniadou et al. (2001) found more conceptual change in experimental group students than in control group students. They also found that understanding concepts in science is difficult because everyday conceptions and synthetic models can contradict science concepts and unless the person is able to have cognitive conflict, they never have a need to confront their beliefs. The experimental group students had more opportunities for cognitive conflict and thus showed greater amounts of conceptual change. The regular classroom teacher scaffolded students through their zones of proximal development. The student interviews were conducted to assess conceptual change but interviews were given by the regular teacher, which makes the reader wonder if the teacher scaffolded students during the interviews, which would produce an inaccurate portrayal of conceptual change in students. The interviews were not the only assessment of conceptual change: the pre and posttests also showed student advances in conceptual change.

Atomic structure is usually decontextualized in textbooks without background on history or philosophy of science or nature of science. Niaz et al. (2002) hypothesized that classroom discussions were based on students arguing and counter arguing the heuristic principles of Thomson, Rutherford, and Bohr based on their atomic models would facilitate students' conceptual understanding of atomic structure. (Niaz et al., 2002) found that given the opportunity to discuss, students' understanding can go beyond the simple regurgitation of experimental details. The experimental group demonstrated contradictions, resistances, and considerable and consistent improvement in conceptual change.

The participants were 160 freshman students in six sections of general chemistry at the Universidad de Oriente in Venezuela. Three instructors each taught two sections, which were randomly assigned to be either the experimental group or the control group.

The three experimental sections had 83 students total and the three control group sections had 77 students total. All three instructors had four to five years of teaching experience.

In all sections of the experimental and control groups, the Thomson, Rutherford, and Bohr atomic models were presented in the traditional manner, emphasizing the experimental details of each scientist leading to the design of the model. After the introduction, the control group did traditional textbook problems. The experimental group was presented with six items, two pertaining to the work of each scientist. Each item consisted of a central question and multiple response choices. The classroom steps for each item were as follows: (1) instructor presented the central question (example: in your opinion, what was most important in Thomson's experiments?) (2) students read the question and response choices (3) students selected a response they most agreed with (4) class discussion: students gave reasons and evidence for choosing their response (5) students listened to and evaluated each others arguments, challenging when they disagreed, with occasional intervention and feedback from the teacher (6) students weighed reasons for each argument and decided whether to keep or change their original response (7) students explained why they kept or changed their responses in writing. The steps were repeated for each of the six items. Three weeks after the six-item classroom discussion, all experimental and control sections were given a monthly exam. Three questions related to the work of Thomson, Rutherford, and Bohr were on the exam. Three weeks after the monthly exam, all experimental and control sections were given the semester exam, which contained two questions related to the work of Thomson, Rutherford, and Bohr. The questions on the monthly and semester exam were taken from the previous study (Blanco & Niaz 1998).

In Blanco and Niaz's 1998 study, students were asked a central question and then to generate a response. Student responses were then classified as positivist (traditional "right" or "wrong"), transitional, or Lakatosian (conceptual). The responses generated in the previous study were used as the response choices for each question item in Niaz et al. (2002). Percentages of students who chose particular responses were compared between studies. The monthly exam was expected to facilitate conceptual change in both the experimental groups and the control groups. The monthly exam showed students who responded conceptually on one item did not necessarily respond conceptually on all three question items. Niaz et al. (2002) attributed this behavior to the contradictory nature of students understanding and their resistance to change. The semester exam was expected to facilitate more conceptual understanding than the monthly exam. Student responses were more consistent than the control groups. The experimental group had more conceptual responses than the control group overall on both exams. The differences were statistically significant in all cases ($p<0.01$). Niaz et al. (2002) determined that student understanding could go beyond memorizing experimental details when students were given the opportunity to discuss and argue. The experimental group showed progressive improvement in conceptual change. The only opportunity the control group had to reflect was on the monthly and semester exams. Results showed that the control group improved conceptual understanding beyond experimental details. Niaz et al. (2002) suggested that even an introductory lecture on historical, epistemological, and philosophical aspects of atomic structure (without discussion and argument) would also facilitate students' conceptual understanding. Niaz et al. (2002) emphasized the importance of teaching experimental results within the context of a history and philosophy of science perspective to move students away from a rhetoric of conclusions (Schwab, 1962 as cited in Niaz et al., 2002) and toward heuristic principles (Lakatos, 1970 as cited in Niaz et al., 2002).

Data collected from the experimental and treatment groups was compared to results from Blanco and Niaz (1998), which gave a point of reference for data as well as an opportunity to build on the work of the previous study. The student responses from in class questions and test questions demonstrated conceptual changes in the experimental group. Given the thorough design of the Niaz et al. (2002) study and the fact that it built on the previous work of Blanco and Niaz (1998), the reader can accept the implications of study results.

The literature in this section studied student conceptual change as an effect of scientific inquiry. Conceptual change leads to conceptual understanding. According to Posner et al. (1982) people resist making conceptual changes unless they are dissatisfied with their current concepts and find an intelligible and plausible alternative that appears fruitful for further inquiry (p. 223). There were several classroom conditions that facilitated conceptual change in inquiry. Dimitrov (2002) and Hansen et al. (2004) found that inquiry-based computer software facilitated student conceptual understanding. Dimitrov, McGee, and Howard (2002) found that some concepts were more developed in computer inquiry students and some were more developed in students who learned science via the traditional approach. There were statistically significant treatment effects for the Mission to Pluto, Search for Life, and alternative treatment groups which according to Dimitrov, McGee, and Howard (2002) indicated learning gains in content and problem solving. Dimitrov, McGee, and Howard (2002) found that the knowledge students developed in the Search for Life research path transferred to their ability to solve

Mission to Pluto problems as well. Fellows (1994) found that writing caused conceptual change and understanding in students. Students' conceptual structures (pictured by concept maps) showed differences in their schemas as a result of instruction. Fellows found that writing ideas, sharing them with peers, reflecting on ideas, and writing again was a mechanism for conceptual change. Niaz et al. (2002) found that writing combined with discussion and argument led to better conceptual understanding in students. The experimental group demonstrated contradictions, resistances, and considerable and consistent improvement in conceptual change. Liang and Gabel (2005) were not able to prove that students learning via inquiry or students learning via traditional science developed more conceptual understanding. Vosniadou et al. (2001) found greater conceptual understanding in the experimental learning environment where small groups engaged in reflective inquiry and presented findings to the rest of the class.

Inquiry Culture

Scientific inquiry as practiced by scientists and students in the classroom is a cultural practice (NRC, 1996). In the past 50 years, there has been a shift among philosophers and sociologists of science away from seeing science as a purely empirical process, to seeing it as a social process of knowledge construction in which imagination and argument play an important role (Driver et al., 2000; Latour & Woolgar, 1986 as cited in Seethaler & Linn, 2004). Student conceptions of the nature of science, epistemologies, and conceptual understanding are all situated in the social and cultural context of scientific inquiry. While classroom culture initially influences students' scientific inquiry experiences, what may develop as a result of inquiry is the inquiry culture where students begin to obtain skills necessary to become independent inquirers about the natural world.

The following studies were concerned with developing an inquiry culture as an effect of scientific inquiry. van Zee and Minstrell, (1997) studied the ways a teacher's questioning guides student thinking. van Zee (2000) conducted an ethnographic case study to determine what aspects of student discourse were indicative of inquiry learning. Rop (2003) ethnographically studied a chemistry class in a US Midwestern suburban high school to understand student participation events in the context of school and classroom culture. Tabak and Baumgartner (2004) studied the role that different teacher participant structures can play in inquiry. Wee et al. (2004) studied whether students perceive environmental science based inquiry differently than past science instruction experiences. Seethaler and Linn (2004) were interested in how successful their GMF curriculum would be in helping middle school students learn to weigh the tradeoffs involved in using one method of agriculture or another and supporting their position with appropriate evidence. Varelas (1997) studied student conceptions of multiple trials in an experiment. Zion, Michalsky, and Mevarech, (2005) studied the effects of four learning methods on students' general scientific ability and domain specific inquiry skills in microbiology. Pine et al. (2006) compared the performance of students taught through hands-on curricula to students taught through textbook curricula.

van Zee and Minstrell (1997) studied the ways a teacher's questioning guides student thinking. Their findings suggested that teachers may shift toward more reflective discourse by asking questions that help students to make their meanings clear, to consider various points of view in a neutral manner, and to monitor the discussion and their own thinking.

Participants were 31 students, two thirds were female. The teacher, Minstrell, had taught at the high school for 25 years and had extensive experience on reflecting on his own teaching practices and had participated in a great deal of research. Students met in Minstrell's physics class for 50 minutes five days per week. Data collected include: audiotape of discussion in class on the fourth day of the school year and audio of debriefing sessions and field notes. The evolution of the analysis is given for selecting discussions to analyze, defining questions, making initial analysis, visual representations for questioning sequences, selecting an episode for detailed analysis, inferring immediate action plans, emerging goals, sub goals, and beliefs behind Minstrell's questioning during the episode. van Zee and Minstrell (1997) defined the reflective toss as a questioning strategy where the teacher gives the students responsibility for thinking. Three goals emerged from Minstrell's use of reflective tosses during discussion: engage everyone in considering a method unexpectedly proposed by a student, begin refinement process by clarifying a method discussed earlier, evaluate an alternative method given by a student. Three sub goal themes emerged as well: use of questions to help students make meanings clear, use of questioning to help students consider a variety of views in a neutral manner, and use of questions to help students monitor the discussion and their own thinking. The sub goals matched an interpretive framework of Minstrell's goals and beliefs. Based on their results and the work of others, van Zee and Minstrell (1997) suggested teachers may shift toward more reflective discourse by asking questions that help students to make their meanings clear, to consider various points of view in a neutral manner, and to monitor the discussion and their own thinking.

van Zee and Minstrell (1997) were aware of the limited generalizability of a study based on eight minutes of dialogue, so they triangulated their findings with other research on communicative moves and action plans implemented during class discussions. This allowed the findings of their small study to have larger implications than it would have had alone.

van Zee (2000) conducted an ethnographic case study to determine what aspects of student discourse were indicative of inquiry learning. She also studied what kinds of questions students ask each other in discussion and how students collaborate in making sense of their own observations and interpretations. van Zee (2000) discovered that in distributing her authority as a teacher and quietness cultivated student led inquiry discussions. The study was conducted during an undergraduate seminar on math and science education that van Zee taught at a public research university. During the seminar, students and van Zee engaged in discussion about the phases of the moon similar to discussions in Duckworth (1987) and McDermott (1996). Participants were six undergraduates and two faculty members. Data sources were audio and videotapes, class discussions, copies of student papers, and van Zee's reflective journals. As a result, van Zee did not consider herself a facilitator of discussions, but an organizer of learning events. She shared her authority with students to make decisions about what to do and say next.

van Zee did not intend to generalize the results of this study to a larger population. Her study showed how the role she played as a teacher in the environment she created allowed her students to be engaged in discussion. van Zee does not suggest that this method would work in all classrooms, but her methods might work for other teachers in similar classroom settings.

Rop (2003) ethnographically studied a chemistry class in a US Midwestern suburban high school to understand student participation events in the context of the school and classroom culture (Erickson, 1986, 1992 as cited in Rop, 2003). The high school was selected because it was mainly Caucasian and middle class and 85-90% of students continue on to higher education. Rop (2003) hoped that the demographics coupled with academic achievements of the school would give student participation indicative of a self-motivated desire to understand subject matter. He was specifically interested in student inquiry questions (SIQs) for which he had three criteria: (1) the question in some way is related to the content under discussion (2) the question seems to originate in student curiosity (3) the question is self described as an attempt to pursue personal inquiry beyond the delivered or expected curriculum. Rop (2003) focused on six 16-17 year old Caucasian students, two female, four male. The students gave two reasons for SIQs in class: (1) to alleviate boredom and engage in intellectual challenges (2) to fill an intellectual hunger to understand subject matter better. Students described two main teacher responses to SIQs: (1) the put off "we'll talk about that later" and (2) "the slam" the teacher is mad or annoyed by the student question. Students also described social pressures that cause them to refrain from too many SIQs in class. Rop (2003) identified student reasons for SIQs as close to the NRC (2000) conception of scientific inquiry and questioning in a classroom inquiry environment. Students and teachers are caught in time constraints between the content coverage and depth of understanding. To foster an environment of inquiry consistent with the *National Science Education Standards*, Rop suggested, "teachers listen for intellectual hunger in student questions and encourage scientific thought patterns to make space for the stimulating wonder and a spirit of inquiry," (2003, p. 31).

Rop (2003) did not generalize the results of this small ethnography. Based on Rop's findings, students interviewed would ask more questions if the environment was more receptive to questioning. The questions raised in this study could be the base for more research and if triangulated with other work could have generalizable implications.

Tabak and Baumgartner (2004) studied the role that different teacher participant structures can play in inquiry. Specifically, they wanted to know how often dialogue, like that which occurs between students working collaboratively on an investigation, happens between teachers and students and if peer-like interactions hold promise for supporting student learning. Tabak and Baumgartner (2004) found that students were able to gain the cultural tools of science through inquiry when the teacher relinquished knowledge authority and puzzles along with students.

Participant observers in the classroom observed five teachers from five schools for the entire five-week high school biology unit on evolution. The unit involved two computer-based inquiry activities: the BGuILE project which involved Galápagos Finches and the MWM (material worlds models) project. Both pieces of software were designed to scaffold students through inquiry. The researchers were looking for and observing three teacher participant structures: (1) teacher as monitor: ensure tasks are carried out. (2) teacher as a mentor: focuses on supporting the substance of the inquiry process and the dialogue is asymmetrical and there is more IR than E which leaves the conversation more open for exploration. (3) teacher as a partner: similar to the mentor but the teacher presents herself/himself as a peer and joins the group for a few minutes and investigates as a group member, making the teacher student dialogue symmetrical. During the five-week unit, students worked on the inquiry software and the classroom teacher circulated and interacted with groups in one of the three participant styles. Out of five teachers, only one was observed using the partner participation structure. Data sources were field notes, video, audio, and formal and informal teacher student interviews. Analyses started broad and became more narrow and purposeful, eventually focusing on the one teacher that used the partner participation structure. Tabak and Baumgartner (2004) found that when the teacher participated as a partner, it gave students some authority and then the self-image as someone that can contribute to science, not just memorize what others have already determined. Students were able to gain the cultural tools of science through inquiry when the teacher relinquished knowledge authority and puzzled along with the students. The pronouns used by the teacher indicated what participation position the teacher is in and also the authority that they are commanding versus the students. Symmetrical dialogue and teacher participation as a partner allow students to learn cultural tools of science through inquiry. Tabak and Baumgartner (2004) suggested that instead of viewing the teacher as a guide or facilitator of discussion, inquiry teaching should adopt the metaphor that the teacher is a partner. Tabak and Baumgartner (2004) made recommendations for effective inquiry experiences based on this case study, but they were not trying to generalize their findings. It is unclear whether the teacher as a partner was leading students to draw conclusions and master the cultural tool (structure function reasoning) or if the teacher was working along with students, unaware of the cultural tool, and by collaborating with the teacher the students were able to understand the cultural tool. It was also unclear if this partnership work between the teacher and the students would be called scaffolding or if the scaffolding strictly comes from the computer software.

Wee et al. (2004) studied whether students perceive environmental science based inquiry differently than past science instruction experiences. Based on student perceptions, they found that teachers participating in the ENVISON program were successful in presenting environmental inquiry-based science teaching differently than their past experiences with traditional science teaching.

The ENVISION professional development program was a four-week summer institute that engaged teachers in three types of inquiry activities: (1) field studies/environmental monitoring (2) investigative laboratories and models (3) environmental science research. At the end of ENVISION, teachers were required to develop an instructional plan that they will implement in their classrooms during the upcoming school year. Developing the plan required teachers to reflect on their learning experiences at the institute in order to further understand their practice and to plan instruction. ENVISION teachers gave a student perception survey to their classes at the start of the school year and at the conclusion of the implementation of their instructional plans. Thirty one classes, totaling 550 students, were surveyed but due to absences, the sample size of the study was 367 students. Fifty percent of participating classrooms were in rural settings or small towns, 13% were in urban areas, and 37% were in suburban or other areas. The student perception survey was a 29 item Likert scale with responses ranging from 1 to 5: very often, often, sometimes, never, rarely. Each item was designed to measure student perception of instruction as traditional or non-traditional practice. Pre instruction and post instruction surveys were given a chi-squared comparison with a p value of 0.05. The chi square analysis required combining the very often and often categories as well as the sometimes, never, and rarely categories. A post hoc analysis grouped items into (1) non-traditional inquiry (2) non traditional assessment (3) scientific investigations (4) science learning. The post hoc analysis gave a holistic view of student perceptions of their learning experiences. Seventeen out of twenty nine items were answered in a statistically different manner, indicating changes in student perceptions. For non-traditional inquiry, 60% of answers were significantly different, in non-traditional inquiry, 100% of answers were significant, for scientific investigations, 83% of answers were significantly different, and in science learning 33% of answers were significantly different. Based on student perceptions, teacher participation in ENVISION was successful in presenting environmental inquiry science teaching differently than the traditional approaches to science teaching and had a positive impact on students. Students saw teaching inquiry and assessment to be different but they did not see differences in the way science was to be learned. Wee et al. (2004) suggested that the difference may be due to the epistemological lens of the students or that teachers may have emphasized science learning from the traditional perspective even though the teaching and assessments were non traditional. This study did not have a control group, the control was the past science experiences of students. The study was investigating whether the current instruction methods differed from past experiences but a control group that was taught in the traditional way and given the same perception survey at the beginning and end of the school year may have given more insight into student perceptions.

Seethaler and Linn (2004) designed a curriculum to help students come to an integrated understanding of the genetically modified food (GMF) controversy. In particular, they were interested in how successful the GMF curriculum would be in helping middle school students learn to weigh the tradeoffs involved in using one method of agriculture or another and supporting their position with appropriate evidence. Analysis of students' final papers showed that students were able to give evidence for and against their positions, but they were less explicit about how they weighed the tradeoffs.

This study was the second run of the GMF curriculum; the pilot was described in Seethaler (2002). Modifications to the curriculum after the pilot were minor. Seethaler and Linn (2004) compared the results of the pilot and the second run. The pilot group was a class of 17 eighth grade students in an ethnically diverse school in an urban mostly middle class neighborhood. The teacher of the class had a PhD in environmental science. The participants for the second run were 173 sixth grade students taught by a teacher with a BS in biology in a moderately diverse suburban middle class school. The unit took place over ten 45 minute class periods. Data collected included: pre and posttests (short answer and reflective thinking), student written work, online notes students took during the unit, offline notes from group presentations, and student position papers. The GMF curriculum was designed in the WISE (web based inquiry science environment) based on principles of SKI (scaffolded knowledge integration). The goal was for the curriculum to present a view as balanced as possible and genetically modified foods were presented in the context of other methods of agriculture to help students understand that all agricultural practices have risks and benefits. Students researched one of four positions: for or against GMF and for or against organic foods. Pairs and groups gave presentations to share their findings with the rest of the class. During presentations, students took notes on a form designed to scaffold note taking and provide opportunity for reflection. After each presentation, the class discussed and debated the information given in the presentation. After all evidence for and against each position was presented, students chose one agricultural practice to be used in their geographic region (GMF, organic, or conventional intensive farming). Each student wrote a paper defending her/his position. Students were scaffolded in writing by pages designed to help organize arguments and evidence for their position.

The pre and posttests were assessed for changes in students understanding of GMF and agricultural practices. Responses were given points with more points being given to correct (or normative) responses. A second coder analyzed a subset of the tests with an inter-rater reliability of greater than 85 per cent. Student final papers were assessed based on seven aspects (the number of pieces of evidence used, themes/topics of evidence used, scientific normativity, the degree of elaboration of evidence students presented in favor of their position, the degree of elaboration of evidence students presented against their position, the degree of elaboration of the evidence used by the students to address the evidence against their position, and the quality of students' conclusions) and rated on the KI (knowledge integration) scale. Two coders were used with an inter-rater reliability of 90%. Both the pilot and second run group exhibited significant ($p<0.0001$) gains between the pre and posttests. Students averaged three to four pieces of evidence in their papers from the unit and three pieces of evidence from elsewhere. Almost half of the evidence given in papers was counter evidence, which was unusual according to Seethaler and Linn's past research. Seethaler and Linn (2004) attributed use of counter evidence to the context of the curriculum, the way students were scaffolded into creating their arguments, and the fact that students were not asked to produce evidence “out of the blue.” Students recognized and gave examples of tradeoffs in the controversy, but were not explicit about how they weighed the tradeoffs. Seethaler and Linn (2004) suggested that the GMF curriculum could help students become autonomous science learners and to think critically about issues that affect their lives.

The curriculum used by Seethaler and Linn (2004) had been used in a previous study and necessary adjustments were made before the 2004 study. Students in the school were ethnically diverse and there were quantitative and qualitative aspects to the study. These aspects make the study strong and generalizable.

Varelas (1997) studied student conceptions of multiple trials in an experiment and found that many students had not conceptualized the procedure of repeating trials and finding the best representative of the results in a way that adult practitioners do. The participants were 24 third and fourth grade students from a suburban school in the Chicago area. The school was 70% white, 25% black, 3% Hispanic, and 10% low income. The school’s test scores, including science, were above state and national averages. The school adopted a new science and math curriculum which students had used for two years prior to the study. The children were used to performing experimental inquiries and the curriculum encouraged students to take three trials (repeat an experimental condition three times) and then find the average of these trials, which was actually taken by the students to be the median (middle) of the three numbers. The 24 students were selected from four classrooms based on a range of academic achievements, closely representing the racial composition of the school, and their agreement to participate in the study. Varelas worked with the students in pairs or threes for one to two hours. The students designed and implemented an experiment after reading a short story.

Varelas presented herself as a historian to the students and used her questioning and probing to reveal student thinking as necessary to accurately document the work of the students. Data collected were video and transcripts. Data were analyzed based on a qualitative interpretive design looking for themes or patterns in the transcripts. Varelas (1997) used triangulation and constant comparison techniques (based in Lincoln & Guba 1985) throughout the analysis to ensure "the knowledge constructed constitutes a coordination of data and interpretation robust enough to serve communities of science educators concerned with these issues," (Varelas, 1997, p. 859). Varelas found three major themes in student conceptions of repeated trials as they collected experimental data: (1) whether and why repeated trials in an experiment yield different measurements for a continuous dependent variable (2) the value of repeated trials in an experiment (3) the best representative of these repeated trials. Her findings supported her idea that many of the children had not conceptualized the procedure of repeating trials and finding the best representative of the results in the way adult practitioners do. Varelas (1997) gave five pedagogological recommendations based on her findings: (1) link strongly experimental investigations with appropriate theoretical understanding of the phenomena explored (2) students need to experience a wide range of experimental error from small to large (3) teachers and students need to develop a good grasp of the difference between systematic and random experimental error (4) exploring and developing and understanding of repeated trials and best representatives should occur in conjunction with developing the mathematical ideas concerning the representation of a set of numbers (5) give opportunity in science lessons for reflection on the process of constructing knowledge (Carey et al., 1989 as cited in Varelas, 1997). While Varelas said she triangulated the data in her analysis, she did not indicate how that triangulation was done. The constant comparison techniques were based on Lincoln and Guba (1985), but she did not go into depth on either item. It is hard to accept her pedagological recommendations based on her study due to uncertainties in her triangulation that made her feel the findings are generalizable enough to make such recommendations. I could accept her recommendations if they triangulate with the findings and recommendations of other studies.

Zion, Michalsky, and Mevarech (2005) studied the effects of four learning methods on student's general scientific ability and domain specific inquiry skills in microbiology. (a) metacognitive guided inquiry within asynchronous learning networked technology (MINT) (b) an asynchronous learning network (ALN) with no metacognitive guidance (c) metacognitive guided inquiry embedded within face to face (F2F) interaction (d) F2F interaction with no metacognitive guidance. They found that the MINT group (a) significantly outperformed all other research groups, the F2F with no metacognitive guidance group (d) had the lowest mean scores, and there was no statistically significant difference between groups (b) and (c).

The participants were 407 tenth grade students (198 male 209 female) in 16 classes randomly selected from five Israel high schools similar in size, socioeconomic status, and science achievement. The sixteen teachers (four male twelve female) with at least six years experience teaching biology and degrees in biology and biology education participated in a two-day inservice training program to prepare them for the three-month instructional unit. All classes were observed twice a week by one of the authors. The instructional unit was "Invitation to Inquiry," a computer-based microbiology program that engages students first in guided inquiry, then structured inquiry, and the beginning of open inquiry. The four study groups were as follows:

(a) the MINT with metacognitive guided inquiry group was heterogeneous learning groups composed of four to five students from different schools. Students completed a new "Invitation to Inquiry" activity every three weeks and responded in writing to metacognitive guidance questions. They were able to refer back to their written discourse on the computer when answering the metacognitive questions.

(b) the ALN with no metacognitive guidance group was heterogeneous learning groups composed of four or five students from different schools. Students completed "Invitation to Inquiry" activities with no metacognitive guidance.

(c) the metacognitive guided inquiry embedded within F2F interaction group was heterogeneous learning groups composed of four to five students from the same class with metacognitive guidance. When students answered the metacognitive guidance questions, they had to remember their problem solving activities.

(d) the F2F interaction with no metacognitive guidance group was heterogeneous learning groups composed of four to five students from the same class without metacognitive guidance.

All students were given two pre and posttests. They were given the TGSA (test of general scientific ability) a month into the school year and then the TODIS (the test of domain specific inquiry skills) a week after the TGSA. After the three-month unit, students were given the TGSA and TODIS again. The TGSA consisted of 15 multiple-choice questions focusing on measuring, constructing and interpreting graphs, comprehending information, designing experiments, and drawing conclusions. The correlation between TGSA pre and posttest scores was 0.56. The Alpha Cronbach reliability was 0.75 for the pretest and 0.78 for the posttest. The first part of the TODIS is ten open ended items that focus in identifying relevant variables, interpreting results of given experiments, and drawing valid conclusions. The second part of the TODIS is five open ended questions with a focus on students formulating additional hypotheses on the basis of data collected, designing a follow up experiment, identifying relevant variables and explaining the rationale for suggesting an experiment. The pre TODIS topic was dysentery disease and the post TODIS was red spots on corn pudding. The correlation between pre and posttest scores was 0.54 and the Alpha Cronbach was 0.82 for the pretest and 0.79 for the posttest.

Due to the significant correlations on the pre and posttests ($r= 0.47$ and 0.57 both $p<0.0001$), MANOVA was performed. Before the study there were no statistically significant differences between student groups on TGSA or TODIS. Zion, Michalsky, and Mevarech (2005) found that students who studied science in the MINT group (ALN and metacognitive guidance) significantly outperformed all other groups in general scientific ability and inquiry skills in the domain-specific learning (microbiology). The F2F with no metacognitive guidance group had the lowest mean scores, and there was no statistically significant difference between groups. Zion, Michalsky, and Mevarech (2005) suggested that using ALN and metacognitive activities synergistically contribute to the planning and conclusion states as part of a flexible inquiry problem solving process (Chinn & Malhotra, 2002; NRC, 2000; Shin et al., 2003 as cited in Zion et al., 2005).

Four hundred seven students broken into four study groups in five different schools was a good sample size. The schools were chosen for similar demographics and socioeconomic levels. Teachers were trained how to teach the unit. Students were given two pre and posttests and MANCOVA was used to analyze the results. Zion, Michalsky, and Mevarech (2005) designed a strong study and their suggestions based on findings could be adopted into curricula.

Pine et al. (2006) compared the performance of students in hands-on curricula with an equal number of students with textbook curricula. They found no curricular effect between textbook and hands-on students in performance assessments. Pine et al. (2006) wanted to compare inquiry-based curricula with textbook curricula. The two terms "hands-on" and "inquiry-based" were used together a lot in this study, giving the reader the impression that Pine et al. (2006) considered the two to be synonymous.

The participants were 1000 fifth grade students from 41 classrooms in nine school districts in three states. The students were broken into four groups, "cells," based on their science curricula and socioeconomic status. There were about 250 students in each cell with the groups as follows:

- HOHI: hands-on, high socioeconomic status (SES) less than 50% on free or reduced lunch
- HOLO: hands-on, low SES more than 50% on free or reduced lunch
- TXHI: textbook, high SES less than 50% on free or reduced lunch
- TXLO: textbook, low SES more than 50% on free or reduced lunch

Students were given a 65 question short answer test to control for basic aptitude. Questions were about literacy, mathematics, and figure analysis. They were given a 25 item TIMSS (Third International Math and Science Study) test consisting of 23 multiple choice and two open ended questions. Students were also given four performance assessments: (1) spring which took one class period (2) paper towels which took one class period (3) ice cubes which took three class periods (4) flatworms which took three class periods. In the performance assessments, the major inquiry skills measured were: (1) planning an inquiry (2) observation (3) data collection (4) graphical and pictorial representation (5) inference (6) explanation based on evidence. Each performance assessment was scored independently.

Significant differences in cognitive ability test scores were found between high and low SES cells and between hands-on and textbook low SES cells. There was a significant hands-on advantage ($p<0.05$) in the flatworms performance assessment. Gender differences were not statistically significant except that girls performed better on the flatworms performance assessment ($p<0.05$). It was expected that students in hands-on curricula would perform better than the textbook group, but this was not the case. Pine et al. (2006) controlled for possible bias in students' cognitive abilities, school SES level, and teacher professional development and experience. Pine et al. attributed the lack of difference in student performance to the curricula and to the way they are implemented by the teachers studied. Pine et al. (2006) also offered an alternate explanation that the students may be able to do the investigations but that the assessments were not good measures of the ability. They suggested that hands-on students' higher performance in the flatworms performance assessment might be due to a larger amount of time spent in hands-on classes on life science than in textbook classes. They found that students of all socioeconomic status levels performed the same average level on inquiry tasks when controlled for cognitive ability. Pine et al. (2006) suggest that even in schools with high standardized test scores, elementary teachers may not be teaching the reform curricula well enough for students to develop desired inquiry skills. Pine et al. (2006) conclude that poor implementation of inquiry skills may be widespread across all student demographics.

This was a large quantitative study that controlled for a wide range of biases and took into account several demographics. The large sample size and quantitative analysis make the findings of Pine et al. (2006) generalizable. The implication that lack of difference between text-based and hands-on based classrooms is based on teacher implementation warrants investigation. Pine et al. (2006) made it clear in their study that they consider hands-on and inquiry-based to be synonymous, which is a misinformed assumption. While inquiry-based and textbook-based curricula are different instructional methods, and many inquiry-based curricula are hands-on, not all hands-on curricula are inquiry-based (Zemelman, Daniels, & Hyde, 2005). The interchangeable use of the terms "hands-on" and "inquiry-based" may have contributed to the fact that they found no curricular effect between textbook-based and hands-on student groups in performance assessments.

Literature reviewed in this section revolved around inquiry culture as both a process and a way of learning. Conceptions of the nature of science, epistemological beliefs, and conceptual understanding contributed to inquiry culture. This analysis found that the following additional aspects contributed to inquiry culture in the classroom: acquiring cultural tools, teacher authority, teacher attitude, argument, and questioning. Tabak and Baumgartner (2004) and Varelas (1997) describe students acquiring cultural tools. Students using inquiry-based computer software in Tabak and Baumgartner (2004) acquired the cultural tool of structure-function reasoning through the scaffolding of the software and the partner-like participation of the teacher. In Varelas (1997), students acquired making multiple trials as a cultural tool but were unaware of the reasoning for doing so. Distribution of teacher authority was found to be helpful for students engaging in inquiry in both van Zee (2000) and Tabak and Baumgartner (2004). The attitude of the teacher contributed to the inquiry culture in both Rop (2003) and Wee et al. (2004). In Rop (2003) students reported that social pressures from teachers and fellow students prevented an inquiry culture from forming in the classroom. In Wee et al. (2004), teachers created an inquiry culture in their classrooms that differed from students' past science experiences. Argument contributed to inquiry culture in Seethaler and Linn (2004) when students made arguments and counter arguments backed with evidence in their final papers. Rop (2003) found that the inquiry culture was not able to exist in classrooms where social pressures from teachers and other students did not welcome student-generated questions. van Zee and Minstrell (1997) found reflective questioning to be an effective way to promote inquiry culture in students.

Conclusion

Students' understanding of the nature of science, epistemological understanding, conceptual understanding, and the inquiry culture are some effects of science by inquiry on students' knowledge and application of scientific principles. The implications of the effects of inquiry, how they apply to my future classroom practice, emergent themes, and unanswered questions will be discussed in chapter four.

CHAPTER FOUR: CONCLUSION

In the last three chapters, I explored the question: what are the effects of science by inquiry on students' knowledge and application of scientific principles? I first posed the question in light of the debate between inquiry-based science instruction, the *National Science Education Standards*, and the No Child Left Behind Act. Inquiry is a central component of the *National Science Education Standards* and the passing of the No Child Left Behind Act made establishing standards a required part of state and federal accountability systems. Science by inquiry was a subject of debate long before the establishment of the *National Science Education Standards.* In the progressive era, Dewey pushed for science education to be similar to the investigative processes of practicing scientists. In the post Sputnik era, inquiry was a central component of the NSF sponsored "alphabet soup" curriculum projects. Inquiry is again a central point of focus in the standards-based education era. The current movement differs from past movements in that it places emphasis on all citizens becoming scientifically literate, not a select few. In the critical review of the literature, I examined the effects of inquiry on students' understanding of the nature of science, epistemological understanding, conceptual understanding, and development of inquiry culture. In the pages that follow, I will examine themes across the effects of inquiry on students, implications of my findings to my practice as a teacher, and suggestions for future research.

Themes

I have observed common themes across students' understanding of the nature of science, epistemological understanding, conceptual understanding, and development of inquiry culture:

Argument Supported with Evidence

Vosniadou et al. (2001), Niaz et al. (2002), and Seethaler and Linn (2004) incorporated discussion and debate into their classrooms. Seethaler and Linn (2004) emphasized arguments supported with evidence into their unit as a requirement for student final papers. Niaz et al. (2002) asked students to select an answer to a question and defend their choice based on their knowledge of experiments leading to Thomson, Rutherford, and Bohr atomic models. Students that had to defend their choice with evidence from experiments were found to have consistent improvement in conceptual change.

Effects of Inquiry via Computer Scaffolding

Depending on the aspect of inquiry being studied, students gained understanding of the nature of science, epistemological understanding, conceptual understanding, and parts of inquiry culture. In Hansen et al. (2004), students who used the software had better understanding of spatial astronomical concepts, and the students taught by traditional instruction had better understandings of fact oriented astronomical knowledge. While computer-based inquiry software is advantageous, many researchers in these studies warn that the curriculum should not rely solely on student use of the computer-based inquiry software.

Context

Scientific inquiry is a cultural practice embedded in a sociocultural context. Leach et al. (2000) found that students used different epistemologies in different contexts.

Lawson (2005) determined what epistemological reasoning students used based on questions that were not in a meaningful science context. Metz (2004) showed that inquiry for younger elementary school students is decontextualized, not necessarily situated in the sociocultural practices of science, to make inquiry more accessible to younger students. Metz (2004) found that young students could engage in authentic inquiry in context if they were scaffolded and under certain conditions. Sandoval and Morrison (2003) found student epistemic ideas were fragmented, "appropriated in an incoherent way from the implicit epistemology of the authoritative objectivist discourse of a typical science classroom," (p. 383). Samarapungavan and Westby (2006) found that epistemological beliefs varied with expertise and exposure to authentic research.

The social context of inquiry is important to consider as well. Scientists collaborate with peers thus the philosophy of inquiry is that students should also collaborate with peers. Fellows (1994) found that writing ideas and sharing ideas with peers led to conceptual change in students. Hogan (1999) examined how students collaborate in learning and found that the personal frameworks that were closest to student sociocognitive behaviors that were their learning referenced points of view. Vosniadou et al. (2001) and Zion, Michalsky, and Mevarech (2005) used study groups in their inquiry classrooms.

Cultural Practice

Scientific inquiry is a cultural practice. Varelas (1997) and Tabak and Baumgartner (2004) described students acquiring use of cultural tools. Varelas (1997) described students conducting multiple trials in an experiment. The students designed and conducted the experiment based on a story they were read. They knew they had to do multiple trials, they were taught to measure three times in class, but they could not explain why. Tabak and Baumgartner (2004) described students using inquiry-based computer software acquiring understanding of structure-function reasoning. In the case of Varelas (1997), the students needed more explicit instruction regarding the nature of science and the methodology surrounding their experimental practices.

Discourse

Classroom discourse was influential in scientific inquiry. van Zee (2000), van Zee and Minstrell (1997), and Rop (2003) specifically examined the role of questioning. van Zee and Minstrell (1997) observed Minstrell's discourse was reflective; he often used student questions or answers to ask more questions of the students. Minstrell also encouraged students to ask questions of the teacher and each other. Rop (2003) found that social pressures by the teacher and students discouraged student-generated questions in the classroom. van Zee (2000) found that she could encourage student discussion and student-to-student questioning by distributing her authority and prolonging her quietness. An atmosphere of questioning and reflection is important in inquiry and the teacher largely sets the tone for classroom discourse.

Discrepant Events

Posner et al. (1982) and Vosniadou et al. (2001) specifically mentioned the use of discrepant events (also known as cognitive conflicts) in the classroom. Posner et al. (1982) found that people resist making conceptual changes unless they are "dissatisfied with their current concepts and find an intelligible and plausible alternative that appears fruitful for further inquiry" (1982, p. 223). Vosniadou et al. (2001) structured the learning environment so that students would engage in cognitive conflict, which created a strong motivation to seek scientific answers.

Explicit Reflective Metacognition

Khishfe and Abd-El-Khalick (2002) studied the effects of explicitly teaching the nature of science instead of expecting student understanding of the nature of science to be a by-product of inquiry. Zion, Michalsky, and Mevarech (2005) found that explicit reflective metacognition questions improved student performance over groups that were not explicitly given metacognitive reflection questions. Hakkarainen (2004) and Metz (2004) were able to scaffold young students to do inquiry partially by explicitly teaching epistemology. Sandoval and Morrison (2003) found that students' epistemic ideas were fragmented due to implicit epistemology of the typical science classroom. These studies emphasized the importance of explicitly teaching students skills the lesson expects them to acquire.

Hands-on vs. Inquiry

Pine et al. (2006) and Varelas (1997) studied students who participated in hands-on curricula. Pine et al. (2006) conducted a study on 1000 students divided into four groups and did not find significant results. The students in Varelas (1997) were able to design and conduct investigations. It is important to make the distinction that while inquiry can be hands-on, hands-on activities are not necessarily scientific inquiry

(Zemelman, Daniels, & Hyde, 2005). This may be why the results of Pine et al. (2000) were inconclusive.

Metacognition

Metacognition is awareness of thinking and epistemology. Several studies implied metacognition, Zion, Michalsky, and Mevarech (2005) and Hand, Wallace, and Yang (2004) specifically included metacognition. Zion, Michalsky, and Mevarech (2005) included reflective metacognitive questions in the curricula of two of their four treatment groups. Hand, Wallace, and Yang (2004) examined the effects of a science writing heuristic on students. Students reported metacognition as a result of the writing. Metacognition is an important part of problem solving and having the dispositions to use the skills, abilities, and attitudes associated with science (NRC, 1996).

Teacher Role

The role of the teacher in inquiry is sometimes described as a facilitator. Tabak and Baumgartner (2004) suggested that the teacher is a partner in inquiry teaching. Tabak and Baumgartner (2004), van Zee (2000), and Vosniadou et al. (2001) advocate for the distribution of the teacher's authority. In inquiry the teacher is not the sole source of knowledge and students need to feel like they can contribute to science (Vosniadou et al., 2001). In Vosniadou et al.'s study, the teacher introduced Newton's third law as the work of another student so that students would disagree and discuss the idea. In Tabak and Baumgartner's study, the classroom of the teacher that participated in student inquiry as a partner was the one where students acquired the cultural tool of structure-function reasoning. One of the goals of inquiry in the *National Science Education Standards* is for students to become independent learners about the natural world (NRC, 1996). This can start in the classroom with the teacher adopting the role of partner.

Writing

Hand, Wallace, and Yang, (2004), Niaz et al. (2002), Fellows (1994), and Seethaler and Linn (2004) studied the effects of writing on aspects of inquiry. Hand, Wallace, and Yang (2004) studied the effects of a science writing heuristic on students. The group that used the heuristic and wrote a textbook passage to the audience of a classmate had more metacognitive knowledge and gained more conceptual knowledge. Niaz et al. (2002) asked the treatment group a question and then to select one of multiple responses. Students had to write their reasons for selection and then debate and discuss their answers. After the discussion, students had to decide whether to change their answer or to keep it the same and explain their reasoning in writing. These students showed more consistent conceptual change on tests than the group that did not argue or write. Fellows (1994) found that students experienced conceptual change as a result of writing. This was evident from concept maps of student writing and from student reports in interviews. Students said the writing helped them think and to see what they understood. Seethaler and Linn (2004) used writing at the end of a unit where students examined the complexities of a controversial topic. Students had to take a position in a final paper and support arguments for and against their position. In all of these studies, writing had a positive impact on students' understanding of the nature of science, conceptual understanding, and epistemological understanding.

Application to Practice

The emergent themes described above have several implications for me as a teacher. Based on my research, I will adopt several ideas and aspects of scientific inquiry into my classroom practice. I will encourage students to use arguments supported by evidence. I will use, but not completely rely on, inquiry-based software. I will provide a meaningful sociocultural context for science. I will promote peer collaboration. I will foster reflective, questioning discourse and distribute my teacher authority. I will provide students with discrepant events and motivation to learn. I will explicitly teach methodology as opposed to expecting students to implicitly absorb it. This includes aspects of the nature of science, metacognition, and epistemology. I will use writing as a tool for metacognition, conceptual understanding, epistemological understanding.

Based on Lawson (2005) I cannot confirm that students engage in hypothetico-deductive reasoning. Also based on my research I do not feel comfortable decontextualizing information or implicitly teaching specific methods. I also cannot assume that all hands-on lessons are also inquiry lessons. Inquiry must also be minds-on and engage students in cognitively challenging ways.

Implications for Future Research

Pine et al. (2000) conducted a large-scale, comprehensive, quantitative study comparing hands-on curricula with traditional curricula and produced inconclusive results. I did not find any research comparing inquiry-based curricula with traditional methods. This would be an important comparison to make and may help calm some of the controversies around inquiry as a teaching method. I would be interested to see a study involving inquiry-based curricula and student performance on standardized tests like the Washington Assessment of Student Learning. A lot of the inquiry debate is seated around whether teachers have time to teach via inquiry and have students do well on standardized tests. Given the accountability components of the No Child Left Behind Act and the standards-based education reform movement, this is an important area open to study. Hakkarainen (2004) and Metz (2004) both found that young students could conduct inquiry under certain conditions. It would be compelling to find more generalizable conditions that facilitate the participation of young students in inquiry. Studies that focused on student conceptions of the nature of science and student epistemological understanding alluded to explicit instruction in the nature of science and that it takes time to develop sophisticated conceptions of the nature of science. A long-term study following student conceptions of the nature of science when explicitly taught vs. implicitly taught would be very interesting. I did not come across research that followed the development of students' understanding of the nature of science as they progress through school.

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