AN EDUCATIONAL ETHNOGRAPHY OF TEACHER DEVELOPED SCIENCE

CURRICULUM IMPLEMENTATION: ENACTING CONCEPTUAL CHANGE

BASED SCIENCE INQUIRY WITH HISPANIC STUDENTS

by

Eric Steven Brunsell

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APPROVAL

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Eric Steven Brunsell

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Dr. Elisabeth Swanson

Approved for the Department of Education

Dr. Robert Carson

Approved for the Division of Graduate Education

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Dr. Joseph J. Fedock

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Eric Steven Brunsell

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TABLE OF CONTENTS

TABLE OF CONTENTS - CONTINUED

TABLE OF CONTENTS - CONTINUED

TABLE OF CONTENTS - CONTINUED

TABLE OF CONTENTS - CONTINUED

TABLE OF CONTENTS - CONTINUED

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - CONTINUED

ABSTRACT

An achievement gap exists between White and Hispanic students in the United States. Research has shown that improving the quality of instruction for minority students is an effective way to narrow this gap. Science education reform movements emphasize that science should be taught using a science inquiry approach. Extensive research in teaching and learning science also shows that a conceptual change model of teaching is effective in helping students learn science. Finally, research into how Hispanic students learn best has provided a number of suggestions for science instruction. The Inquiry for Conceptual Change model merges these three research strands into a comprehensive yet accessible model for instruction.

This study investigates two questions. First, what are teachers' perceptions of science inquiry and its implementation in the classroom? Second, how does the use of the Inquiry for Conceptual Change model affect the learning of students in a predominantly Hispanic, urban neighborhood. Five teachers participated in a professional development project where they developed and implemented a science unit based on the Inquiry for Conceptual Change model. Three units were developed and implemented for this study. This is a qualitative study that included data from interviews, participant reflections and journals, student pre- and post- assessments, and researcher observations.

This study provides an in-depth description of the role of professional development in helping teachers understand how science inquiry can be used to improve instructional quality for students in a predominantly Hispanic, urban neighborhood. These teachers demonstrated that it is important for professional development to be collaborative and provide opportunities for teachers to enact and reflect on new teaching paradigms. This study also shows promising results for the ability of the Inquiry for Conceptual Change model to improve student learning.

CHAPTER 1

INTRODUCTION

This chapter will introduce and provide background information on the problem, identify the purpose and major questions of this study, and discuss the importance of the study. This chapter will also discuss the assumptions and limitations of the study and describe the organization of the remainder of this proposal.

Statement of the Problem

General Statement of the Problem

Educational quality has always been an important local issue, but since the publication "A Nation at Risk" 20 years ago, the quality of K-12 education has been an enduring issue on the national stage. Parents are concerned about the experiences and needs of their own children. Business leaders point to inadequately prepared workers.

One aspect of the focus on measuring school success is the issue of educational equity across gender, racial/ethnic, socio-economic status, and English language proficiency differences. Persistent gaps in achievement have been noted, in spite of the efforts made to address them.

The Federal No Child Left Behind Act further focuses the spotlight of accountability on local schools and teachers. One of the laudable aspects of the law is its acknowledgement of the need for all groups of children to succeed in school. The education research literature has addressed many aspects of the achievement gap. Many

factors internal and external to school systems contribute to this achievement gap. Most of these factors can not be addressed by teachers and individual schools. One of the most critical avenues for bridging the achievement gap within the purview of the education establishment is increasing the quality of instruction.

A National Overview of the Achievement Gap

The National Assessment of Educational Progress (NAEP) is funded by the federal government and is a nationally representative and continuing assessment of student achievement in mathematics, reading, science, U.S. history, writing, and other subjects. The NAEP Science test measures elements of knowing, including conducting scientific investigations, in specific science context areas.

The current NAEP defines achievement levels. In 2005, slightly more than two-thirds of grade 4 students nationally scored at the *Basic* level or above in science. At grades 8 and 12, the percentages of students scoring at *Basic* or above were 59% and 54% respectively(National Center for Education Statistics, 2006). A comparison of NAEP results for 1996, 2000 and 2005 shows that the number of students scoring at basic in 2005 is statistically significantly higher than in 1996 and 2000. However, there is no statistically significant difference between grade 8 scores in 1996, 2000 and 2005. Grade 12 science scores in 2005 are slightly, but significantly, lower than in 1996. (National Center for Education Statistics, 2006).

There are wide disparities in NAEP scores by racial/ethnic subgroups. This is especially apparent when comparing scores of Hispanic students to those of White students. In 2000, 77% of White students in grade 4 scored basic or proficient in science

compared to 34% of Hispanic students. Grade 4 scores in 2005 were higher for both White (82%) and Hispanic (45%) subgroups. These increases are statistically significant. In grade 8, 73% of White students and 33% of Hispanic students scored basic or proficient on the science portion of the 2000 test. In 2005, 74% of White and 35% of Hispanic students scored basic or proficient in science. The changes from 2000 to 2005 are not statistically significant (National Center for Education Statistics, 2006).

In order to understand the differences in test scores between ethnic groups, Barton (2002) analyzed the achievement gaps in the NAEP results. In the 2000 results, the gap between poor and non-poor, based on free and reduced lunch (32 points), is less than that between White and all minority students (37 points), but the gap between the bottom and top quartiles (88 points) is 2 times that between Whites and minorities (Barton, 2002). Barton also notes that between the 1996 and 2000 results, only one state of the 33 that participated in both years showed an improvement in the bottom quartile of students, while 17 states saw improvements for the top quartile of the student populations. The NAEP data for grade 4 related to disparities between White and Hispanic students is encouraging. The average score for both groups saw statistically significant increases and the achievement gap narrowed. However, the achievement gap between White and Hispanic students in grades 8 and 12 saw no statistically significant changes (National Center for Education Statistics, 2005). Despite at least a decade of attention, little has changed in the disparity between achievement of White and Hispanic students.

The Achievement Gap in Wisconsin

Wisconsin has a proud tradition of providing students with high quality education. However, the state does have a pronounced gap in achievement between White students and minority students. 2005 NAEP data shows that 77% of Wisconsin students scored at Basic or above in science at grade 4 and 71% of Wisconsin students scored at Basic or above in science at grade 8. In grade 4, both White (86% and Hispanic (56%) subgroups scored at Basic or above in science. In grade 8, 79% of White students and 38% of Hispanic students scored at or above in science. The percent scoring at basic or above for these subgroups is higher than the National average. The achievement gap between White and Hispanic students is slightly smaller than the national average in grade 4, but slightly larger in grade 8, Wisconsin 2000 NAEP data is not available (National Center for Education Statistics, 2006). Although achievement in Wisconsin, as measured by NAEP is above the National average, a large achievement gap persists between White and Hispanic students.

The Wisconsin Knowledge and Concept Exam (WKCE) is given every year to Wisconsin students in grades 4, 8, and 10. The results from this exam tell a similar story of the achievement gap as NAEP data. The 2004 results show that 78% of students in grade 4 scored at Proficient or Advanced in science. However, only 54% of Hispanic students in Wisconsin scored at Proficient or Advanced in science compared to 86% of White students. The 2005 results for all students was unchanged, however the percent of Hispanic students scoring at Proficient or Advanced increased to 58% compared to 85% of White students. The 2004 results for grade 8 show, 82% of White students scored

Proficient or Advanced in science compared to 48% of Hispanic students. The 2005 results remained unchanged for Hispanic students and decreased slightly to 80% for White students.

The participants in this study are in a large urban district. Students in this district fared worse than students in the rest of the state. Only 51% of Hispanic of fourth grade students in the district scored advanced or proficient compared to 74% of White students in 2004. In 2005, 54% of Hispanic students and 72% of White students scored proficient or advance. In grade 8, 66% of White students and 35% of Hispanic students scored at the proficient or advanced level in 2004. In 2005, the percentage of White students scoring proficient or advanced was unchanged, but the percentage of Hispanic students scoring proficient or advanced increased to 38%. (Wisconsin Department of Public Instruction, 2006).

Becker School serves more than 700 students in kindergarten through eighth grade. This school serves a diverse neighborhood. Its population is nearly three-quarters Hispanic, 10% White and the remainder African American, Asian and Native American students. (Wisconsin Department of Public Instruction, 2006). Interestingly, just over 40% of Hispanic students at Becker School scored proficient or advanced compared to 38% of White students in 2004. In 2005, Hispanic students were the only group that could be disaggregated. Hispanic students fared slightly better (36%) when compared to all 4th grade students at the school (34%). In 2004 and 2005, Hispanic students were the only ethnic group whose scores could be disaggregated in 8th grade. Compared to 48% of all eighth grade students at the school, 46% of Hispanic 8th grade students scored at the

proficient or advanced level in 2004. In 2005, 39% of all students scored at proficient or advanced levels compared to 34% of Hispanic students. Figure 1 compares results for grades 4 and 8 at the National, State, District, and School level on standardized science tests.

Figure 1.   A comparison of Standardized Science Tests Disaggregated for White and
              Hispanic Students.
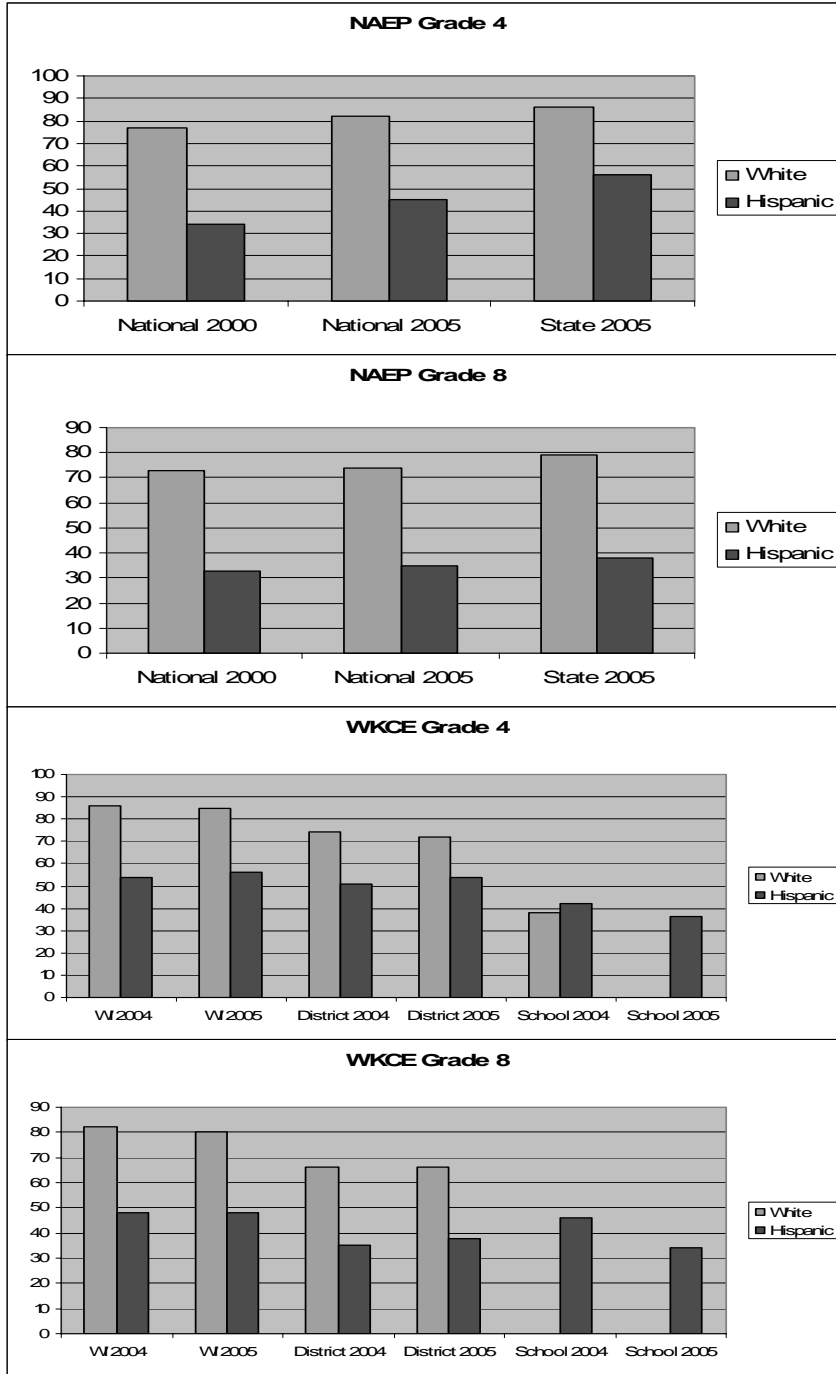
*The Y axis for the NAEP graphs represents the percentage of students scoring basic or
above. The Y axis for the WKCE graphs represents the percentage of students scoring
proficient or above.

Addressing the Problem

A commonly held belief is that improving instruction is a key undertaking that could narrow the achievement gap between White and Hispanic students. In a meta-analysis of research, Marzano (2000) identified several factors that account for variance in student achievement and lead to the achievement gap. Student characteristics such as home environment, background knowledge (pre-formal schooling), and motivation account for 80% of the variance in student achievement, while school-level and teacher-level factors account for the remaining 20%. Although the variance attributed to school-level and teacher-level factors seems small, Marzano (2003) provides a compelling argument that high quality teaching can have a dramatic effect on student achievement.

Marzano's work does not stand alone in connecting teacher quality to student achievement. Ferguson's (1991) review of literature identified that 40% of the variance in students' (grade 1-7) test scores was the result of teacher quality. This amount was greater than contributions from student background factors, parent education and class size. Another review of literature (Darling-Hammond, 2001) cites several studies that show a clear link between teachers' classroom skills and understanding of the learning process and student success. In an examination of elementary student test scores, Sanders and Rivers (1996) observed that differences of as much as 50 percentile points were observed as a result of differences in teacher quality. They also found that as teacher effectiveness increases, lower achieving students are the first to benefit. Since high quality teaching promotes student achievement, it is important to determine what this teaching looks like.

In 1996, the National Research Council (NRC) published the landmark <u>National Science Education Standards</u> (NSES) as a pathway for improving science education in the United States. The NSES teaching standards, grounded in constructivist theory, recommend the use of inquiry teaching strategies as central to good science teaching. Inquiry approaches to teaching can be considered as more representative of how science is conducted. Inquiry refers to the "diverse ways in which scientists study the natural world, propose ideas, and explain and justify assertions based on evidence" (Hofstein & Lunetta, 2004). As described by the NRC (2000), science inquiry instruction should engage students in scientifically oriented questions, give priority to evidence, involve formulating explanations from evidence, connect explanations to scientific knowledge, and communicate and justify explanations. Kahle Meece, and Scantelbury (2000) investigated the effect of science inquiry instructional methods African American students' learning. African American students for 18 middle school science teachers were included in this study. The researchers found there was a significant positive relationship between attitudes toward science and science achievement scores. Additionally, there was a significant, positive correlation between the frequency of standards-based teaching and student achievement. Although this study was limited to African American students, it does suggest that similar teaching strategies may be effective with other minority groups. According to its published school profile, science at Becker School is taught "using inquiry-based activities." However, no specific models of science inquiry instruction are employed at this school.

In addition to the NSES emphasis on using inquiry teaching strategies, research conducted over more than 30 years has shown that students do not enter a science classroom as empty vessels waiting to be filled by science knowledge. Instead, research has shown that these students have pre-instructional notions of how the natural world works. These pre-instructional notions are often not consistent with scientific explanations and are very difficult to change (e.g. Osborne & Freyburg, 1985; Posner et. al., 1982; Macbeth, 1999; Chin & Brewer, 1993). Macbeth (1999) identifies considerable agreement between researchers that instruction should provide opportunities for students to make their own conceptions about a topic explicit so that teachers can provide discussion and investigation, present counter examples, present and review alternative conceptions, and provide opportunities to use the scientific method. These characteristics of teaching for conceptual change agree with the definition of science inquiry instruction provided by NRC. A substantial number of studies have shown that instruction focused on conceptual change can have a positive effect on student learning. For example, studies with middle school students and heat (Wiser & Amin, 2001), osmosis and diffusion (Tekkaya, 2003), forces and motion (Hennessey, 2003), the Greenhouse Effect and global warming (Mason & Santi, 1998), and plate tectonics (Vosniadou et. al., 2001) all show that deliberately teaching for conceptual change has a positive impact on student learning. However, Rodriguez (1998b) warns that evidence for the ability of conceptual change instruction to improve science learning for diverse students is lacking. In his critique of conceptual change instruction, Rodriguez (1998b) seems to focus solely on cold conceptual change research, or conceptual change methods that do not take into

account a learner's individuality. Pintrich and colleagues (1993) started the Intentional Conceptual Change movement to look beyond this cold conceptual change to build an understanding of conceptual change that includes students' motivational beliefs, interest, and other classroom factors. These factors may be especially salient for students that feel disenfranchised with science, including many Hispanic students. Researchers should continue to expand the characteristics of conceptual change instruction to promote learning by diverse students. Additionally, the linkage between conceptual change and science inquiry instruction should be examined.

Rodriguez (2002) and Padron, Waxman, and Rivera (2002) explain that the learning of Hispanic students is improved by the use of instructional conversations, metacognition, and authentic or culturally relevant instruction. During instructional conversations, students have the opportunity to express their ideas about a concept and collaborate with other students to defend and modify ideas as they work toward a common understanding. Metacognition enhances students' cognitive engagement by helping them build awareness of their own learning. Authentic or culturally relevant instruction, as defined by these authors, includes activities that are socially relevant and connected to the students' community. Additionally, authentic activities mirror the way knowledge is constructed within the culture of the discipline. Instruction based in science inquiry and Intentional Conceptual Change research can provide a model of instruction that incorporates many of the strategies that Rodriguez and Padron, Waxman and Rivera found important for helping Hispanic students learn science.

This study will determine how teachers and students react to the Inquiry for Conceptual Change instructional model. This model is built specifically from the research into science inquiry, conceptual change, and how Hispanic students learn best. The components of the Inquiry for Conceptual Change model are Preparing, Wondering, Investigating, Constructing, and Connecting. For the Inquiry for Conceptual Change model to be successful, the classroom environment must also encourage relevancy, instructional conversations, and metacognition. It is also important to note that teachers feel a strong pressure to address local and state education standards. The Inquiry for Conceptual Change model begins with teachers identifying specific learning targets consistent with these standards.

The Purpose of This Study

During this study, five science teachers at Becker Elementary school participated in intense professional development related to conceptual change and science inquiry instruction. As part of this professional development, the participants will developed a unit of study using an Inquiry for Conceptual Change model of instruction. The purpose of this study is twofold. First, the study will examined teachers' perceptions of science inquiry, how it is implemented in diverse classrooms, and how these perceptions change as a result of the professional development. Second, the study will explored how a specific conceptual change–based model of inquiry affects the learning of diverse students. This study consists of two focus questions.

1. What are teachers' perceptions of science inquiry and its implementation in the classroom?

    a. How do teachers' understandings of science inquiry change as a result of professional development and implementation of inquiry?

    b. How do teachers' understandings of science inquiry influence their implementations of inquiry in the classroom?

    c. What challenges do teachers face when implementing science inquiry in a diverse classroom?

2. How does the use of the Inquiry for Conceptual Change model affect the learning of students in a predominantly Hispanic, urban school?

    a. Do science teachers observe any difference in student engagement between the inquiry model and their previous teaching methods?

    b. What types of research questions do students pose?

    c. Is there evidence of a conceptual change in students between the pre- and post-assessment?

    d. Is there evidence of deep cognitive engagement on the part of the students?

<u>Definition of Key Terms</u>

The only term used in this study that is not explicitly defined in the text is the idea of culture. As used in this study, culture refers to a fabric of shared meanings and understanding that develops when groups of people come together and engage in joint activity over a period of time. The participants in a culture are molded by and contribute

to the culture. An individual can participate in many cultures as they associate in different groups (Cole, 1996).

Significance of This Study

Rodriguez (1998a) argues that because Hispanics compose a significant proportion of our population, and represent the fastest growing ethnic group in the country, both a concern for social justice and for a strong economic future requires attention to the achievement gap in science. Marzano (2003) and others argue that improving the quality of instruction can have a dramatic effect on bridging the achievement gap for diverse students. Most science education reform efforts and the National Science Education Standards strongly promote the use of inquiry methods to teach science. However, the literature is lacking on how teachers of diverse students implement science inquiry and how science inquiry affects the learning of diverse students. This study will add valuable insight into these issues.

Limitations

The primary limitation of this study is that it is focused on the teachers and students at one particular school. This focus will allow the researcher to examine these conditions in depth. A multi-site study at a variety of grade levels would broaden the study, but would also limit its depth. The detailed knowledge created in this focused study may lead to insights that may be generalized beyond this study. Additionally, the study is limited by the duration and staffing of the study. Because the study was

completed in one term, it was not possible to determine if changes in teacher or student knowledge was lasting. Furthermore, the professional development was provided with a single facilitator, the researcher.

<u>Organization</u>

Chapter Two of this dissertation will develop the theoretical basis for the study through a comprehensive review of pertinent literature. This review of literature will examine studies related to cognition and conceptual change, definitions of science inquiry, models of inquiry, specific characteristics of instruction that are beneficial to Hispanic learners, and characteristics of successful professional development. Chapter Three of the proposal will describe the intervention, methodology, data collection, and analysis of data. Chapter Four of the proposal will discuss the results of this study. Chapter Five will provide conclusions, implications and suggestions that can be made from the results of the study.

CHAPTER 2

REVIEW OF LITERATURE

This chapter will review the literature that informed this study. The first part of this chapter, "Foundations," will provide a brief overview of the social constructivist foundation for science inquiry and a discussion of the key characteristics of science inquiry. The second part of the chapter will discuss literature related to learners' initial conceptions and conceptual change theories as part of this section, specific attention will be given to the idea of "hot cognition." "Hot cognition" deals with how affective factors, such as interest and motivation, can affect conceptual change. These factors may be particularly important for populations that are underrepresented in science. In the third part of this chapter, "Models of Instruction," specific models of instruction using science inquiry and conceptual change theories will be discussed. The fourth part of this chapter, "Hispanic Learners," will examine literature related to how Hispanic students learn best. The fifth part of the chapter will provide a summary of the characteristics of effective science instruction and student learning described in the first four parts. The final section of this chapter will describe a framework for professional development in science.

Foundations

Figure 2. An Overview of the Foundations Section.

Foundations

Social Constructivism
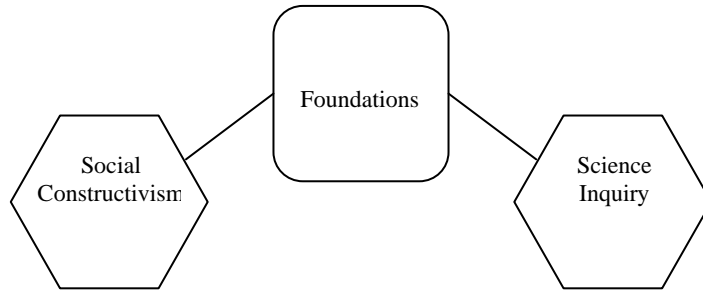
Science Inquiry

This study looks at how a model of science inquiry instruction can be designed and implemented with Hispanic learners in mind. In order to develop this model, we need an understanding of the theoretical underpinnings of science inquiry. The social constructivist perspective provides a compelling argument for the importance of using an instructional approach that mimics the culture of science. This argument is presented in the first part of this section. Any investigation into science inquiry also needs to clearly explain how science inquiry is being defined. This definition is provided in the second part of this section. Figure 2 provides a graphic overview of this section.

Social Constructivism

Vygotsky's work (e.g. 1978) and the social context in which thinking and knowing occur have received increased attention from educational researchers in recent years. Socio-cultural theories view the learning process and knowledge construction as a result of individuals interacting in social environments (interpsychological plane) to create shared knowledge that is appropriated by the individual (intrapsychological plane).

According to Vygotsky, our development is different from other animals because of our use of tools and symbols. Culture is a fabric of shared meanings and understanding that develops when groups of people come together and engage in joint activity over a period of time (Cole, 1996). The participants in a culture are molded by and contribute to the culture. An individual can participate in many cultures as they associate in different groups (e.g. school, home, geographical, racial, etc.). The interactions between cultures provide a lens that mediates what and how an individual learns.

Socio-cultural theorists contend that the activity in which knowledge is developed is not separable from the learning that is taking place. As an individual learns how to use a cognitive tool (eg: routine, algorithm, definition), they build a rich understanding of the world in which it is used. Since cognitive tools reflect the culture in which it is used, it is impossible to learn how to use the tool without understanding the culture (Brown et. al., 1989). In other words, the activities and ideas that represent a culture are framed by its culture. Their meanings are socially constructed by members of that culture. Brown, Collings, and Duguid. (1989) define knowledge as follows:

> Knowledge, we suggest, similarly indexes the situation in which it arises and is used. The embedding circumstances efficiently provide essential parts of its structure and meaning. So knowledge, which comes coded by and connected to the activity and environment in which it is developed, is spread across its component parts, some of which are in the mind and some in the world much as the final picture on a jigsaw is spread across its component pieces.

Since understanding how to use the knowledge of a discipline demands that the learner understands the culture in which the knowledge was created, Brown and colleauges suggest that teaching should be a cognitive apprenticeship. Cognitive

apprenticeship strategies reflect the need for students to learn the tools of a discipline within the culture of that discipline.

Science Inquiry

The quote cited above from Brown and colleagues. (1989) indicates that knowledge and culture are inseparable. The science "knowledge" that students learn in a science classroom is connected to the activity and environment in which it was learned. Wells (1999) states, "Vygotskian theory suggests that the goal of education is to provide an environment in which students, however diverse their background, engage collaboratively in productive purposeful activities which enable them to take over the culture's tool-kit of skills, knowledge and values so that they are able to participate effectively in the practices of the larger society." Both these quotes imply that if the classroom environment does not reflect the culture of science, the students will not have a full appreciation of the science content presented in that classroom.

In 1996, the National Research Council (NRC) published the landmark National Science Education Standards (NSES) as a pathway for improving science education in the United States. The NSES teaching standards, grounded in constructivist theory, recommend the use of inquiry teaching strategies. Science inquiry is defined by the "diverse ways in which scientists study the natural world, propose ideas, and explain and justify assertions based on evidence" (Hofstein & Lunetta, 2004). Inquiry approaches to teaching are more representative of how science is conducted and therefore create a learning environment that reflects the culture of science. The NSES defines inquiry teaching strategies as follows:

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

The NRC (2000) states that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science." Inquiry teaching as described by the NRC has the following essential features:

1. The learner engages in scientifically oriented questions;

2. The learner gives priority to evidence in responding to questions;

3. The learner formulates explanations from evidence;

4. The learner connects explanations to scientific knowledge; and

5. The learner communicates and justifies explanations.

Chinn and Malhotra (2002) describe science inquiry as consisting of classroom activities that are similar to how inquiry is conducted by scientists. Chinn and Malhotra present 11 characteristics of authentic activity that fit within the following four categories: student development of research questions, design of investigations, evaluation of data, and construction of theories. The researchers examined 468 activities that are contained in 9 commonly used middle school textbooks. These activities failed to incorporate aspects of authentic activity, averaging less than 0.5 of the 11 features per activity. Amazingly, none of the textbook activities included student generation of research questions.

Variations in inquiry strategies (or implementation models) can be divided into three categories based on the type of teacher intervention. Open (or Full) Inquiry, involves the least authoritative intervention by the teacher. Students generate questions and design and conduct their own investigations. Guided Inquiry involves more direction from the teacher and generally involves the teacher presenting students with the question to be investigated. Students then plan and conduct their own investigations to answer the question. In Structured Inquiry, teachers provide students with a series of questions and directions for investigations that students should complete. This is a more authoritative intervention: the teacher provides the problem and processes, but students are able to identify alternative outcomes (Martin-Hansen, 2002; Trowbridge & Bybee, 1990; Colburn, 2000).

Summary

Socio-cultural theorists contend that the activity in which knowledge is developed is not separable from the learning that is taking place. As students learn, they build an understanding of the world in which that knowledge is used (e.g. Vygotsky, 1978; Brown et al, 1989). Therefore, it is important that the knowledge that students construct is connected to activities and environments that reflect the culture of science. The NSES and other authors explain that science inquiry approaches to teaching are more representative of how science is conducted (e.g. NRC, 1996; Hofstein & Lunetta, 2004; Chinn & Malhotra, 2002).

Science inquiry approaches include the following essential features: learner engages in scientifically oriented questions; uses evidence in responding to questions;

connects explanations to scientific knowledge; and communicates and justifies explanations (NRC, 2000). Variations in science inquiry approaches are characterized by how much control the teacher exercises over these essential features (e.g. Martin-Hansen, 2002, Trowbridge & Bybee, 1990; Colburn, 2000).

<u>Conceptual Change</u>

Figure 3. A Graphical Organizer for the Conceptual Change Section.
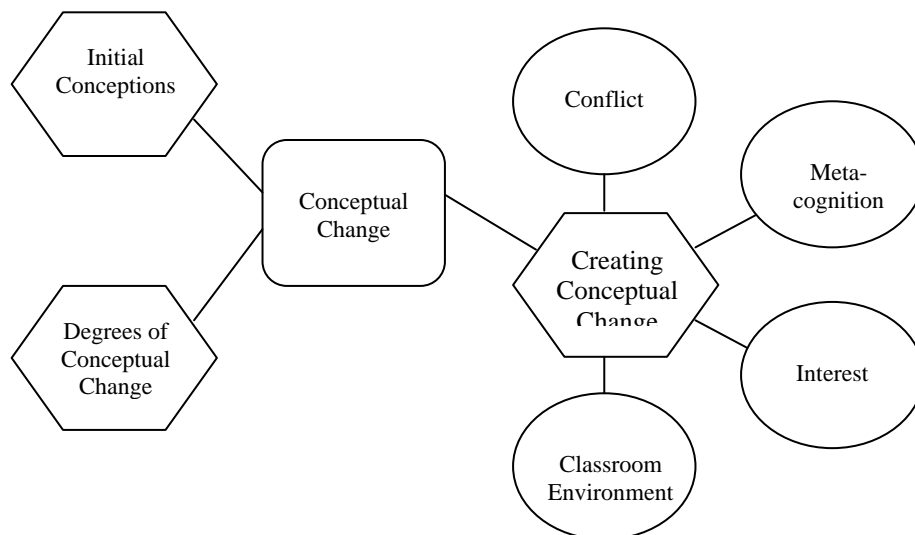
The Inquiry for Conceptual Change model used in this study attempts to place teaching for conceptual change into a science inquiry construct. This section begins with a look at the initial conceptions that students enter science classes with and continues with a discussion of different degrees of change in these conceptions. The section concludes with an examination of literature describing factors that promote conceptual change, including the creation of cognitive conflict, the use of metacognition, and the

importance of student interest and the classroom environment. Figure 3 provides a graphical organizer for this section.

<u>Initial Conceptions</u>

> The higher up you are the stronger gravity is because if you jump down from something high up, you're obviously going to fall a lot heavier than if you jumped from something lower down.
> - 20-year-old student (as cited in Osborne & Freberg, 1985, p. 87)

In order for science inquiry to be successful, we must first realize that students do not enter the classroom with empty heads. Vygotsky (1987) differentiated student knowledge as either spontaneous (everyday) or scientific. Spontaneous knowledge is generated primarily through observations made in everyday, non-school situations. Vygotsky identified the weakness of spontaneous concepts as an individual's inability to manipulate them in a voluntary manner and their lack of systematicity. In contrast to spontaneous knowledge, scientific knowledge is obtained through an intentional process of formal instruction. Vygotsky claimed that the child's capacity to voluntarily use concepts defines the strength of scientific knowledge. According to Vygotsky, the development of scientific knowledge builds upon the existing spontaneous knowledge. "In thinking of the child, one cannot separate the concepts that he acquires in school from those that he acquires at home" (p. 219).

Posner et. al. (1982) describe the knowledge that students enter a classroom with, called initial conceptions, as a conceptual ecology where individual concepts are tied together based on experiential observations. Jones, Carter, and Rua (1999) describe conceptual ecology as "a student's knowledge in a particular domain including the rich

tangle of connections of prior experiences and understanding" (p. 141). Schwedes and Schmidt (1992) describe conceptual ecologies in a similar manner. In their view, a conceptual ecology consists of a fundamental aspect, or nucleus, surrounded by a pool of rules and ideas. Strike and Posner (1992) wrote that since "misconceptions are embedded in a conceptual context, students will have to alter other concepts as well…conceptions often come with their own support group." Students will resist changes to their initial conceptions as long as this "support group" continues to play a role. Additionally, students' initial conceptions are not always clearly articulated. In some cases, they may not previously exist, but are generated on the spot due to intuition and built from other aspects of the learner's conceptual ecology.

Vosniadou (1994) has provided a very clear description of initial conceptions as a framework theory. Students' observations and perceptions of the world are organized into a narrow explanatory theory. Similar to Strike and Posner's description of the spontaneous generation of conceptions due to intuition, Vosniadou explains that students generate synthetic models as a bridge between their initial framework theory and observations that do not conform to the framework. She describes the framework theory as naïve physics (Vosniadou, 2003, p. 381). According to Vosniadou, the human mind has evolved the ability to pick up information from the physical and social world. Naïve physics is knowledge about the physical world that begins developing in infancy and allows individuals to function in a physical environment. Naïve physics is a collection of unrelated pieces of knowledge that provides a narrow but coherent explanatory framework for thinking about the physical world. It attempts to organize sensory

experiences from the everyday world and information learners receive from culture. Scientific explanations generally violate fundamental principles of naïve physics.

<u>Degrees of Conceptual Change</u>

Science education attempts to transform a student's initial, or everyday, conception to one that is closer to a scientific conception. Vosniadou (2003) claims that this conceptual change is required because "the initial explanations of the physical world in naive physics are not fragmented observations but form a coherent whole. Because of this, the learning of science requires acquiring a different theory about the physical world" (p. 381).

Although conceptual change researchers and theorists use a tremendous number of terms to describe conceptual change, they converge on three degrees of conceptual change. The lowest degree of conceptual change involves the addition of ideas to a learner's conceptual ecology without reorganization. This could be called an expansion of their initial conceptual ecology. Posner et. al. (1982) and Strike and Posner (1992) refer to this as 'accretion.' Carey (1985) describes this degree of change as knowledge accumulation without restructuring. Vosniadou (1994) calls it enrichment, and Chi et. al. (1994) refer to the addition of ideas as a process that does not change the ontological membership of the concept. Schwedes and Schmidt (1992) state that this is an addition to the pool of rules and ideas around the nucleus of the concept. Hewson and Hewson (1992) do not recognize the addition of ideas without reorganization as conceptual change.

The second degree of conceptual change involves a surface revision of the conceptual ecology. Schwedes and Schmidt (1992) provide a great description of this degree of conceptual change by stating that the pool of rules around the nucleus of the concept is altered, or new cognitions are attached to the nucleus, but the nucleus itself is not changed. This is also called assimilation (Posner et. al., 1982; Strike & Posner, 1992), though it should be noted that since this is a modification of the knowledge structure, it is not the same as Piaget's assimilation. Other terms include conceptual capture (Hewson & Hewson, 1992) and weak restructuring (Carey, 1985). Vosniadou (1994) describes this as a revision at the level of a specific theory, and Chi et. al. (1994) describe this degree of conceptual change as a shift within a major ontological category. deLeeuw and Chi (2003) refer to this as incremental conceptual change because it requires a modest shift in understanding or a simple exchange of one idea for another.

The third degree of conceptual change involves a complete reorganization of a conceptual ecology. This has been called accommodation (Posner et. al., 1982; Strike & Posner, 1992), conceptual exchange (Hewson & Hewson, 1992), and strong restructuring (Carey, 1985). This is described as a revision at the level of a framework theory by Vosinadou (1994) and a complete change of the nucleus of a concept by Schwedes and Schmidt (1992). Chi et. al. (1994) describe this degree of conceptual change as a shift of a concept from one major ontological category to another. A change in ontological categories is also described by deLeeuw and Chi (2003) as a radical conceptual change because old concepts are completely replaced by new ones since the scientific concept is incompatible with the existing "folk" concept. They provide the example of a radical

conceptual change as the type of change required to conceive of electricity as a kind of process instead of as a substance.

Vosniadou (2003) describes conceptual change as a slow process that requires the replacement of beliefs and presuppositions of naïve physics. She states, "Many so-called misconceptions can be explained as synthetic models formed by learners in their effort to assimilate new information into the existing framework theory. The change of the framework theory is difficult because it forms a coherent explanatory system based on everyday experience and is tied to years of confirmation" (p. 381).

The studies cited above show that conceptual change is a difficult process that can occur through adding concepts to a student's conceptual framework, creating small changes in the conceptual framework, or undergoing a large restructuring of the conceptual framework.

Creating Conceptual Change

Posner et. al (1982) established a theory of conceptual change in an attempt to explain how a person's initial conceptions change from one set of concepts to another set that are incompatible with the first. A student begins with an initial set of concepts and ideas, called a conceptual ecology, of a phenomenon. In order for the initial conception to be changed to a new conception, four conditions must be present. First, students must become dissatisfied with their current conception. Second, the new conception must be understandable or intelligible. Third, the new conception must appear to be initially plausible; it must resolve the student's dissatisfaction with their initial conception. Fourth, the new conception must be fruitful; it must show the possibility of being able to

solve current and future problems. According to Posner et al, if these conditions are met, a student may undergo conceptual change.

Strike and Posner (1992) provided modification and an expansion of their theory of conceptual change. Strike and Ponser wrote that since misconceptions are embedded in a conceptual context or conceptual ecology, changing the misconception may involve changing or modifying many concepts. They also noted that since misconceptions may be generated from intuition, "drowning the misconception in a sea of anomalies may not be the best strategy." Instead, they contend that paying attention to students' collections of metaphors or ordinary language analogues may be more important than a "frontal assault" on misconceptions. Strike and Posner provided the following modifications to their original theory. First, a wider range of factors need to be taken into account when describing a learner's conceptual ecology. A learner's motivation and goals, as well as the institutional and social sources of these goals, are important. Second, current scientific conceptions and misconceptions must be viewed in interaction with other components of the learner's conceptual ecology. Third, conceptions and misconceptions exist in different degrees of articulation. In fact, they may not exist, but can be generated by elements of the learner's conceptual ecology (intuition). Fourth, a developmental view of conceptual ecologies is required. Fifth, an interactionist view of conceptual ecologies is required. Developmental and interactionist views of conceptual ecologies mean that components of a conceptual ecology have a developmental history and must be understood as dynamic and shifting.

Pintrich, Marx, and Boyle (1993) saw the need to expand conceptual change theory to include more variables. They presented a view of "hot cognition" that drew from motivation research to add to conceptual change theory. Their argument described how motivational constructs such as interests, goals, and values may affect conceptual change in the classroom context. They also attempted to describe how social and institutional characteristics of the classroom could affect student's motivation and cognition. Their "hot conceptual change" or Intentional Conceptual Change theory contended that learners' motivational beliefs (interests, goals, values, self-efficacy, control beliefs) about themselves as learners played an important role in conceptual change. Students have to intentionally think to create dissonance and evaluate alternative explanations.

The literature related to conceptual change instruction and the intentional nature of conceptual change converge on four themes. (1) Students must be aware of and dissatisfied with their initial conceptions. In other words, students should feel a conflict between new information and their initial conception. (2) Students should have a metacognitive awareness of their thought process that leads toward conceptual change. (3) Instruction should foster an interest in course content as a means to foster a goal of conceptual understanding or mastery in students. (4) The classroom environment should focus on understanding.

Conflict. The cornerstone of conceptual change theory as provided by Posner et. al. (1982) and Strike and Posner (1992) is the use of a situation, such as anomalous data or a discrepant event, to create dissonance with the learner's initial conception. This

dissonance opens the door for the learner to modify her initial conception or exchange the initial conception for one that is more scientifically acceptable. Tsai (1999) describes the following sources of conflict that can create cognitive dissonance, or dissatisfaction with initial conceptions. (1) Conflicts between students' intuition and scientific views: students often rely on intuition when interpreting scientific phenomena. (2) Conflicts between daily observations and scientific conceptions. (3) Conflicts between people's common language and scientists language. (4) Conflicts between students' ontology and scientists' ontology.

Wiser and Amin (2001) investigated the effect of explicitly integrating everyday knowledge and scientific knowledge on the change in four eighth grade students' conceptions of heat. The goal of the instructional intervention used in this investigation was not to have the students' everyday view of heat replaced by the scientific view. Instead, the goal was to acknowledge the initial conceptualization, have them differentiate between the science view and their everyday view, and then use the scientific view to explain everyday views. Students participated in exploratory computer activities and received direct instruction on molecular theory. Students were tested after this initial instruction and were only able to solve a limited number of simple problems with external support provided by the teacher. Students exhibited significant confusion involving heat, temperature, heat energy, energy, and "hot energy." The participating students then received instruction to explicitly show differences between the everyday views and scientific views and how the scientific view can explain the everyday views. After this instruction, students were able to describe phenomena in appropriate terms of

heat and temperature, which allowed them to solve more conceptually difficult problems and scientifically explain everyday views of heat. The researchers suggest that the advantage of this approach is that it emphasizes the integration of everyday and scientific knowledge where the scientific knowledge explains the everyday views. Both views coexist in the student, but instead of existing as competing conceptualizations, they are explicitly related in the students' conceptual ecology.

Tekkaya (2003) conducted a pre- post-test quasi-experimental design with 24 ninth graders in the experimental group and 20 ninth grade students in the control group. The intervention included the use of conceptual change texts related to osmosis and diffusion. Conceptual change texts introduce a question, directly identify possible alternative conceptions, and explain the scientifically acceptable answer. Concrete examples are then included with the intention of further helping students understand the scientific concept and realize the limitations of their own ideas. In this study, students in the experimental group had a gain of 31.6% in conceptual understanding while students in the control group only had a gain of 19.6%. Students in the experimental group were much more likely to exhibit a conceptual understanding of osmosis and diffusion and demonstrated a larger decrease in the frequency of exhibiting common misconceptions when compared to the control group.

Sungur, Tekkaya, and Geban (2001) provide a similar description of conceptual change texts. In their conceptual change texts, students are asked explicitly to predict what will happen in a situation before being presented with information that demonstrates the inconsistency between common misconceptions and scientific conceptions. Common

misconceptions are explicitly presented, and the scientific view is provided as a stronger alternative. In Sungur, Tekkaya, and Geban's study, 49 students were split into experimental and control groups and received pre- and post intervention tests on the human circulatory system. Both groups were taught similarly, but instruction in the experimental group was supplemented with the use of conceptual change text. Students in the experimental group had a small increase in scores, which was statistically significant compared to the increases in the control group. By analyzing specific test items, the authors showed that, although their was only a small increase in scores, there was a large decrease in common misconceptions among students in the experimental groups compared to the control group.

The introduction of anomalous data or a discrepant event by itself often does not lead to conceptual change. Chin and Brewer (1993) provide a framework that can be used to understand how students protect their initial conceptions despite conflicts. Learners exhibit seven types of responses when confronted with conflicting information. These responses include ignoring, rejecting, excluding, abeyance, reinterpreting, making partial changes, or complete conceptual reorganization. Only the last of these responses results in a substantial conceptual change. The type of response is dependent on whether or not the learner accepts the data, explains the data, and changes his initial conceptions. Table 1 summarizes these responses. These results are very similar to Piaget's ideas that a learner may either alter their perceptions or alter their schema if the two are not consistent.

Table 1. Responses to Anomalous Data (Chin and Brewer, 1993, pg 13).

Response	Does the Individual Accept the Data?	Does the Individual Explain the Data?	Does the Individual Change Theory?
Ignore	No	No	No
Reject	No	Yes	No
Exclude	Yes or Maybe	No	No
Abeyance (explainable by current theory at some future date)	Yes	Not Yet	No
Reinterpret	Yes	Yes	No
Peripheral change (Only a small change in theory)	Yes	Yes	Partial
Theory change (A complete reorganization of theory or core beliefs)	Yes	Yes	Yes

Chin and Brewer's results were based on a study of undergraduate students. Mason (2001) found similar results in younger students. Mason studied 126 eighth graders in Northern Italy to determine their reaction to anomalous data. The students completed a pre- and post-survey that measured their beliefs by assigning a believability rating to determine how strongly held their beliefs were, their ability to identify anomalous data, and a rationale for changing or not changing their beliefs from the pre-intervention survey. Mason found that the students' responses to the anomalous data showed evidence from all of Chinn and Brewer's categories of response. Additionally, Mason noted that students exhibited a strong belief in the authoritative source of knowledge. In many cases, students used the fact that it was stated by an expert or that it was taught in class as an explanation for why a specific belief is true. Limon (2001)

echoes Mason's and Chin and Brewer's work when she states that the introduction of anomalous data is only one strategy to generate cognitive conflict. Analogies, metaphors, and dyad or group discussions may also lead to meaningful cognitive conflict. Limon states the following about this idea:

> Therefore, if we expect students to achieve this first step (meaningful conflict) many variables have to be taken into account. To present just contradictory data that, from the students' point of view do not contradict anything or that are not interesting at all for them is not enough to lead students to a meaningful conflict. If this first requirement is not achieved, it is quite reasonable that students do not change anything at all. (p. 366)

Limon goes on to say, "From a teaching perspective, what seems to be the starting point to promote any change in the conceptual network is to lead the individual to be aware of the difference between their own beliefs, concepts or theories and the new information" (p. 374). The importance of identifying an individual's initial concepts and differences between these beliefs and new information is particularly important for diverse students. This point is elaborated on during the discussion of culturally relevant instruction later in this chapter.

Hatano and Inagaki (2003) state that conceptual change in schools does not occur spontaneously, but is the result of activities lead by a teacher and supported by peers. Conceptual change may occur in an individual, but it is enacted socio-culturally. There are three reasons that this is true. (1) Comprehension activities involve investigating an interpretation and monitoring its plausibility. Students might apply an existing conception without the realization that the existing conception is false. (2) Learners have a tendency to preserve prior knowledge through biased collection and analysis of new pieces of information. They often ignore or modify discrepant information. (3) Individuals may not

know how their beliefs should be revised or where to search for alternatives. The authors explain that learners are motivated to change their understanding when they realize that their comprehension is inadequate. This state is called cognitive incongruity. There are three states that lead to cognitive incongruity. Surprise occurs when learners encounter an event or information that contradicts their prior knowledge. They are motivated to understand what is wrong and repair knowledge. Perplexity occurs when a learner is confronted with two or more plausible but competing ideas. Learners are motivated to undergo plausibility comparison to understand how to pick and justify one of the ideas. Learners feel cognitive incongruity when they face discoordination, or a situation where multiple pieces of information cannot be connected to or by their previous knowledge. The process of conceptual coordination occurs when learners make the target concept more convincing by connecting it to other pieces of knowledge.

The research summarized in this section indicates that students need to identify and commit to their initial conceptions. Next, they need to become perturbed or dissatisfied with this conception. Finally, the dissatisfaction must be resolved. As it is resolved, students should be able to explain their initial conceptions by using their new conception. This dissatisfaction can be caused by conflicts between alternative views, conflicts between views and everyday phenomena, conflicts between "everyday" language and scientist language, and conflicts between ontology classifications. The dissatisfaction can manifest itself as surprise, perplexity, or discoordination. However, it is not enough to present students with a discrepant event or data that is not consistent with their initial conceptions. It is essential that students are aware that they have reached

a state of cognitive incongruity, a state where they realize that their initial conception is flawed and inadequate. Conflicts between students' initial conceptions and classroom events may set the stage for cognitive incongruity to take place, but other instructional characteristics are needed in order to focus students' awareness.

Metacognition. Georghiades (2000) emphasizes that it is important that students are able to transfer skills and concepts to contexts that are different from how they were learned. Georghiades also identifies the problem of conceptual decay. The intent of conceptual change is to move students from an initial conception toward a more scientific conception. However, if the new conception is not durable, the student will revert to the initial conception. He contends that student self-reflection using their own words will lead to deeper understanding, and therefore the new conceptions will be more durable and students will be better able to transfer to them to different settings.

The study looked at 68 fifth grade students in a quasi-experimental design. The control and experimental groups received identical instruction except for the infusion of two to three minute "metacognitive instances" at selected points in the instruction for the experimental group. These metacognitive instances included brief discussion, comments, thinking, writing and drawing tasks, and pair activities. The brief time spent on these activities helped to hold student interest and participation. Table 2 provides examples of the types of activities that students were asked to complete. Students involved with metacognition activities were more engaged in discussions and remembered more of the taught material when compared to the control group. Additionally, interviews and testing were conducted one week, two months, and eight months after instruction. In each case,

the experimental group outperformed the control group. The researchers also noted that metacognitive instances conducted in small groups were more effective than those conducted in large groups. Students seemed more comfortable to reveal their thoughts to smaller groups, had more effective discussions, and allowed for more personalized feedback. In a later section of this literature review, similar findings related to small group sizes will be discussed for Hispanic students.

Table 2. Metacognitive Instances (Georghiades, 2000, pg 131).

Activity Type	Example
Questions / Discussions	Before having this lesson, what was your belief regarding (X…)? Have you changed your views? If so, why? Explain to your friend the way you solved that problem. Can you name two reasons why we are learning these things? How can they be useful in everyday life?
Keeping a Diary	Write down three things you learned in today's lesson and any points that might not be very clear. (This was also done in the form of an anonymous Question Box.)
Annotated Drawing	Draw any tool you want that can safely be used by an electrician, indicating the material(s) from which it is made.
Concept Mapping	Create a concept map as either a whole-class or individual activity.

Hennessey (2003) describes two studies she conducted to investigate metacognition and conceptual change. In the first study, 20 sixth grade students were asked to write about the status of alternative ideas by reflecting on the ideas intelligibility, plausibility, and fruitfulness during a unit on forces and motion. In the second study, Hennessey examined the change in students' (ages 6-12) metacognitive

ability over a three-year period. Additionally, she examined the relationship between students' metacognitive ability and conceptual change learning.

Hennessey describes her pedagogical strategy as beginning by giving students a set of phenomena to explore. The students record questions they found problematic, attempt to articulate and refine the questions they want to explore, and plan how to pursue their investigations. Students are expected to track how their conceptions and process changes during their exploration. Students are encouraged to make their ideas public through poster production, concept maps, modeling, drawing, writing, and small and large group discussions. Analysis of field notes, observations, student work samples, and interviews provided evidence that elementary students were able to develop metacognitive skills. Additionally, Hennessey concludes that metacognitive engagement and intentional conceptual change are highly interconnected.

These studies show that metacognition is vital for durable conceptual change. Students need to "think about their thoughts." They need to be asked to express and support their ideas. Integrating metacognition into the classroom does not have to be a burden. Short instances of metacognition and proper phrasing of student questioning can have a dramatic impact on conceptual change.

Interest. The two research studies described in this section specifically show the connection between student interest and conceptual change. Although these studies involve college students, they illustrate the relationship between interest, experience and conceptual change. A series of studies discussed later in this chapter conclude that student interest helps Hispanic students better learn science. Andre and Windschitl (2003)

conducted a study to determine the effect of student interest on conceptual change. Specifically, they believe that interest affects conceptual change because it results in a deeper processing of information. The researchers were investigating the implementation of a conceptual change unit on electricity in an introductory college physics course. The participants were given a pre- test that included a series of questions that gauged their interest and experience with electricity and electronic gadgets. Participants were also given a post-test to determine their change in understanding of electric circuits. Researchers found that males displayed more interest $[F(1,279) = 102.18, p <0.0001]$ and experience $[F(1,279) = 168.13, p<0.0001]$ than females. There was also a correlation between interest and experience $[r=0.65, p<0.0001]$. Interest and experience showed a significant relationship with post-test performance that was independent of gender.

Andre and Windschitl (2003) also conducted a study to see how interest is related to conceptual change. They hypothesized that students with higher interest should be more motivated to engage in conceptual change that occurs after the influence of an experience. They found that interest exerts an effect on post-test performance that is independent of the effect of experience. The researchers conclude that interest influences the learner's intention to engage in the cognitive processing necessary for conceptual change. However, they note that they only studied the effect of personal interest and not situated interest, which is interest generated by environmental conditions. Personal interest is defined as interest displayed by the student outside of the classroom, while situated interest is defined as interest that is created by the use of a "hook" during instruction. They state that future research should determine whether instructional

interventions designed to increase situational interest would produce similar effects on conceptual change. Andre and Windschitl conclude that instruction should be based on essential questions that are related to the real world. They explain that these types of questions generate interest because they are relevant to students' lives and involve authentic concerns. They also state that teachers should provide regular opportunities for sense-making during class as opposed to unproblematically absorbing information. Students should have extended opportunities to work with phenomena and should have access to multiple representations of the phenomena. Students should be allowed to express their understanding using a variety of modes and should engage in dialogue with the teacher and peers.

Classroom Environment. Newton, Driver, and Osborne (1999) investigated what opportunities were provided for discussion and social construction of knowledge in 34 secondary science lessons in England. They found that the highest percentage of student time was spent passively listening. The researchers contend that the social constructivist model recommends opportunities for reflective interaction between students to support the co-construction of knowledge. However, the lesson observations showed that opportunities for discussion that lasted for more than 10 minutes were only offered in two of the 34 cases. The dominant form of interaction in the classroom was teacher talk. When opportunities were provided for student talk, through teacher questioning, they invariably lead to students "guessing what is in the teacher's mind," instead of assisting the development of understanding through student contribution of emerging understandings. The researchers conclude that lessons should be organized so that

students participate actively in thinking through issues and developing their own arguments. Students need to be given a greater voice in lessons.

Pintrich and Sinatra (2003) state that a classroom environment that focuses on promoting mastery goals and dialogue for understanding is critical for conceptual change to occur. Linnenbrink and Pintrich (2003) investigated the relationship between the achievement goals held by students and the amount of conceptual change that they underwent. The authors found that students hold one of two goals related to school achievement. Students that hold mastery goals focus on learning and understanding content. Students with performance goals focus on demonstrating their ability in comparison to other students. The researchers conclude that students who reported a focus on understanding as their primary goal orientation showed the greatest gains in conceptual understanding.

The students were actively engaged in activities and had an improved understanding of the concepts after the lessons. Students at the University of Michigan who endorsed mastery goal orientations showed a greater gain in their understanding of Newtonian physics than those students who did not endorse mastery goals. Students who espouse performance goals and do not endorse mastery goals show little or no improvement in conceptual understanding. In fact, performance goals without mastery goals have at best no effect on conceptual change, or may even hinder conceptual change. Mastery goals are promoted in contexts where the teachers emphasize learning and create situations where students can make choices and feel autonomous. Recognizing students for improvement can also help promote the adoption of mastery goals. Performance goals

are promoted in contexts where teachers use normative grading and recognize students for their performance relative to others. Since Linnenbrink and Pintrich's (2003) study focused on students attending a highly selective school, it is possible that these results will not be generalizeable to the population of students in my study. However, the instructional strategies described for promoting mastery goals will also be shown to be effective with Hispanic students later in this chapter. Therefore, it is likely that an emphasis on learning over grades, student decision making, and increased student control may lead to mastery goals and increased learning.

Hatano and Inagaki (2003) conducted a study involving 87 students in fourth grade. The control group consisted of two classes totaling 43 students, and the experimental group consisted of 44 students in two classes. The intervention consisted of an instructional strategy called Hypothesis-Experiment-Instruction (HEI). HEI consists of six steps. (1) Students are introduced to a problem having multiple alternative answers. The alternatives are testable predictions. (2) Students choose one answer by themselves. (3) Student responses are counted by a show of hand and tabulated. (4) Students explain and discuss choices with one another. (5) Students choose an alternative once again. They may change their initial choice. (6) Students test their predictions by observing an experiment or reading a passage. The teacher acts as a moderator who stays neutral during the discussion. Therefore, the teacher has control over the kinds of activity in which the students engage, but she is not viewed as the source of knowledge. The experimental group completed all six steps, while the control group only completed steps 1, 2, and 6. The control group did not conduct a whole group discussion of the

alternatives. The students were presented with a question about the weight of water before and after sugar was dissolved. In step 6, they completed the activity. After instruction, the students in both groups were able to correctly answer the initial question. However, none of the control students could generate an adequate explanation for their answer, while a majority of the students in the experimental group could. Additionally, the experimental group showed a much greater ability to apply the principle of conservation of weight (mass) to other situations beyond the one used in the HEI activity. The researchers conclude that dialogical interaction and a cognitive scaffold given by teachers are indispensable social context for the elaboration and revision of students' conceptual knowledge.

Mason and Santi (1998) investigated the changes of conceptions about the Greenhouse Effect and global warming due to the socio-cognitive interaction developed in small and large group discussions among fifth grade students. The researchers specifically looked at the effect of collaborative discourse reasoning and the relationship between metaconceptual awareness of changes and conceptual development. The students participated by having focused small group discussions on specific aspects of the Greenhouse Effect and global warming. Students then conducted large group discussions on the outcomes from the smaller groups and converged on themes and issues. The teacher actively facilitated discussion by posing initial questions and explicitly drawing out evidence and justifications. Mason and Santi found that there was a positive correlation between conceptual understanding and metacognitive awareness of the change ($r = 0.846$, $P<0.001$). Qualitative evidence found in interviews also showed that

the socio-cognitive interactions advanced student learning on the individual plane. The researcher concludes that communication can be used as a cognitive tool for structuring and restructuring knowledge:

> Discourse is not a mere vehicle to transmit disciplinary information, used by the teacher in order to give answers to never raised questions, but rather as a way to express personal ideas, sharing with other thinkers the understanding of examined phenomena by confronting different conceptions and reflecting on them. It can be stated that a classroom discussion, as a learning environment which encourages questioning, criticizing, evaluating and produces dissatisfaction with the existing state of knowledge, can act as a fruitful breeding ground for conceptual change.

Eryilmaz (2002) investigated the impact of discourse and conceptual homework questions on 396 high school physics students in 18 classes. Students were given two tests to measure misconceptions related to force and motion and achievement in typical force and motion problems. The tests were given before and after instruction. The students were divided into four groups that received identical instruction except for the type of discussion and homework questions. Group one received conceptual change discussion and conceptual homework questions; group two received conceptual change discussion and quantitative homework questions. Group three did not participate in conceptual change discussions and received conceptual homework questions, and group four did not participate in conceptual change discussions and received quantitative homework questions. The conceptual questions had students explain everyday phenomena using physics concepts, and the quantitative questions were considered traditional "textbook" application questions. The guidelines for the conceptual change discussions are located in Table 3

Group one (conceptual questions and conceptual change discussion) students had the greatest decrease in misconceptions. Group three students (conceptual questions, but no conceptual change discussion) had the smallest change in misconceptions. The conceptual assignments allowed students to observe and think about daily life phenomena. Without the proper discussion, these assignments tended to reinforce students' misconceptions derived from years of personal experience. The researchers conclude that a discussion that elicits student understandings and allows them to argue multiple perspectives leads to a greater likelihood of conceptual change occurring.

Table 3. Conceptual Change Discussion Guidelines (Eryilmaz, 2002, p. 1007).

1. Use the conceptual question as an exposing event that helps students expose their conceptions about a specific concept or rule.
2. Allow all students to make their own conceptions or hypotheses explicit (verbally and pictorially).
3. Ask what students believe or think about the phenomena and why they think so.
4. Write or draw students' ideas on the blackboard even if they are not correct.
5. Be neutral during the discussion. If one or some students give the correct answer, take it as another suggestion and play the devil's advocate.
6. Be patient. Give enough time to the students to think and respond to the questions.
7. Ask only descriptive questions in this part to understand what students really think about the phenomena.
8. Try to get more students involved in the discussion by asking questions of each student.
9. Assist students in stating their ideas clearly and concisely, thereby making them aware of the elements in their own preconceptions.
10. Encourage confrontation in which students debate the pros and cons of their different preconceptions and increase their awareness and understanding of the differences between their own preconceptions and those of their classmates.
11. Encourage interaction among students.
12. Create a discrepant event, one that creates conflict between exposed preconceptions and some observed phenomenon that students cannot explain.
13. Let students become aware of this conflict: cognitive dissonance, conceptual conflict, or disequilibrium.

Table 3. Continued.

14. Help students to accommodate the new ideas presented to them. The teacher does not bring students the message, but she makes them aware of their situation through dialogue.
15. Make a brief summary from beginning to the end of the discussion.
16. Show explicitly where oversimplification, exemplification, association, and multiple representations have happened, if any. If not, give exemplification, associations with other topics, and multiple representations for the topic.
17. Give students a feeling of progress and growth in mental power, and help them develop confidence in themselves and their abilities.

Vosniadou, Ioannides, Dimitrakopoulou, and Papademetriou (2001) claim that learning is not an activity that occurs only in the head, but is also an activity that happens in a social and cultural context. The researchers contend that it is important to create a learning environment that provides for deep exploration of fewer concepts, takes into consideration student's prior knowledge, provides meaningful experiences, facilitates metaconceptual awareness and allows students to express and commit to initial conceptions, addresses students' entrenched presuppositions, provides motivation for conceptual change, creates cognitive conflict, and provides the opportunity to interact with models and external representations.

Vosniadou et. al.'s study involved two fifth grade courses learning about mechanics. One of the courses followed a discourse strategy of asking simple, relatively unrelated questions that did not require elaborate explanations. The other class used a variety of strategies to activate prior knowledge and elicit extended responses from students. Analysis of the discourse in the two courses showed that the experimental teacher spent much more time asking questions related to subject matter while the control teacher spent more time on managing the interaction. The experimental teacher was more

likely to ask students to explain while the control teacher was more likely to provide explanations. The control teacher asked more specification and description questions while the experimental group teacher elaborated on student answers by asking students to validate and clarify explanations. The experimental group students used many more "utterances" to *explain* phenomena compared to control group students who spent more of their time *describing* phenomena. A pre- and post-test comparison shows a positive, statistically significant difference between the experimental and control group.

Driver, Newton, and Osborne (1998) explain that the type of discourse usually seen in science classrooms has given the false impression of science as the "unproblematic collection of facts about the world." It also fails to empower students with the ability to critically examine scientific claims and knowledge. Driver and her associates contend that dialogical or multivoiced argumentation should be an integral part of the discourse in a science classroom. During multivoiced argumentation, different perspectives are examined, and different individuals take differing positions over the claims advanced. The change in the way people think happens as others' perspectives restructure, alter or fine-tune a student's personal knowledge. Student learning and conceptual change is dependent upon the opportunity to socially construct and reconstruct one's personal knowledge through a process of argument. The teacher should orchestrate a discussion to identify different lines of thought and invite students to evaluate these and move toward an agreed outcome.

The research in this section describes how social aspects of a learning environment can increase the likelihood that conceptual change will occur on the

individual level. During dialogic interactions, students should discuss, explain, and attempt to justify alternative concepts. Discussion should elicit student understandings and allow them to argue multiple perspectives. Discussions should take place in pairs, small groups, and large groups, with teachers facilitating by posing open-ended questions and explicitly drawing out evidence and justification instead of questioning for recall. Dialogue should focus on creation of knowledge instead of transmission of knowledge. Improvement and the construction of knowledge should be celebrated instead of comparison between peers.

<u>Summary</u>

For science inquiry to be successful, we must keep in mind that students enter the classroom with knowledge about how the world around them works. Effective science instruction can change students' initial concepts to concepts that are more reflective of scientific understanding. Much of the research into how students' science conceptions change show that students must be cognitively engaged in the learning process, become dissatisfied with their initial conceptions, be able to understand the new conception, and be able to see how the new conception solves their initial dissatisfaction (e.g. Posner et. al., 1982; Strike & Posner, 1992; Pintrich, Marx, & Boyle, 1993; Wiser and Amin, 2001; Chin & Brewer, 1993; Mason, 2001; Limon, 2001; Hatano & Inagaki, 2003).

The literature in this section identified interest, instructional conversations, and metacognition as three characteristics of instruction that improve student learning during conceptual change approaches to teaching. Student interest improves student learning because it results in a deeper processing of information. Interest can be fostered by

providing students with the opportunity to work with phenomena for extended periods of time, investigating multiple representation of the phenomena, investigating questions of their own design, engaging in dialogue with the teacher and peers, and expressing their understanding using a variety of modes (Andre & Windschitl, 2003).

Instructional conversations are those that allow students to engage in extended dialogue around concepts and identify them. Instructional conversations allow students to identify, compare, and refine different lines of thought. Instructional conversations are student-directed and give students a greater voice in lessons. Instructional conversations provide students with opportunities for extended dialogue in areas that have educational value as well as relevance for them. During instructional conversations, students present claims to their peers and provide evidence to support these claims. During instructional conversations, students converge on themes and build consensus on explanations for phenomena. The change in the way people think happens as others' perspectives restructure, alter, or fine-tune a student's personal knowledge (e.g. Mason & Santi, 1998; Hatano & Inagaki, 2003; Eryilmaz, 2002; Vosniadou et. al., 2001; Driver, Newton, & Osborne, 1998). Instructional conversations foster an environment that promotes learning for understanding over learning for obtaining a good grade (Pintrich & Sinatra, 2003; Linnenbrink & Pintrich 2003).

If students are able to use metacognitive skills, they are more likely to become cognitively engaged in the learning process. Metacognition involves students understanding not just what they are learning, but how and why they are learning. Students ask questions such as, "Why is this important?", "Why did I choose to

accomplish this task in this manner?", and "How is this different from what I understood before this task?" Including Metacognition activities during instruction improves student learning, even if it only involves brief instances of metacognition (Hennessey, 2003; Georghiades, 2000).

Models of Instruction

Figure 4. An Overview of the Models of Instruction Section.
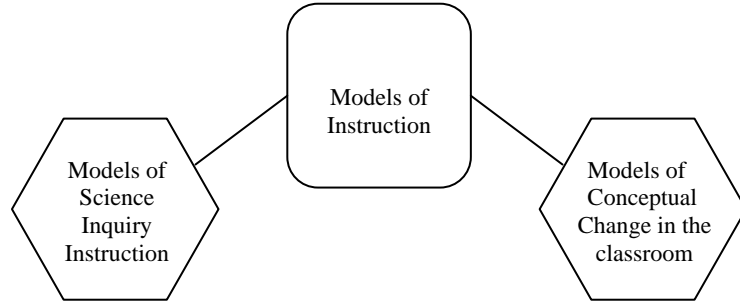
This section discusses models of instruction used in science inquiry and conceptual change as presented in the literature. Many of these models provide suggest "best practices" for incorporating science inquiry and conceptual change teaching into the classroom. These best practices provide a framework for the Inquiry for Conceptual Change model that is described in Chapter Three. Figure 4 provides a graphical organizer for this section.

Models of Science Inquiry Instruction

Five science inquiry implementation models were chosen to illustrate the key characteristics and variations of science inquiry. As described earlier, science inquiry

instruction should involve students answering scientifically oriented questions by collecting evidence. Students should also be expected to share these results. Variations in science inquiry are based on how much control teachers exert over the asking of the central question, methods of finding a solution (solution pathway), and communication of results. Table 4 illustrates how these five models incorporate variations of the key characteristics (question, solution pathway, use of evidence, scientific orientation, and communication) of science inquiry. These five models were chosen because they provide examples of the range of variation in each of these characteristics.

Table 4. Key Characteristics Found in Five Science Inquiry Implementation Models.

	Circle of Inquiry	Physics by Inquiry	Explanation-Driven Inquiry	SSCS – Earth Science	Problem Solving Environmental Science
Question	The model provides flexibility in how open or closed the question generating process is.	Instructor provides students with carefully sequenced activities and questions.	Students provide a context and initial inquiry questions. Students develop sub-questions.	Students generate researchable questions using teacher-selected articles for inspiration.	Teachers provide a driving question and context for the students. Student groups determine sub-questions for inquiry.
Solution Pathway	Students develop investigations and collect data.	Instructor provides students with procedures for completing tasks and making observations.	Students use computer-generated scenarios to collect and data.	Students individually generate and conduct a plan to determine solutions to specific questions.	Students generate procedures for collecting evidence and answering sub-questions.

Table 4. Continued.

	Circle of Inquiry	Physics by Inquiry	Explanation-Driven Inquiry	SSCS – Earth Science	Problem Solving Environmental Science
Evidence Based	Students use data to formulate and evaluate solutions.	Students make predictions and answer questions based on observations made during tasks.	A computer-based structure is used to make sure students support their solutions with evidence.	Students determine what evidence is available or can be collected and apply it to solve the question.	Students collect evidence and used it to craft products, including presentations of findings.
Communi-cation	The model does not specifically call for student presentations or artifact creation for the means of communicating solutions and processes.	Students work in groups to build a conceptual model of the target phenomena. Students communicate explanations within their group and to the instructor.	Students work in small groups on inquiry activities. Peer critiques are used to evaluate students' use of evidence in their explanations.	Students work in small groups to build consensus on solutions. Students share solutions with a larger group.	Students create products and present research questions, methodologies, and findings to the class.

The Circle of Inquiry (Haury, 1995) is a simple model that can be easily understood and facilitates an understanding of the nature of scientific inquiry. The model includes four stages that are presented in a circle to show that inquiry is not a linear process, and the stages can feed backward and forward to other stages. In the "Wondering" stage, students formulate questions, challenge ideas, and plan investigations. In the "Collecting Data" stage, students conduct investigations to find evidence to answer questions. In the "Studying Data" stage, students analyze data to formulate and evaluate solutions. In the "Making Connections" stage, students connect solutions to other scientific content and verify their mental models. Pilot testing of the

model by 55 elementary teachers was conducted. These teachers participated in a series of five workshops on inquiry strategies and were introduced to the model. The results of the pilot test showed that the model was positively received and was used in planning and implementing science lessons. Participating teachers stated that the model helped students ask more and better questions, conduct investigations, use evidence, and develop their own ideas about the content. Since this is a "generic" inquiry model, it provides teachers with an incredible amount of flexibility to use open or closed questions of a variety of types and use teacher-provided or student-generated procedures. Additionally, since this model is intended to be used as a planning tool, it is expected that the teacher will build connections to the science content. Finally, student communication and sharing is not prescribed in this model, but may be a strong addition.

Physics by Inquiry (e.g. McDermott, 1996) is a curriculum product that includes tutorials covering many introductory physics concepts. The curriculum is appropriate for high school and introductory college students. Physics by Inquiry consists of carefully sequenced activities and questions that guide students in the development of conceptual models of physics phenomena. The sequence is based on research into difficulties students have in learning these concepts. The authors describe Physics by Inquiry as a guided inquiry approach (McDermott, Shaffer, & Constantinou, 2000), but the structure, presentation of questions, tasks, and investigations fit more into a structured inquiry category. Although it is highly structured, it still fits the definition of inquiry because students are expected to support their explanations with evidence. The questions provided in the curriculum usually fit in the cause and effect or mental model verification

taxonomies. Students do not formally share their findings but are expected to explain their thinking to group members and instructors. Pre-service and in-service teachers using this inquiry approach in coursework and professional development have experienced greater gains than students in a more traditional instructional approach (McDermott, Shaffer, & Constantinou, 2000). Additionally, introductory physics students using Physics by Inquiry showed significantly greater gains than students in more traditional instructional experiences (Woslilait, Heron, Shaffer, & McDermott, 1998).

The researchers involved in Explanation-Driven Inquiry are predominantly concerned that science is typically taught in a manner where theoretical ideas are presented as facts, stripped of the history of their development (Sandoval & Reiser, 2004). They approach inquiry as a cognitive apprenticeship into scientific practice where students are engaged in reasoning and discursive practices similar to those of professional scientists. This model emphasizes two criteria: the articulation of coherent causal accounts and the use of data to support causal claims. Students use computer-based tutorials to investigate phenomena related to natural selection and build causal claims for problems by using data sets provided in the computer-based environment. Students are able to develop sub-questions and can determine how to best use available data to support solutions. Students also communicate their findings in small groups and whole-class discussions. Case studies conducted in two suburban high schools were used to show that the model does support an increase in the use of data to support causal claims. The effectiveness of this model for student learning was not formally studied. However, the

importance of this study is the finding that students will increase their use of data to support claims if routinely asked to do so.

Chang and Barufaldi (1999) studied the use of the Search, Solve, Create, Share (SSCS) problem-solving model with ninth grade Earth Science students who were not experienced with inquiry instruction. The SSCS model includes 4 stages for conducting inquiry (Pizzini, Shepardson, & Abell, 1989). In the Search stage, students brainstorm researchable questions or problems in science. The instructor can provide demonstrations, magazines, textbooks, or other resources as inspiration and constraints for the brainstorming. In the Solve phase, students focus on specific problems while developing and conducting investigations to form solutions. In the Create stage, students create products to illustrate their solutions. In the Share stage, students share their products with other students and the instructor and receive feedback. This feedback can lead back to earlier stages in the model. In Chang and Barufaldi's study, 86 students participated in Earth Science classes taught using the SSCS model. These students were provided with the context for the problem but were expected to brainstorm their own questions and develop and conduct their own investigations. Students then worked in small groups to come to consensus on solutions and communicate their findings. Two classes of 86 students participated in traditional classes as a control. Student achievement was the dependent variable. Topics covered during the SSCS units included plate tectonics and related Earth science phenomena. The researchers found that the experimental group had significantly higher gains than the control group.

Krajcik et. al. (1998) describe a problem-based learning model as a way to promote inquiry in the classroom. Their model consists of a driving question that encompasses worthwhile and meaningful real-world content; investigations and artifact creation that allow students to learn concepts, apply information, and represent knowledge; collaborations among students, teachers, and others in the community; and the use of technological tools. The researchers investigated an introductory unit and two project units. The introductory unit transitions students to project-based instruction through the use of structured inquiry. During the two project units, students explored decomposition and water use. Students were provided with initial questions but were responsible for developing sub-questions and conducting investigations to answer those questions. The teachers also interspersed "benchmark" activities to explicitly connect science concepts to the driving questions. Students were expected to share their research questions, methodologies, and findings through two presentations. The study was conducted in an urban seventh grade classroom. Four boys and four girls were selected for intense observations: two were African American, one was Asian American, and five were Caucasian. The researchers concluded that the students were able to participate in sophisticated inquiry. Additionally, students were enthusiastic and engaged in the projects. However, the researchers noted that students seemed to focus on procedural aspects and needed intervention from the teacher in order to focus on substantive principles, concepts, and connections in their projects.

Models of Conceptual Change in the Classroom

Earlier in this chapter, research related to students' initial conceptions, degrees of conceptual change, and conditions necessary for conceptual change were discussed. This section of the chapter provides examples of instructional models that can be used to generate conceptual change. Posner et. al. (1982) state that in order for students to undergo conceptual change, they must become dissatisfied with their current conception, and the new conception must be intelligible, plausible, and fruitful. Strike and Posner (1992) also identify a few recommendations for instruction. First, science conceptions are usually socially constructed. If instruction provided by a teacher does not agree with a learner's conceptual ecology, they are likely to be ignored. Educators should pay less attention to generating "correct" answers and more attention to building connections between science concepts, experimental evidence, and learners' initial conceptions. Strike and Posner state, "If conceptual change theory suggests anything about instruction, it is that the handles to effective instruction are to be found in persistent attention to the argument and in less attention to the right answers" (p. 171).

Osborne, Freyberg, and their colleagues (1985) proposed a "generative learning" model and teaching strategies that could be used to address and modify students' initial conceptions of science. This model is based on a number of understandings. (1) Teachers must have a clear understanding of the initial conceptions that their students bring to the classroom. (2) Teachers must have a clear understanding of the science concept that is the subject of the instruction. This must also include a clear purpose of what the teacher expects students to understand after instruction. (3) Students need to experience the

concept in "everyday" situations and undergo self-clarification of their views of the concept. The self-clarification of views should be debated between students to identify pros and cons of the variety of views held by students. (4) Students should participate in activities that modify their expressed views toward the scientifically appropriate view. (5) Students should participate in activities and discussions to elaborate, consolidate, and apply their new, more scientific view of the concept. The four phases of the generative model are summarized in table 5.

Table 5.   Phases of the Generative Learning Model (modified from Osborne and Freyberg, 1985, p. 109).

Phase	Teacher Activity	Student Activity
Preliminary	Determines and classifies students' views; identifies scientific views and evidence.	Completes surveys or other activities that identify initial conceptions.
Focus	Establishes a context and provides motivating experiences; facilitates discussion with open-ended questions; interprets and elucidates students' expressed views.	Becomes familiar with, describes, and clarifies what s/he knows about the concept. Presents own view to small or large group.
Challenge	Facilitates exchange of views, keeps discussion moving, suggests activities, and provides evidence to move students toward a scientific suggestion; accepts the tentative nature of students' reactions to new view.	Considers the views of other students; tests the validity of views by seeking evidence; compares scientist view with class's view.
Application	Develops activities and problems that can be simply and elegantly solved using the new scientific view. Assists pupils to clarify the new view and use it to describe all situations. Ensures students are able to verbally describe solutions, stimulate, contribute, and participate in discussion on solutions. Helps solve advanced problems and suggest where additional help can be sought.	Solves practical problems using the new scientific view. Presents, discusses, and evaluates solutions. Suggests further problems arising from the solutions presented.

She (2002) proposes the use of the Dual Situated Learning Model (DSLM) to promote conceptual change. She defines "dual situated" as opportunities for students to create dissonance with their initial ideas and become exposed to a new concept. DSLM consists of six phases. In the first phase, the instructor examines the attributes of the concept of study in order to determine what aspects or facets are crucial for student understanding. In the second phase, the instructor determines the students' initial conceptions of the target concept. The third phase includes an analysis of the facets of the target concept that the students do not understand. In the fourth phase, the instructor designs dual-situated learning events that create dissonance with the initial concept and provide students with the ability to construct a more scientific concept. These events are then used in instructing students in the fifth phase. In the sixth phase, a challenge learning event is presented to the students to give them an opportunity to apply their new conception. This challenge event also allows the instructor to assess student understanding. Twenty Taiwanese ninth grade students were randomly selected to participate in clinical, one-on-one interviews that used DSLM for instruction in air pressure and buoyancy. Most of these students had initial conceptions that were not consistent with scientific views. During the interviews, evidence was exhibited that showed dual-situated events change student conceptions toward a more scientific view. After instruction using DSLM, 90% of the participating students successfully applied the expected scientific concepts to the challenge event.

The success of the DSLM clinical interview study led to a contextual study of the use of DSLM in a classroom setting (She, 2003). A teacher of 32 ninth grade students in

Taiwan worked with She to use DSLM for the instruction of Thermal Expansion. Students participated independently in a series of classroom activities based on this approach. During the activities, students were not allowed to interact with the teacher or other students. Before instruction, 97% of the students had misconceptions related to thermal expansion. After instruction, 60% of the students exhibited a conceptual change by successfully applying the scientific explanation to the challenge event.

Tsai (2000) describes the use of conflict maps as a tool to guide conceptual change instruction. Tsai notes that the act of identifying a discrepant event is not always followed by a change in students' initial conceptions. Instead, the students attempt to reconcile the discrepant event using their initial conceptions. This sets up two distinct conflicts that must be resolved. The first conflict is the generation of dissonance with the students' initial conceptions; the second conflict is the resolution of that dissonance by accepting a new theory. In order for the second conflict to be resolved, four conditions must be solved. First, students must have a minimal understanding of the scientific concept that will be studied. Second, the learning process should involve a critical event to directly address the target scientific concept. Third, there must be other scientific concepts that support the target concept. Fourth, there must be other perceptions or thought experiments that can sustain the scientific concept. Based on these criteria, Tsai proposes the creation of a conflict map that contains the students' alternative conception, the discrepant event, the target scientific concept, the critical event (resolves conflict #2), supporting concepts, and other perception supports. A conflict map for electric circuits is located in Figure 5.

Figure 5. A Conflict Map for Electric Circuits (Tsai, 2003).
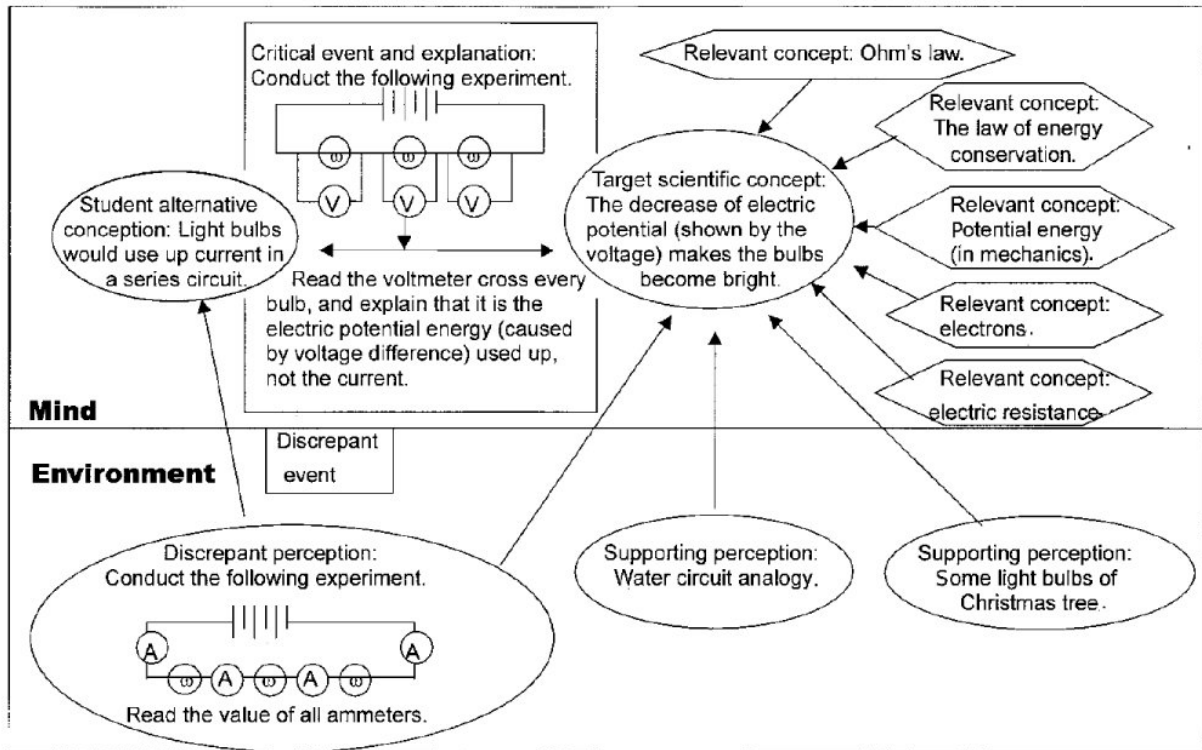
Conflict maps also highlight a suggested instructional sequence. Figure 6 illustrates this sequence. C_1' represents a student's initial conception. C_1 represents the target scientific conception. $C_2 - C_4$ represent concepts that support the scientific conception. P_1 is a perception or thought experiment that can produce dissonance with the student's initial conception. $P_2 - P_4$ represent additional perceptions that support the scientific conception. DE represents a discrepant event, and CE represents the critical event. The use of a conflict map as an instructional tool includes lessons with the following sequence: discrepant perception, target scientific concept identification, critical event and explanation, relevant concepts, and supporting perceptions. The discrepant

perception fulfills the requirement of dissatisfaction with existing conception (Posner et. al., 1982). The identification of the scientific concept fulfills the requirement that the new conception must be intelligible (Posner et. al., 1982). The critical event fulfills the initially plausible requirement ((Posner et. al., 1982). Instruction on relevant concepts and supporting perceptions strengthen the plausible requirement and develop the fruitful (open to new areas of inquiry) requirement (Posner et. al., 1982).

Figure 6: Conflict Map as an Instructional Tool (Tsai, 2000).
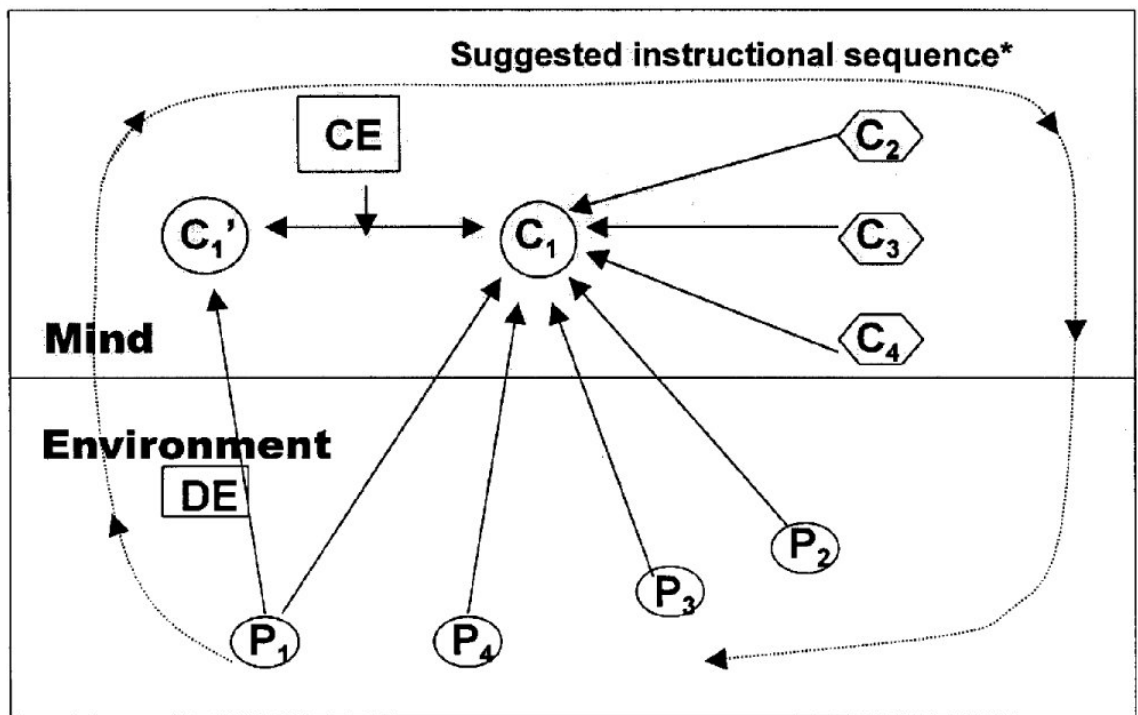
Tsai (2003) studied the effectiveness of using conflict maps as an instructional tool for teaching electric circuits to eighth grade students. The study included 97 students in the experimental group and 93 students in a control group. The experimental group

received instruction based on the conflict map in Figure 5. The control group received traditional instruction. Instruction for both groups lasted three days. Pre-test data shows that only 25% of students from each group were able to correctly determine that current is not 'used up' in an electric circuit. After instruction, 63.9% of the experimental group and 39.8% of the control group were able to explain that current remained constant in a simple circuit and voltage decreased over a resistance. The difference between the experimental and control groups was statistically significant (chi-square = 15.60, $p<0.05$).

The models described in this section focus on disturbing students' initial conceptions and helping them build and apply new conceptions. Based on a synthesis of the models reviewed, a full cycle of stages in conceptual change instruction could include (1) instructors determining the initial conceptions held by their students, (2) students identifying and committing to their initial conceptions, (3) an event that engenders conflict with the students' initial conceptions, (4) introduction or development of a more scientific conception of the phenomena, and (5) application of the new scientific conception. Table 6 summarizes the stages of conceptual change instruction for each of the models described. It is interesting to note that multiple studies described earlier in this chapter specifically concluded that students must recognize differences between their initial conceptions and new information in order for conceptual change to occur (Chin and Brewer, 1993; Mason, 2001; Limon, 2001; Hatano and Inagaki, 2003), however, only one of the four models described expects students to explicitly identify their initial conceptions.

Table 6: A Comparison of Selected Conceptual Change Models of Instruction.

	Prepare	Identify Conceptions	Disturb Initial Conception	New Conception	Apply New Conception
Posner et. al.			Dissatisfaction	Intelligible, plausible	Fruitful
Generative Learning Module	(Preliminary) Determine student views; determine target conception.	(Focus) Students recognize and commit to initial conception.	(Challenge) Consider and compare students' conceptions w/ scientific conception.	(Challenge) Consider and compare students' w/ scientist. (Apply) Use scientist to solve problems.	(Apply) Use scientific conception to solve multiple problems and suggest further problems.
DSLM	(1) Determine attributes of scientific concept (2) Determine students' concept (3) Compare scientific and students' concept to determine what needs to be changed (4) Design activities to create dissonance and introduce scientific concept		(5) Use dual-situated activity.	(5) Use dual-situated activity.	(6) Challenge activity allows for the application of new concept.
Conflict Maps	Build a conflict map that shows facets of initial conception and target conception.		Discrepant perception creates conflict w/ students' conceptions	Critical event to introduce and show plausibility of target concept.	Introduce supporting concepts and perceptions.

Summary

This review explored five different science inquiry implementation models. These models incorporated all the essential features of science inquiry but exhibited different levels of teacher control. Each of these models included the use scientifically based questions, multiple solution pathways, evidence-based explanations, and communication of results. The Circle of Inquiry (Haury, 1995) provides a simple model that incorporates many of the essential features of science inquiry and has shown promise as a tool to conceptualize and plan science inquiry instruction. Physics by Inquiry (McDermott, 1996) follows a highly structured format that forces students to confront their initial ideas and use evidence to modify these ideas. Explanation-Driven inquiry (Sandoval & Reiser, 2004) focuses on student reasoning, the development of questions, and use of evidence from provided data to develop solutions for their questions. The Search, Solve, Create, Share model (Chang & Barufaldi, 1999) involves providing students with the context of the problem. From this point, students develop their own investigatable questions, conduct investigations, draw conclusions, and share their findings with the entire class. In the problem-based learning model (Krajcik et. al., 1998), the teacher provides students with an overarching question. Students develop and investigate sub-questions that they find worthwhile and meaningful. From their investigations, students draw conclusions and share their results with the rest of the class. The authors of this model realized that students may not build a strong connection to some of the required curriculum standards. Additionally, they noted that students may struggle with portions of their investigation because they are missing pre-requisite scientific knowledge. To remedy these problems,

the problem-based learning model includes the use of "benchmark" activities. These structured or guided inquiry activities are interspersed throughout the unit to explicitly connect science concepts to the driving questions.

The conceptual change instructional modules generally focus on identifying students' initial conceptions, disturbing these conceptions, introducing new conceptions, and applying the new conceptions. Each of these models illustrate the importance of identifying student initial conceptions (Osborne & Freyberg, 1985; She, 2002; She 2003; Tsai, 2000; Tsai, 2003). The Generative Learning model (Osborne & Freyberg, 1985), Dual Situated Learning Model (She, 2002; She, 2003) and Conflict Mapping (Tsai, 2000; Tsai, 2003) also specifically address the importance of teacher preparation for instruction. The preparation phase in Dual Situation Learning Model (DSLM) includes identifying attributes of the scientific conception, identifying attributes of the students' conceptions, determining student learning needs, and identifying specific activities for creating dissonance and introducing scientific ideas (She, 2002). Conflict Maps (Tsai, 2000) provide a particularly useful organizer for the preparation described in DSLM.

Diverse Learners

Figure 7. A Graphical Organizer for the Diverse Learners Section.
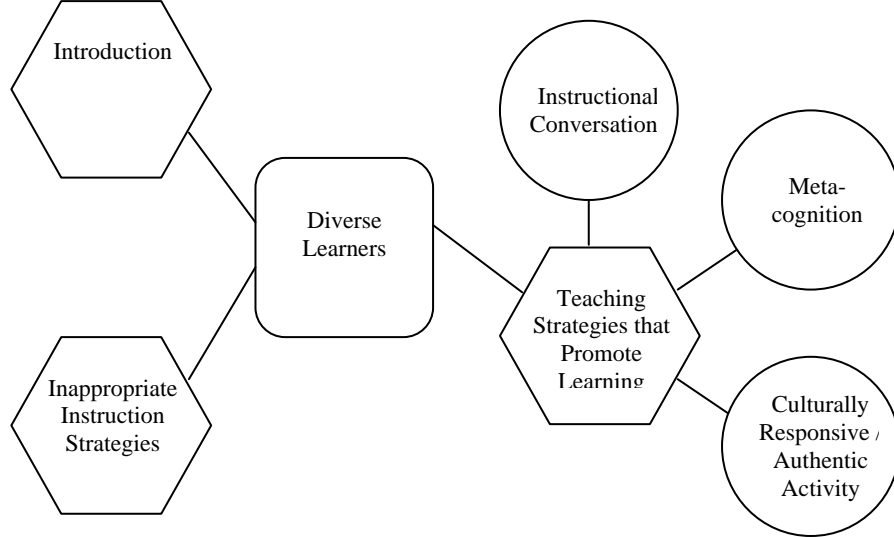
In a meta-analysis of research, Marzano (2003) concludes that the quality of instruction is one factor that contributes to the gap in White student achievement compared to the achievement of minority students. This study explores the development and implementation of a model of science inquiry for use with Hispanic students. Therefore, it is crucial to understand what the literature recommends for improving instructional quality for Hispanic students. This section of the literature review will begin by discussing the instructional strategies that are currently common in classrooms with large populations of diverse students. Then, instructional strategies that improve learning of diverse students, specifically Hispanic students, will be discussed. Figure 7 provides a graphical organizer for this section.

Inappropriate Instruction Strategies

Before describing instructional strategies that are particularly useful for improving the science learning of Hispanic students, it is important to identify what strategies are currently being used in science classrooms. Waxman, Huang, and Padron (1995) found that Hispanic students were commonly involved in whole-class instruction with little time for verbal interaction. Students rarely selected their own activities and were generally passive. Haberman (1991) describes this emphasis on seatwork, lecture, and drill and practice as a "pedagogy of poverty." Rodriguez (1998a) states that the use of pre-packaged, unconnected, simplistic activities is the norm in many classrooms. The TIMMS 1999 video study of eight grade science teaching (2006) found that U.S. science lessons provide activities with either weak or no explicit connections to science content more often than lessons in most high-achieving countries.

Chinn and Malhotra (2002) confirm Rodriguez's assertion that many of the activities currently used in science classrooms are simplistic and do not reflect the characteristics of science inquiry. Chinn and Malhotra present 11 characteristics of science inquiry that fit within the following four categories: student development of research questions, design of investigations, evaluation of data, and construction of theories. The researchers examined 468 activities that are contained in nine commonly used middle school textbooks. These activities failed to incorporate aspects of science inquiry, averaging less than 0.5 of the 11 features per activity. Amazingly, none of the textbook activities included student generation of research questions.

Observations of discourse in urban science classrooms (Norman, Ault, Bentz, & Meskimen, 2001) show a similar pattern, but with the addition of cultural conflict or tension. This cultural conflict is a result of the opposition of teacher cultural behavior norms and student cultural behavior norms. During an interview, a participating teacher said, "I see lots of social interaction and kids wanting to be recognized and accepted by their peers, and that requires a lot of talking to the point that that becomes a priority rather than the lessons that we do in class" (p. 1106). However, the researchers found that the students saw themselves as wanting to learn and being frustrated at the lack of opportunities to participate in what they considered interesting activities. Norman and his associates found that the dominant discussion pattern in the classrooms that they observed was teacher monologue and triadic dialogue, where the teacher asks a simple question, a student supplies an answer, and the teacher evaluates that answer. The researchers observed a "pedagogy of poverty," where a premium is placed on recall and not on construction of knowledge. Student talk, especially animated talk, is seen as disruptive and discouraged through the use of a variety of punishment techniques. The researchers conclude that this animated student talk should be harnessed to construct knowledge and optimize learning instead of minimized to preserve a traditional, orderly classroom.

The common practices described in this section are the exact opposite of the practices that the research in the next section shows are best for teaching students from diverse backgrounds.

Teaching Strategies that Promote Learning by Students of Diverse Backgrounds

Rodriguez (Rodriguez, 1998b; Rodriguez & Berryman, 2002) describes a theory of learning called Sociotransformative Constructivism (STC) that includes principles that should guide instruction for Hispanic students. These principles include dialogic conversation, metacognition, authentic activity, and reflexivity. The research base for these principles will be discussed later. Rodriguez and Berryman (2002) describe a research project with two high school teachers and 38 students in the rural Southwest. Most (95%) of the students were Latino/a, were in the free and reduced lunch program, and spoke English as a second language. The research project examined how a STC-based, 10 day curriculum intervention titled "Water in my Community" affected student learning of science content and interest in science. Data was collected through field notes, interviews, and semi-structured concept maps. Pre- and post-instruction concept maps showed statistically significant increases in student knowledge. Additionally, interviews showed that students could see themselves in science-related careers but had poor awareness of career and academic requirements. Interview data also demonstrated an increased sense of empowerment to act on water- and health-related issues in their communities and led to implementing various water conservation strategies at home.

In a comprehensive review of literature, Padron, Waxman, and Rivera (2002) suggest five teaching practices that benefit Hispanic students. These practices include instructional conversations, metacognition, culturally-responsive teaching, and authentic activity.

Instructional Conversations. Rodriguez (Rodriguez & Berryman, 2002; Rodriguez 1998b) describes the "Dialogic Conversation" component of STC as involving a deep understanding of how each individual engages in a conversation to construct context-relevant meaning. Dialogic conversation moves beyond just understanding what is said, to understanding why the speaker chooses to say what is said. Trust is integral to this type of conversation because people in different hierarchal and sociocultural positions need to come together. Padron, Waxman, and Rivera (2002) cite August and Hakuta (1998) as stating that "instructional conversations provide students with opportunities for extended dialogue in areas that have educational value as well as relevance for them."

Padron, Waxman, and Rivera (2002) explain that providing students with opportunities to work cooperatively allows them to discuss and defend their ideas with others. This influences Hispanic students by providing opportunities for students to communicate with others, enhancing instructional conversations, decreasing anxiety, and developing social, academic, and communication skills.

> Hispanic students need to be assured that they are important, and that they can make valuable contributions to society. When students are not given these opportunities to participate in the development of classroom activities and when their involvement is minimized, the implicit message is that teachers do not care about their experiences or what they have to say. For this reason, students may miss out on the type of classroom discourse that encourages them to make sense of new concepts and information. (Padron, Waxman, & Rivera, 2002, p.15)

Research described earlier (Hatano & Inagaki, 2003; Eryilmaz, 2002; Vosniadou et. al., 2001; Driver, Newton, & Osborne, 1998; Mason & Santi, 1998) also show the importance of instructional or dialogic conversation on conceptual change.

Metacognition. Padron, Waxman, and Rivera (2002) state that cognitively guided instruction enhances metacognitive skills of students. Rodriguez's (Rodriguez & Berryman, 2002; Rodriguez 1998b) portrayal of STC relies on Gunstone's (1994) description of metacognition as the knowledge, awareness, and control of one's own learning by encouraging students to ask, "What am I meant to be doing?" "Do I know what to write or look for?" "What is the purpose of this task?" STC expands this line of questioning by including questions like, "Why am I learning about this topic?" and "What control do I have in how to proceed?" in order to move toward a sense of consciousness and agency in one's learning. Emphasizing metacognition during instruction for Hispanic students is important because it increases their cognitive engagement on tasks and helps students focus on their understanding. Additionally, metacognitive questioning can help students identify the relevancy of the tasks and answer the question, "Why should I care?" Two studies described earlier (Hennessey, 2003; Georghiades, 2000) illustrate the importance of metacognition to conceptual change.

Culturally Responsive Teaching. Padron, Waxman, and Rivera (2002) describe culturally responsive teaching as incorporating students' everyday concerns, issues and ways of knowing into the curriculum. According to Padron, Waxman and Rivera, culturally responsive teaching improves retention of new knowledge by working from students' existing knowledge base and improves self-confidence by emphasizing existing knowledge. Culturally responsive teaching addresses the needs of students by improving motivation and engagement (Ginsberg & Wlodkowski, 2000).

Gay (2000) defines culturally responsive teaching as using the cultural knowledge, prior experiences and performance styles of diverse students to make learning more appropriate and effective and calls for culturally responsive teaching to unleash the higher learning potentials of ethnically diverse students. Gay describes culturally responsive teaching as having these characteristics:

- It acknowledges the legitimacy of cultural heritages of different ethnic groups

- It build bridges of meaningfulness between home and school experiences as well as between academic abstractions and lived sociocultural realities.

- It uses a wide variety of instructional strategies that are connected to different learning styles

- It teaches students to know and praise their own and each others' cultural heritages.

- It incorporates multicultural information, resources and materials in all the subjects and skills routinely taught in schools.

Lee and Fradd (1998) describe that, traditionally, science has been taught with the expectation that students will understand and learn when teachers present the content in a scientifically appropriate way, with little consideration given to students' cultural understandings. This practice may contribute to the underrepresentation and alienation of diverse students in science. Nelson-Barber and Trumbull (1995) state, "When we pretend that domains of knowledge as taught in schools are neutral – not attached to particular ways of thinking, valuing and knowing – we excuse ourselves from acknowledging other

equally valid perspectives and epistemologies and from creating ways for children to make connections and comparisons between different ways of knowing." Nelson-Barber and Trumbull provide an example of this in the National Science Education Standards. The standards call for teachers to develop a community of science learners by demanding and displaying respect for and value the ideas, experiences and needs of all students, and giving students a significant voice in decisions about the content and context of their work. However, shortly after these comments, the NSES states that teachers should structure and facilitate ongoing formal and informal discussion based on a shared understanding of the rules of scientific discourse and model and emphasize the methods, attitudes, and habits of mind of scientific inquiry. Nelson-Barber and Trumbull state that these statements are contradictory because they ask for respect for all students' voices, but later state what discourse and activities are appropriate. They ask, "Were this tested against a Navaho science curriculum and pedagogy, would there be overlap? Would there be conflict?" Nelson-Barber and Trumbull (1995) argue that a culturally responsive teacher acts as a mediator between her students' cultures and the cultures of the school and academic discipline.

Lee and Fradd (1998) explain that there may be overlap between the culture of science and most cultures, because the scientific values of wondering, curiosity, interest, diligence, persistence, openness to new ideas, imagination and respect toward nature are found in most cultures. However, other values of science, such as thinking critically and independently, reasoning, using empirical criteria, making arguments based on logic, questioning, openly criticizing, tolerating ambiguity, and demonstrating evidence rather

than deferring to authority, may not be as common in non-Western European cultures. For example, when students culturally value collectivism it becomes difficult to argue their perspective or critique others' ideas. Lee and Fradd (1998) identify three realms where Hispanic students' cultural understandings are particularly important: knowing science, doing science, and talking science.

Knowing Science. Lee and Fradd (1998) state that the role of prior knowledge is especially important for Hispanic students. Because the knowledge students bring to the learning process may differ from the mainstream, identifying relevant experiences can play a major role in linking what students already know with what they are expected to learn. By developing learning activities based on familiar concepts teachers facilitate content learning by helping Hispanic students more comfortable and confident with their work (Peregoy & Boyle, 2000). According to Rivera and Zehler (1991) beginning by validating students' existing knowledge base, knowledge acquisition and retention of new knowledge can be improved and the student's self-confidence and self-esteem can be developed. Hispanic students' experiences and everyday living may not be parallel to those experiences found in the school environment, so making lesson relevant and significant, the transfer of school-taught knowledge to real life situations can be increased. Nelson-Barber and Trumbull (1995) explain that prior knowledge can be used to introduce a topic by asking students to describe their own experiences, observations and interactions wit the topic itself. They continue to argue that this type of teaching offers the potential for an active classroom role for each student because it requires students interpretation of ideas that they are more familiar with.

Earlier in this chapter, the importance of identifying students' initial conceptions was discussed. Limon (2001) explains that meaningful conflict only occurs if students' perceive a difference between their initial conceptions and new information. This is not possible if instruction does not begin by identifying these initial conceptions.

Doing Science. Lee and Fradd (1998) state that Hispanic students may experience problems because they have not been encouraged to ask questions or devise plans for investigations on their own. Students from cultures that respect authority may be more receptive to teachers telling and directing them, rather than to inquiry. Griggs and Dunn (1995) explain that Hispanic students generally required a higher degree of structure than did other groups. Additionally Hispanic middle school students were more group-oriented and less competitive than White students. Rothstein-Fisch, Greenfield and Trumbull (1999) contend that Hispanic students' hold a collectivistic value system that emphasizes the importance of the group of the individual. Therefore, it is common nature for Hispanic students to attempt to help each other, even in situations where the mainstream culture expects individual work. This may cause teachers to admonish them or accuse them of cheating. The authors describe a strategy used successfully by one teacher. When homework was passed out, students were allowed to discuss the questions but were not allowed to write down answers until they go home. This resulted in a 100% homework return rate.

Talking Science. Lee and Fradd (1998) explain that the correct use of vocabulary is an indicator of precision and sophistication of understanding. However, the correct use

of vocabulary becomes more difficult when comparable terms do not exist across languages. Therefore, meanings must be understood within cultural context. Additionally, Hispanic students may lack the "why-because" discourse pattern that is expected in science. They may include personal experiences and emotional reactions as well as science related ideas.   Rothstein-Fisch, Greenfield and Trumbull (1999) argue that because Hispanic culture holds a collectivistic value system that emphasizes the social context of learning, Hispanic students often do not separate scientific information from the context that they are embedded in. This often comes in conflict with the culture of U.S. schools that emphasize information disengaged from social context. The authors describe a situation where a park docent asked students what they knew about hummingbirds. The students proceeded to tell stories about their family experiences with hummingbirds. The docent was expecting scientific descriptions and grew frustrated. When he told the students to stop telling stories, they became silent. After the docent left, the teacher invited the students to tell their family stories. She wrote story highlights on the left side of the chalkboard and scientific aspects of the experiences on the right side. The teacher and class were able to value the stories and scientific information equally.

Neslon-Barber and Trumbull (1995) suggest an instructional sequence incorporates students' cultural understanding in each of these three realms. The sequence starts with real-world experience, moves to formal procedures, principles and abstracted concepts an back again to real-world context may be one way to link realms of theory, procedure, and practice. Nelson-Barber and Trumbull argue that the instructional sequence should strongly reflect a local context because it may allow students to enter the

tasks more effectively and could make the task more relevant, inviting and motivating. The project conducted by Seiler (2001) provides an example of how formal scientific procedures and concepts can grow out of students' existing interests and skills. Seiler (2001) developed a science study group specifically for African-American male students. The Science Lunch Group consists of eight African-American males and the researcher, a white female. During the group meetings, topics emerge from student interests and include how drums make different sounds, how tall buildings are built, the physics of a wrecking ball, the chemistry of hair products, and the safety of cell phones. The emergence of these topics battles the perception that science is a collection of facts and leads to the idea of "reflexive science" that begins with what the students knew, could do, and wanted to do, instead of beginning with the Eurocentric science as represented by traditional school science. Students developed rich arguments that included the use of data, graphs, and multimedia. Most of the discussion involved student-student interaction and co-construction of knowledge. The researcher noted that the ability of the students to participate in scientific discourse (creation of scientific arguments) and their learning of specific science content knowledge increased during the Science Lunch Group meetings. Seiler concludes that teachers should create space in their instruction for their students' interests and cultural funds of knowledge. Lessons should connect science with students' ideas, interests, prior knowledge, and abilities. Seiler states, "We start from their interests, pull in their prior knowledge and skills, and end up talking and doing science in ways I have never seen enacted in science classes at this high school" (p. 1012). Seiler continues by stating, "While grounding the content in topics connected with and sensitive

to the lives and cultural histories of African-American students, I also believe that teaching of many critical skills (for science) can be based on abilities and cultural attributes already within the students' repertoires" (p. 1012).

Summary. Culturally responsive teaching uses the cultural knowledge, experiences and performance styles of diverse students to make learning more effective (Gay, 2000). Science has traditionally been taught by focusing on the culture of science – questioning, reason and conclusions based on empirical evidence – that may not only be foreign to students' cultures, but antagonistic to it. (Lee & Fradd, 1998; Neslson-Barber & Trunbull, 1995) For example, Hispanic students tend to be more group-oriented and socially oriented than other students (Rothstein-Fisch, Greenfield and Trumbull, 1999). This may make them uncomfortable stating a belief or criticizing a belief presented by other students. Culturally responsive teachers must respect students' cultures and use them as a basis for introducing and learning about the culture of science.

The role of prior knowledge in learning science may be especially important for Hispanic students because the experiences they bring to the classroom are often different than the mainstream (Lee and Fradd, 1998). Learning activities based on these prior experiences can facilitate learning by helping Hispanic students become more comfortable and confident with their work (Peregoy & Boyle, 2000; Rivera and Zehler, 1991). Focusing on students' initial conceptions and experiences can create an active classroom role for each student because it requires students' interpretations of ideas that they are more familiar with (Nelson-Barber & Trumbull, 1995).

Hispanic students may experience difficulty engaging in science inquiry because they have not been encouraged to ask questions or devise investigations (Lee and Fradd, 1998). Instead, they may be more receptive to teacher direction and structure (Lee and Fradd, 1998; Griggs & Dunn, 1995). Hispanic students' collectivistic value system emphasizes the social context of knowledge and often do not separate scientific information from the context that they are embedded in. Therefore, Hispanic students may lack the "why-because" discourse pattern that is expected in science (Lee and Fradd, 1998; Rothstein-Fisch, Greenfield and Trumbull, 1999).

An instructional sequence that begins firmly within the cultural experiences of the students, moves to the formalized procedures and principles of science, and then returns to real-world experience may be valuable for helping Hispanic students learn science. This sequence strongly reflects a local context and allows students to enter classroom tasks more effectively by increasing their comfort and confidence. By using students' cultural experience as a starting point, learning tasks become more relevant, inviting and motivating (Neslon-Barber and Trumbull, 1995; Seiler, 2001).

Authentic Activity. Rodriguez (1998b) includes authentic activity as one characteristic of STC. He describes authentic activity as both "hands-on" and "minds-on." Also, authentic activities provide students with the opportunity to explore how the subject under study is socially relevant and connected to their everyday lives. STC demands that instruction move away from using a collection of disconnected hands-on activities toward interaction and manipulation of ideas that are valuable beyond the school walls.

Griffard and Wandersee (1999) conducted case studies of two African-American females at an urban science high school to determine what factors adversely affect meaningful learning. The researchers describe that the rhetoric in science education is that hands-on is the way to teach science. All the teachers observed employed hands-on activities, but none pressed their students for cognitive engagement. Both the African-American females did their schoolwork; the teachers provided abundant hands-on experiences, but there was no evidence that this led to robust learning. Cognitive engagement and accountability for the learning that the students believe they have achieved were missing from both these students' science instruction.

Kahle, Meece, and Scantlebury (2000) investigated if incorporating open-ended questioning, extended inquiry, and problem solving makes a difference when teaching urban African American middle school science students. These characteristics reflect Rodriguez's (1998) vision of Authentic Instruction. All the African-American students for each of 18 teachers in urban schools participated in this investigation. Student learning was measured using tests constructed from publicly released NAEP questions, and teaching strategy data was collected from teacher and student surveys. The researchers found there was a significant positive relationship between attitudes toward science and science achievement scores. Additionally, there was a significant, positive correlation between the frequency of standards-based teaching and student achievement.

The Authentic Activity component of STC specifically identifies that activities should be socially relevant and connected to the students' community. This will improve student interest in science. Zwick and Miller (1996) compared the impact of an outdoor

education curriculum and traditional textbook curriculum on American Indian students. The researchers developed an activity-based science program that require students to do the following: (1) utilize the processes of science (collection of data, measuring, classifying, etc.); (2) analyze the data collected (critical thinking, processing data, interpreting data); (3) apply the knowledge or insights gained through data analysis to solve problems or use as a basis for group discussion; (4) evaluate the meaning of data collected and the validity of the method of using the data when applied to problem solving or in class discussion; (5) work in groups and have input into group discussions concerning the activities; and (6) make connections between science, society, art and the language arts. The "hands-on" activities developed for use in a rural district with a high percentage of Native American students are performed in groups in which much discussion within and between groups takes place. Students learn to respect, value, and critically evaluate the opinions of others, as well as their own opinions. The activities require students to use various methods in the processing of data collected and to integrate and apply the science concepts learned to the fields of social sciences, art, language arts, and mathematics. The characteristics of this activity-based curriculum are consistent with the description of authentic activity provided earlier by Chinn and Malhotra. Additionally, the curriculum is consistent with suggestions for culturally responsive teaching.

In Zwick and Miller's (1996) study, two fourth grade classes were studied. The control group used a traditional, textbook driven curriculum. The experimental group

used the activity-based science program. Students in the experimental group achieved significantly greater gains than the control class.

The research related to authentic activity shows that authentic activity may not be commonly found in science classroom settings. Authentic activity should include cognitive engagement in addition to "hands-on" activity. Authentic activity should also resemble inquiry conducted within the science community by having students generate research questions, design investigations, evaluate data, and construct theories. Student interest and relevancy is important as a mediator for learning since it increases the likelihood of sustained cognitive engagement.

Summary

The research reviewed in this section identifies four characteristics of instruction that can help Hispanic students learn science. These characteristics include, instructional conversations, metacognition, culturally responsive instruction, and authentic instruction.

Instructional conversations have specific benefits for Hispanic students. Maximizing student involvement through discussions sends the message that the teacher cares about students' experiences and what they have to say. Instructional conversations help students make sense of new concepts and information. Additionally, instructional conversations help people in different sociocultural positions come together (Rodriguez & Berryman, 2002; Rodriguez, 1998b; Padron, Waxman, & Rivera, 2002). Including metacognition in activities also has been shown to improve Hispanic student learning (Rodriguez & Berryman, 2002; Padron, Waxman & Rivera, 2002)

Culturally responsive instruction incorporates students' everyday concerns, interests and ways of knowing into the curriculum. Lee and Fradd (1998) argues that incorporating prior knowledge is especially important for Hispanic students. Incorporating prior knowledge provides an accessible entry point for learners and provides a link between what they already know and what they are expected to learn. Rothstein-Fisch, Greenfield and Turnbull (1999) contend that teachers should be cognizant of Hispanic students' collectivistic value system which emphasizes social connections and a group orientation. This value system may impact their classroom behavior and discourse patterns. Nelson-Barber and Trumbull (1995) suggest a culturally responsible instructional sequence that begins with students' conceptual understandings in real-world experience, progresses to formal procedures and abstract scientific conceptions and returns to real-world experiences and applications. Seiler (2001) presents an example of how culturally responsive instruction can be implemented in science. Seiler builds starts with student interests, pulls in prior knowledge and skills, and moves students towards formal processes of science.

Authentic Instruction, which introduces the essential features of science inquiry in a context that is interesting and relevant to students, has been shown to be effective for improving learning among Hispanic students. Open-ended questioning, extended inquiry, and problem solving makes a positive difference when teaching African American middle school students (Kahle, Meece, & Scantlebury, 2000). Instruction that incorporates processes of science, analyzation of collected data, application of knowledge, and communication of results increases learning with Native American

students (Zwick & Miller, 1998). Instruction that promotes students investigating questions of their choosing, analyzing data, and communicating findings can increase learning with Hispanic students (Rodriguez & Berryman, 2002). Student interest and relevancy has been shown to be beneficial for learning by students from diverse backgrounds. Relevant instruction incorporates students' everyday concerns and ideas and draws from students' existing knowledge, skills, and abilities (Rodriguez & Berryman, 2002; Padron, Waxman, & Rivera, 2002; Seiler, 2001; Giffard & Wandersee, 1999).

<div align="center">Professional Development</div>

Figure 8. A Graphic Organizer for the Professional Development Section.

One purpose of this study is to determine how teachers' understanding of science inquiry teaching changes as a result of professional development. This section looks at the literature related to professional development and teacher learning from three perspectives. The first perspective investigates a model for understanding how teacher beliefs are related to their teaching changes. The second perspective identifies characteristics of effective professional development. The third perspective looks specifically at one model for professional development that may prove effective at creating change in teachers' beliefs about how they teach. The research described in this section was selected because of their connection to conceptual change and science inquiry literature and its capacity to inform how professional development should be constructed. Figure 8 provides a graphic organizer for this section.

<u>Teacher Beliefs</u>

Feldman (2000) describes a framework for understanding teachers' practical theories that is based on the conceptual change model. Practical theories are the conceptual structures and visions that help provide teachers with a reason for how they teach. Teachers' practical theories are derived from many influences, including time spent in the classroom as a student and teacher, professional development opportunities, and reading education journals. A teacher's practical theory can be tenacious. Just as a learner may become dissatisfied with her understanding of a concept, Feldman explains that a teacher may become discontented with a practical theory because she recognizes it as ineffective or unsuccessful in practice. Posner et al. (1982) argues that in order for a learner to accommodate a new concept, it must be intelligible. Feldman suggests that a

new practical theory should be sensible. It should be reasonable in particular situations. In the conceptual change model, a new conception must also be plausible. Feldman suggests that a new practical theory should have beneficialness, the teacher must see how it will lead to better teaching actions. Finally, the conceptual change model adds that the learner needs to find the new conception fruitful, it should have the potential to be extended to new situations. Similarly, Feldman states that a new practical theory should be illuminating or enlightening in the sense that it can provide insight into actions that can be taken in different situations. Feldman (2000) is able to apply this framework of practical theory accommodation to show how two physics teachers with similar backgrounds can realize different outcomes from the same professional development program.

Borko and Putnam (1995) argue, on the basis of analysis of three successful professional development programs, that the central goal of professional development should be the 'elaboration and expansion of a teacher's knowledge base' (p. 58) and that in reforming their educational practice, teachers 'must acquire richer knowledge of subject matter, pedagogy, and subject-specific pedagogy and they must come to hold new beliefs in these domains. (p. 60). According to Feldman (2000), in order for this goal to to be met, professional development designers need to understand the initial practical theories that participants bring to the table.

Bonstetter (1998) provides a continuum of science inquiry teaching that can be useful to describe a teacher's practical theory. Bonstetter's continuum (1998) is defined by the level of teacher control versus the level of student control. Table 7 illustrates this

continuum. Traditional hands-on activities are characterized by pre-packaged, 45-minute activities in which the students follow specific directions and find the single expected answer. This teaching strategy has been referred to as "activity-mania" by Moscovici and Holdlund-Nelson (1998). The 1999 TIMMS Video study examined how eighth grade science lessons were actually delivered to students and found that in the "United States, eighth-grade science lessons were characterized by a variety of activities that may engage students in doing science work, with less focus on connecting these activities to the development of science content ideas (Roth et al, 2006)." This finding indicates that activity-mania may be the norm in classrooms throughout the country. Moscovici and Holdlund-Nelson (1998) contend that this is a by-product of the science inquiry reform movement. Based on Feldman's framework, it may be symptomatic of a practical theory that has only partially accommodated a science inquiry approach. In structured inquiry, the teacher provides the topic, question, materials, and procedures. The student works with the teacher to analyze data and the student provides a conclusion. In guided inquiry, the teacher provides the topic, question, and materials. The student develops the procedure, analyzes data, and provides the conclusion. In student directed inquiry, the teacher sets the topics, but the student is responsible for determining an investigatable question, procedures, analysis, and conclusion. In student research, the teacher and student collaborate on selecting the topic, while the student is responsible for the other aspects of inquiry. Bonstetter notes that as teachers become more comfortable with inquiry, they are more likely to evolve from the traditional activity sequence toward student research. Bonstetter explains this as follows:

This process of moving from traditional to at least guided inquiry creates several very exciting end results. It alters the role of the teacher, the intellectual development of the students and even the classroom learning climate. The graph above [Table 7, below] shows how we can use inquiry to move toward more student centered classrooms and create a classroom where the focus is clearly on learning and not on the teacher teaching.

Table 7. Inquiry as an Evolutionary Process (Bonstetter, 1998)

	Traditional Hands-on	Structured	Guided	Student Directed	Student Research
Topic	Teacher	Teacher	Teacher	Teacher	Teacher/ Student
Question	Teacher	Teacher	Teacher	Teacher/ Student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedures/ Design	Teacher	Teacher	Teacher/ Student	Student	Student
Results/ Analysis	Teacher	Teacher/ Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student

Characteristics of Effective Professional Development

Little (1993) claims that "the test of teachers' professional development is its capacity to equip teachers individually and collectively to act as shapers, promoters, and well-informed critics of reform." Additionally, Richardson (1997) suggests that the main objective of professional development should be to foster changes in teachers' knowledge, beliefs, and attitudes because these components of teacher cognition are closely tied to teaching practice. Professional development must give teachers opportunities to examine their values and beliefs which will open their thinking to changes in how they teach.

Darling-Hammond & McLaughlin (1995) state that teachers need professional development that extends far beyond the one-shot workshop. They need opportunities to learn how to question, analyze and change instruction to teach challenging content. According to Loucks-Horsley et. al. (2003), teacher learning is "driven by a well-defined image of effective classroom teaching and learning." Loucks-Horsley et. al. argue that effective professional development should: provide opportunities for teachers to build content and pedagogical content knowledge; be research based and engages teachers in the learning approaches they will use with their students; provide opportunities for teachers to collaborate; supports teachers to serve in leadership roles, links with other parts of the education system and; is based on student data and is continuously evaluated.

A comprehensive study conducted by Garet et. al. (2001) identifies six components of professional development. The study is based on survey responses from more than 1000 math and science teachers that participated in the federal Eisenhower Professional Development Program. The teachers self reported characteristics of professional development that they found effective in increasing their knowledge and skills and resulted in changed practice.

Garet et. al. (2001) identified three structural features, including the form of the activity, the duration of the activity and the composition of the participants. They also identified three core features, including the content focus, degree of active learning and the coherency of the activity. Garet et. al. (2001) found that the type of activity is less important than emphasis on the core features, duration and collective participation. Additionally, teachers who experience professional development that is aligned with

teachers' goals and state or local content and performance standards are more likely to change their practice.

A Collaborative Model for Professional Development

Krajcik and colleagues (1994) describe the model of professional development that they used in their work on project-based instruction with middle school science teachers. This model focuses on teachers' social construction of knowledge through collaboration, classroom enactment, and reflection. Figure 9 illustrates this model. Bell and Gilbert (1994) argue that teaching is fundamentally a social activity and that teacher development is critically dependant on social interactions. Krajcik and his colleagues note that it is quite common for professional development opportunities to rely entirely on consultation with experts as the impetus for change. Instead, their model stresses collaboration between teachers and university faculty. University faculty provide information on current scientific knowledge and new approaches to teaching, while teachers provide knowledge of what does and does not work in their classroom. Collaboration provides opportunities for sharing and critiquing of ideas and plans.

Krajcik and colleagues (1994) argues that, while collaborative conversations can serve as a stimulus for change, they are not enough to promote teachers' learning. Experience and reflection are also important. Teachers must try complex innovations in their classroom in order to understand them. Additionally, teachers must reflect on their teaching in order to extract from the experience the knowledge that leads to improved student learning.

Ladewski, Krajcik and Harvey (1994) describe the growth of a teacher's understanding of constructivist teaching through the collaborative model of professional development. The authors conclude that the cycle of enactment, collaboration and reflection were critical in fostering learning of a new way of teaching. They suggest that, if teachers are to develop complex new conceptions and strategies for instruction, they need to be supported by a collaborative effort that includes classroom enactment and reflection, instead of the isolated opportunities that are common in professional development efforts. Marx et. al. (1994) describe the challenges and growth of four teachers implementing constructivist teaching through the collaborative model of professional development. These authors conclude that the cycle of collaboration, enactment, and reflection provided opportunities for teachers to gain a practical understanding of how constructivist teaching can actually be used, instead of just a theoretical knowledge of constructivism.

Figure 9: Krajcik et. al. (1994) Model of Teacher Learning.

Collaboration
Inform, Share
Support
Critique

Enactment
Carry-out
Plan

Reflection

Emerging Visions
Possibilities
Conceptions
Strategies
Congruent Practices
Beliefs
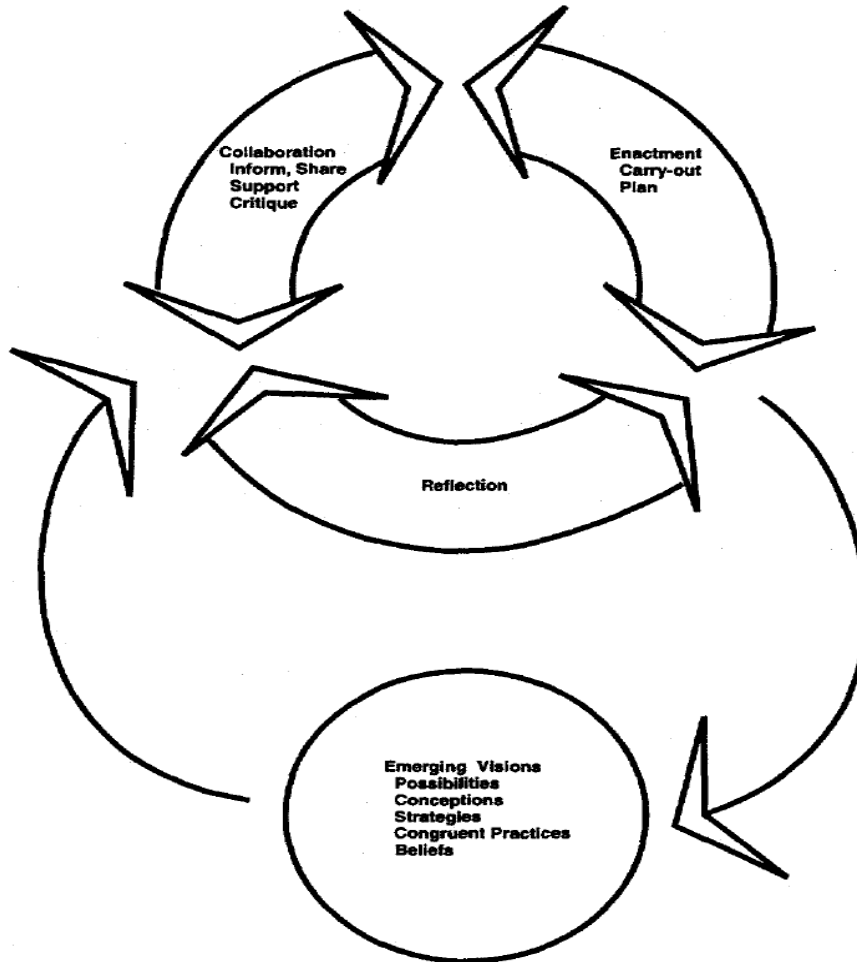
When coupled with a well defined image of effective classroom teaching and learning, Krajcik et. al.'s (1994) collaborative model of professional development is consistent with the characteristics of effective professional development described by Loucks-Horsley et. al. (2003) and Garet et. al. (2001). The focus on collaboration and reflection provides opportunities for teachers to build content and pedagogical knowledge and engage in learning approaches that they will use with their students. Additionally, collaboration between university faculty and teachers by nature occurs over long

durations and ensures that the professional development remains aligned with the teachers' goals and standards.

Summary

The literature reviewed in this section focuses on how teachers can improve their understanding of instruction through professional development. Feldman (2000) provides a framework for understanding how teachers change their practical theories. A practical theory is a conceptual structure that gives a basis for how teachers plan and implement instruction. This framework follows the conceptual change model provided by Posner et. al. (1982). Teachers must become discontented with their current practical theory, find the new practical theory sensible and see how it will lead to better teaching practices (beneficialness). Additionally, the new practical theory should be illuminating, in that it should provide insight into actions that can be taken in different situations. Bonstetter (1998) provides a continuum of teachers' understanding of and comfort with science inquiry that can be used to describe teachers' practical theories. This continuum progresses from a very teacher-centered pedagogy to one that is almost totally student-centered.

Professional development experiences should move beyond one-shot workshops (Darling-Hammond & McLaughlin, 1995) and should be driven by a well-defined image of classroom teaching (Loucks-Horsley et. al., 2003). Professional development should focus on sustained interaction, collective participation, active learning, content, and connections to the participants' learning goals (Garet et. al., 2001).

Krajcik et. al. (1994) describe a model of professional development that involves collaboration, enactment and reflection. They suggest that if teachers are to develop complex new conceptions and strategies for instruction, they need to be supported by a collaborative effort that includes opportunities for participants to gain a practical understanding of the new conceptions, instead of just theoretical knowledge.

<u>A Synthesis of Characteristics for Good Instruction</u>

Figure 10. An Overview of the Synthesis of Characteristics for Good Instruction Section.
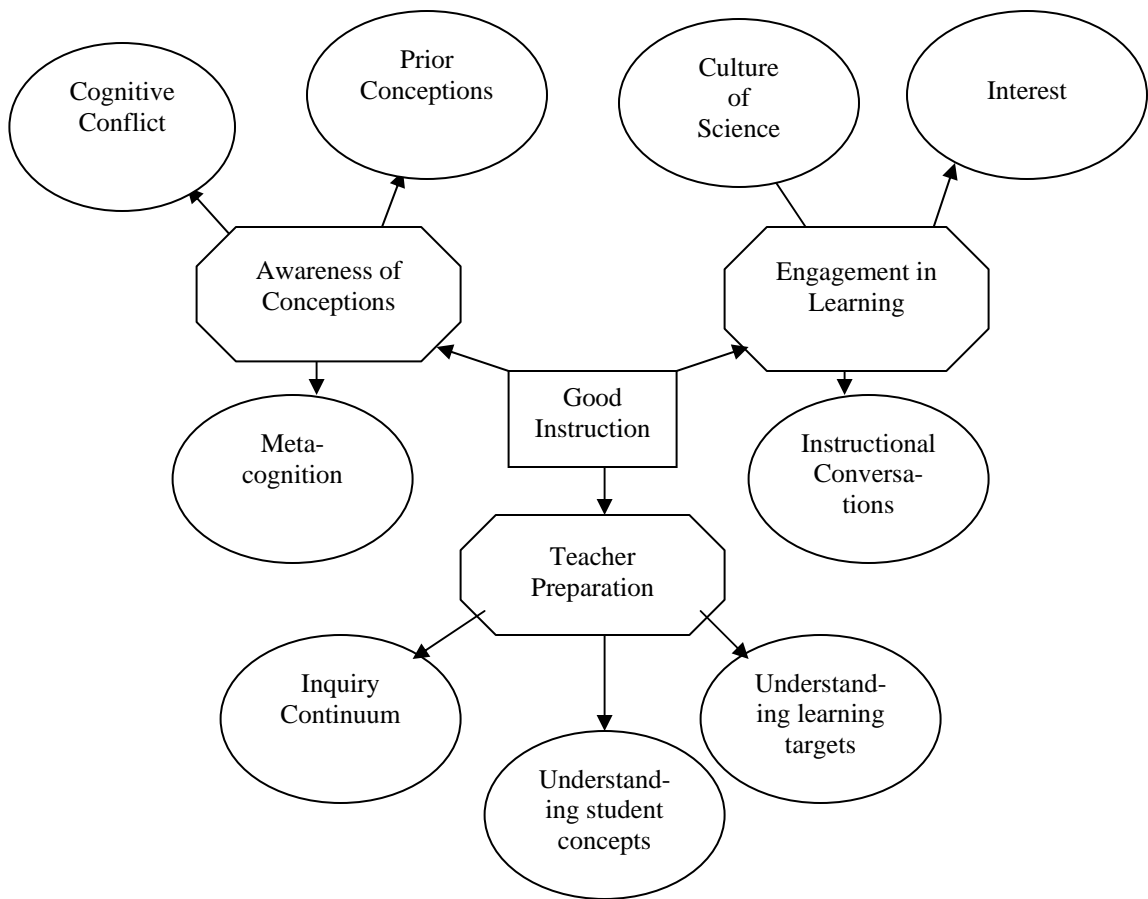
The research discussed in this section presents a large number of concerns and successful strategies for improving learning within four realms: conceptual change; science inquiry; diverse students; and teacher professional development. This section of the literature review will synthesize these strategies into characteristics for instruction that is particularly useful in helping Hispanic students learn science. These strategies can be placed within three broad themes, awareness of conceptions, engagement in learning, and teacher preparation before instruction. The characteristics described in these three themes provide the foundation for the Inquiry for Conceptual Change model, which is the instructional model used in this study and is described in Chapter Three. Figure 10 provides a graphic organizer for this section.

Awareness of Conceptions

This theme consists of three characteristics of instruction that can increase Hispanic learning of science. Each of these characteristics is related to students being aware of the conceptions that they hold about a science topic and how those conceptions change during instruction. First, instruction should be based on students' prior knowledge and experiences related to the topic. Second, instruction should generate cognitive conflict with students' prior knowledge and experience. Third, instruction should emphasize student metacognition. Students should consider their initial conceptions in relation to more scientific conceptions and explicitly think about how the tasks they complete modify their conceptions.

Prior Conceptions. Students enter the classroom with robust, if naïve, conceptions about how the world works. These conceptions are often deeply held, intuitive and highly resistant to change. Therefore, learning science often requires the challenging task of understanding and accepting different conceptions of the physical world (Vygotsky, 1978; Vosniadou, 1994; Vosniadou, 2003; Jones, Carter and Rua, 1999; Schwedes and Schmidt, 1992; Strike and Posner, 1992). This change in conceptions can occur at three different levels. The easiest level of conceptual change involves the addition of ideas without revising an existing conception. Making surface revisions to an existing conception is more difficult. Completely restructuring a conception represents the most difficult level of conceptual change (Schwedes & Schmidt, 1992; Posner et. al., 1982; Strike and Posner, 1992; Carey, 1985; Chi et.al., 1994; Vosniadou, 1994; deLeeuw and Chi, 2003). If students are not aware of their initial conceptions, it is likely that they will not undergo any significant conceptual change. If they are not aware of their initial conception, it is likely that they will ignore discrepant information and revert to their initial conceptions in situations that demand applications beyond rote regurgitation of ideas (Chinn and Brewer, 1993; Osborne and Freyberg, 1985).

Prior knowledge may play an especially important role in learning science for Hispanic students. These students often bring experiences to the classroom that are different from the mainstream (Lee and Fradd). Activities based on these prior experiences help Hispanic students become more comfortable and confident with their work. Additionally, discussion and examination of these prior experiences can create an

active role for each student (Peregoy and Boyle, 2000; Rivera and Zehler, 1991; Nelson-Barber and Trumbull, 1995).

Cognitive Conflict. Posner et. al. (1982) describe four conditions that are necessary in order for conceptual change to occur. The student must become dissatisfied with her initial conception. The student must also be able to understand the new conception, how it can be used to resolve the dissatisfaction, and how it can be used in other situations.

Student dissatisfaction with their initial concepts can be caused by conflicts between alternative student views, conflicts between student intuition and scientific views, conflicts between everyday phenomena and scientific views and conflicts between everyday language and scientists' language (Tsai, 1999; Wiser and Amin, 2001; Chin and Brewer, 1993; Mason, 2001; Limon, 2001). Research also shows that conflict should be created socially as students discuss each others' conflicting ideas and scientific evidence (Hatano and Inagaki, 2003; Mason, 2001; Limon, 2001).

Metacognition. Metacognition leads to vital and durable conceptual change by increasing students' engagement in the learning process. Students need to "think about their thoughts" and need to explicitly express and support their ideas (Georghiades, 2000; Hennessey, 2003) Short instances of metacognition, including the proper phrasing of questions, can have a dramatic impact on conceptual change without placing additional burdens on instruction (Georghiades, 2000).

Metacognition has been found to specifically improve learning by Hispanic students by increasing cognitive engagement and focusing students on their understanding. Metacognition also helps Hispanic students identify the relevancy of classroom tasks (Rodriguez and Berryman, 2002; Rodriguez, 1998b; Waxman and Rivera, 2002).

Engagement in Learning

The three characteristics included in this theme have been shown to have a positive effect on Hispanic students' learning of science. Each of the characteristics in this theme is related to increasing student engagement in learning activities and the learning process. First, instruction should be relevant and interesting to students. Second, instruction should take place in a context that reflects the culture of science while respecting each student's unique culture. Third, instructional conversations should be used to socially construct knowledge in a context that is meaningful for students.

Interest. Student interest is an important mediator for learning science because it increases the likelihood of sustained cognitive engagement and motivation for learning. Therefore, students that are interested in a subject are more likely to undergo conceptual change. It is not clear if there is a difference in engagement with students that show interest in a topic outside of class or those that are interested as a result of a "hook" during instruction (Andre and Windschitl, 2003).

Interest in a topic may be specifically important in promoting cognitive engagement among Hispanic learners. Student interest provides a starting point for

learning because it makes tasks more relevant, inviting and motivating (Nelson-Barber and Trumbull, 1995; Zwick and Miller, 1996; Seiler, 2001).

Culture of Science. Social constructivists argue that the context in which knowledge is developed is not separable from the learning that is taking place. Therefore, students will not appreciate the nature of science unless they learn in a context that reflects the culture of science (eg. Brown et. al., 1989). A science inquiry pedagogy provides a reflection of how scientists engage in the process of creating knowledge. Students should engage in scientifically oriented questions and attempt to answer these questions using evidence. Students should be able to communicate and justify these explanations (NRC, 2000). These types of activity have been shown to be effective in helping diverse students learn science (Kahle, Meede and Scantlebury, 2000; Rodriguez and Berryman, 2002; Rodriguez, 1998b; Zwick and Miller, 1996; Seiler, 2001)

The values of science – questioning, reason and evidence based arguments – may not only be unfamiliar to students from non-mainstream cultures, but actually conflict with other cultures. Hispanic students may experience difficulty engaging in science inquiry because they have not been encouraged to ask questions or devise investigations. Additionally, Hispanic students may lack the "why-because" discourse pattern of using evidence to support arguments that is expected in science (Lee and Fradd, 1998; Rothstein-Fisch, Greenfield and Trumbull, 1999). A culturally responsive teacher respects these cultural values and uses them as a basis for introducing and mediating between her students' cultural experiences and the culture of science (Nelson-Barber and Turnbull, 1995).

Instructional Conversations. Research shows that creating cognitive conflict and presenting a new scientific conception in an individual setting is often not enough to cause conceptual change. It is necessary to encourage instructional conversations that elicits student understanding, allows students to argue multiple perspectives, and emphasizes evidence and justification for arguments as a means to create conceptual change. Classroom discussions should focus on the creation of knowledge instead of a transmission of knowledge (Hatano and Inagaki, 2003; Mason and Santi, 1998; Eryilmaz, 2002; Vosniadou et. al., 2001); Driver, Newton & Osborne, 1998).

Instructional conversations provide Hispanic students with opportunities for extended dialogue in areas that have educational value as well as relevance for them. These types of conversation builds trust by sending the message that the teacher cares about student experiences (Rodriguez and Berryman, 2002; Rodriguez, 1998b; August and Hakuta, 1998; Padron, Waxman, and Rivera, 2002). Additionally, instructional conversations help Hispanic students construct context-relevant meaning for classroom concepts. This social context of knowledge is valued in Hispanic students' collectivistic culture (Rothstein-Fisch, Greenfield and Trumbull, 1999; Lee and Fradd, 1998).

Teacher Preparation for Instruction

The previous two themes identify the importance of teachers understanding not just the content and culture of science, but also their students' prior conceptions and cultural experiences. The importance of understanding the students in a learning situation suggest that how a teacher prepares for instruction is vital to good instruction. The three suggestions in this theme are directly related to how a teacher should prepare for

instruction. Teachers should understand the continuum of science inquiry instruction, understand their students' prior knowledge and cultural experiences and understand the specific learning targets and outcomes that they would like their students to have at the end of instruction.

Inquiry Continuum. The inquiry continuum describes the level of control a teacher has over question generation, solution pathways, the use of evidence, conclusion making, and communication of findings in science inquiry instruction. On one extreme, the teacher controls all of these functions. At the other extreme, the teacher controls none of these. Structured inquiry involves teacher control over the problem and processes while students are responsible for outcomes. Open inquiry may involve teacher control over the topic of inquiry, but students are responsible for the other functions. (Martin-Hansen, 2002; Trowbridge & Bybee, 1990; Colburn, 2000) Teachers should have an understanding of when different levels of control are needed to best facilitate student learning.

Understanding of Students' Prior Conceptions and Cultural Experiences. The importance of students' initial conceptions and cultural experiences has been described in the previous themes. Teachers must have a clear understanding of the concepts that their students bring to the classroom. These initial conceptions should provide the starting point and basis for creating an instructional sequence (Osborne and Freyburg, 1985; She, 2002; She 2003; Tsai, 2000; Tsai 2003). Additionally, teachers should have an understanding of students' cultural experiences so that they can begin with what students

already know and can do before moving into the formal processes and principles of science. Teachers must show respect for these cultural values and mediate between their students' cultures and the culture of science (Lee and Fradd, 1998; Neslon-Barber and Trumbull, 1995; Rothstein-Fisch, Greenfield and Trumbull, 1999).

Understanding Learning Targets. The act of learning science involves modifying a student's initial conceptions towards conceptions that are more scientifically acceptable. In order for teachers to create instructional sequences that facilitate learning, they must have a clear understanding of the science concept that is the subject of instruction. Additionally, they must have a clear purpose of what they expect students to be able to do and understand at the end of instruction (Osborne and Freyburg, 1985; She, 2002; She 2003; Tsai, 2000; Tsai 2003).

CHAPTER 3

METHODOLOGY

Understanding how teachers of diverse students perceive inquiry and how professional development may change those perceptions will help professional development providers develop stronger programs. Additionally, the experiences of these teachers will provide insight into how science inquiry can be implemented in diverse classrooms.

Patton (2002) advocates "a 'paradigm of choices' rather than becoming a handmaiden of any single and inevitably narrow disciplinary or methodological paradigm." Instead, researchers should carefully fit the methodology to their questions. This study has two focus questions that call for two unique methodological paradigms. The overall design of this study falls within the qualitative paradigm. A qualitative paradigm is best suited to providing a robust description of teacher perceptions toward science inquiry and how those perceptions change.

This chapter will describe the research paradigm used in the study. The chapter will also describe the participants and design of the study.

The Qualitative Paradigm

The primary consideration in determining which inquiry paradigm to choose is the nature of the research question. The two questions that drive this study are as follows:

1. What are teachers' perceptions of science inquiry and its implementation in the classroom?

2. How does the use of the Inquiry for Conceptual Change model affect the learning of students in a predominantly Hispanic, urban school?

Qualitative research seeks to understand phenomena in context-specific situations. Qualitative researchers examine a problem by recording detailed views of participants in their natural setting. The qualitative researcher constructs a complex portrait (Creswell, 1994) from the multiple realities of the participants in the study. Qualitative research directly investigates participants' subjective experiences and allows for naturalistic observation and description instead of hypothesis testing (Auerbach & Silverstein, 2003). Patton (2002) states that the constructivist paradigm seeks answers to the following fundamental questions: How have the people in this setting constructed reality? What are their reported perceptions, "truths," explanations, beliefs, and world-views? What are the consequences of their constructions for their behaviors and for those with whom they interact? Constructivism assumes multiple, conflicting, yet understandable social realities. Qualitative research is particularly well suited to study this diversity because it does not assume that there is one universal truth to be discovered, but rather, focuses on listening to the subjective experiences and stories of the people being studied (Auerbach & Silverstein, 2003). Guba and Lincoln (as cited in Patton, 2001) include the following assumptions of constructivism:

- "Truth" is a matter of consensus among informed people, not correspondence with objective reality.

- "Facts" have no meaning except within some value framework

- Phenomena can only be understood within the context in which they are studied.

This study will examine how individual participants construct and reconstruct the meaning of the phenomena of science inquiry. The study will look for themes that emerge from these constructions. Additionally, the study will determine the effect of implementing Inquiry for Conceptual Change with diverse students.

<u>Selection of Participants</u>

The participants in this study included four classroom teachers and the science laboratory teacher from Becker School on a voluntary basis. Four of the participants are white males and one is a white female. Becker School is located in a large urban district and serves more than 700 students in kindergarten through eighth grade. This school serves a diverse neighborhood. Its population is nearly three-quarters Hispanic, 10% White and the remainder African American, Asian and Native American students. (Wisconsin Department of Public Instruction, 2006).

The participants in this study were selected through a process that Patton (2002) refers to as snowball sampling. Participants in this study were required to be middle-level teachers (grades 5 – 8) and teach in a school with a significant Hispanic population. I had worked with one of the participants, John, in the past and knew that the teachers at his school met the study's requirements. Additionally, John has a broad range of teaching experience in urban schools that would be beneficial for this study. I approached John

approximately one year before the study began and asked him to suggest additional teachers at his building that would provide a wide range of experiences. Approximately four months before the study began, I met with eight teachers from Becker Elementary school. Six of the teachers, including John, were interested in participating. We met again in January, 2006 to discuss logistics and scheduling for the project. Of the six teachers at this meeting, five agreed to participate in the study. In addition to John, one other participant had worked with me in the past. Steve took an online, graduate level, science education course that I had recently offered.

Patton (2002) explains that a rich description of participants in a qualitative study is necessary for the reader to build an understanding of the participant's experiences during the study. I will briefly introduce the participants in this chapter and provide a more complete description of the participants at the beginning of Chapter four. All five of the participating teachers are white. Sam has taught for more than 20 years, with nine years teaching only science. As part of a federal grant, Sam worked at the district office providing professional development as a science support teacher. Last year, Sam was the laboratory science teacher at Becker Elementary. All of the students meet either once or twice per week with the laboratory science teacher for a one hour science activity. This year he is teaching all subjects in 5th grade. Jason has taught all subjects for almost five years. He currently teaches 6th grade. Emma also teachers all subjects for 6th grade. This is her third year of teaching. Emma is fluent in Spanish and teaches the bilingual / limited English proficiency class. Steve has taught as a generalist for the past eleven years. He is currently teaching 8th grade. John has been a classroom teacher for 15 years. Of those, all

but two were teaching only science. John also worked at the district office providing professional development for teachers as a science support teacher. This is John's first year as Becker School's science laboratory teacher.

Becker School is located in a predominantly Hispanic neighborhood. Hispanic students comprise a majority of the students taught by the participants in this study. Sam has 21 students, including 16 Hispanic students. Jason has 28 students, of which 21 are Hispanic. Steve teaches 21 students, including 15 Hispanic students. Emma teaches 27 students in a bilingual class. Twenty-six of these students are Hispanic. Overall, this study included 97 students. Of these, 78 (80%) were Hispanic and 9 (9%) are White. The remaining 10 students represent a variety of culture and language backgrounds.

This study was granted an exemption from the requirement for a full committee review by the Institutional Review Board of Montana State. Privacy safeguards and other protections were described in the exemption application for this study. Permission to conduct research was also granted from the district's research and assessment office. All of the requirements for human subjects protection from the university and distrect were met in this study. One requirement necessary for protecting the privacy of the participants was to refer to them by using a pseudonym. Each participant reviewed and signed a consent form. Since this study involved collecting pre- and post- test data and observational data from students, all parents were provided with a consent form. These consent forms were provided in English and Spanish. Data was not collected from students whose parents either declined their participation or did not return consent forms. These students still participated in activities, but their teacher did not provide me with

their assessment results. The participant consent forms are located in Appendix A. The parent consent forms are located in Appendix B. The district has a policy of providing a stipend for any district sponsored professional development opportunity equal to the participating teacher's hourly pay rate for any district sponsored professional development opportunity. Although this study was approved by the district, it did not fall under the district's stipend policy. Participants were provided with a moderate stipend that was slightly less than the district rate.

<u>Positionality</u>

The researcher in a qualitative study does not play the role of a neutral observer. The perspective that a researcher brings to a qualitative inquiry is part of the context for the findings (Patton, 2002). It is important that I am aware of the origins of my perspective and those of the participants in the study. Patton explains that the credibility of the researche is enhanced by the presentation of the researcher's background.

My mother and father are both teachers, so I have been around teachers for almost my entire life. My father taught middle school science and my mother taught elementary school. I began my education career as a physics and physical science teacher in a suburban high school. After 3 years, I left the classroom to work for a non-profit organization that provides professional development opportunities in Earth and Space science for teachers throughout the nation. Although I am still certified to teach in Wisconsin, I have not taught in a classroom for six years.

Two years ago, I began thinking earnestly about what I was interested in for my dissertation research. At the time, I was positive that I wanted to focus on professional development strategies, specifically in online environments. At the same time, I had become very interested in conceptual change models of teaching. In the summer of 2004, I had the opportunity to hear a talk by a science educator about guidelines for helping Hispanic teachers learn science. I was quite dismayed when he said that conceptual change models had failed with minority students. Although I did not agree with his conclusion, I was interested in his approach. I came to the realization that it was more important for me to develop a fundamental understanding of what good science teaching could look like than continuing down a professional development research path.

After I came to this realization, I had the opportunity to be a graduate assistant for an elementary science methods class at Montana State University. This was followed by an adjunct instructor position at a university in Wisconsin for a similar class. These classes got me thinking about what science inquiry looks like and how pre-service (and inservice) teachers could gain an understanding of science inquiry teaching. A short time later, the idea for a comprehensive model that melded conceptual change teaching, research suggestions for teaching Hispanic students and science inquiry arose. The Inquiry for Conceptual Change model was born.

My mantra throughout the development of the Inquiry for Conceptual Change model was, "comprehensive yet practical." What do these three fields of research have in common that could inform science teachers, particularly those that teach Hispanic students?

As this study began, I already knew two of the participants. John had participated in many professional development opportunities that I had led. Steve had participated in one online course that I taught. I did not know the other three teachers. During the study, we quickly established a trusting, collaborative relationship. By the end of the study, I had gained an appreciation and respect for the energy and dedication that they brought to their teaching.

<u>Design</u>

The purpose of this study is to examine teachers' understandings of science inquiry as they participate in a professional development experience and to determine the effect of the professional development experience on student learning. The intervention used in the study has two distinct components. First, the participants gained specific experience with the foundations and characteristics of the Inquiry for Conceptual Change model. As part of this experience, participants developed a unit of study. These are based on the Inquiry for Conceptual Change model and lasted a minimum of 10 hours. Participants met during six sessions spread over two months. The total contact time during these sessions was approximately 18 hours. In addition to the formal meetings, participants interacted informally with the researcher and peers while developing their unit of study. The two 6th grade teachers collaborated to develop one unit. Second, participants implemented the unit of study in their classroom. During implementation, participants administered pre- and post-assessments and formative assessments to their students.

The participants in this study developed original assessments and units for implementation instead of using a pre-packaged inquiry unit. The decision to use this approach was deliberately made for two reasons. First, teachers in this district do not have ready access to commercial kits. Exposure to one pre-packaged unit would have provided them with the understanding needed to use the unit in future years, but they might not be able to transfer this new understanding to other topics. Second, the use of a pre-packaged unit would remove the tension and challenge created by having participants focus on their students' initial knowledge and interests. Through the development process, participants had to think deeply about how to best engage their students. It is not the intention of this study to turn the participants into curriculum developers. Instead, it is hoped that the understandings that the participants gain by using the deliberate planning process and inquiry components described by the Inquiry for Conceptual Change model will help them modify and adapt curriculum for their students in the future.

<u>Inquiry for Conceptual Change</u>

Haury's (1995) Circle of Inquiry is a straightforward model that includes four easily understood stages. In the "Wondering" stage, students begin to formulate questions on a topic. In the "Collecting Data" stage, students conduct investigations and find evidence to answer their questions. In the "Studying Data" stage, students analyze data to formulate solutions. In the "Making Connections" stage, students connect solutions to other scientific content. With the exception that this model does not specifically ask students to communicate their results, this model does incorporate the characteristics of science inquiry. The students are involved in generating questions; their investigations

can take multiple paths to arrive at an answer; students are expected to use evidence to support their conclusions; and the context of the activities should be scientifically oriented. These characteristics make the Circle of Inquiry a good starting point for the development of a science inquiry model that is appropriate for Hispanic students. Figure 11 illustrates the Circle of Inquiry Model.

Figure 11. Haury's (1995) Circle of Inquiry Instructional Model.
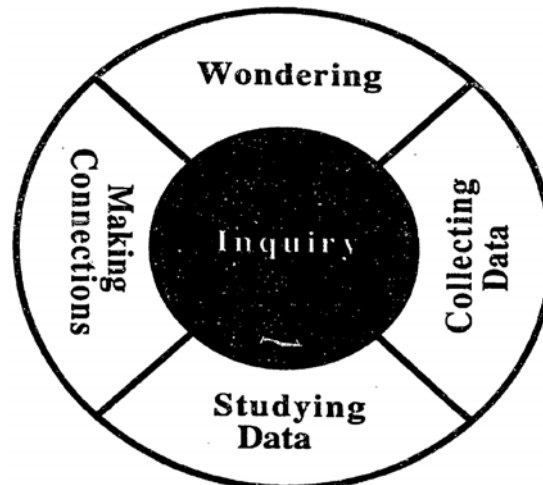
The Inquiry for Conceptual Change model presented here is based on Haury's Circle of Inquiry but incorporates additional themes that emerged from the review of literature in Chapter 2. Drawing from the research described in the Conceptual Change section of the literature review, the model should also focus students' attention on their initial knowledge of a phenomenon and use multiple methods to cause them to become dissatisfied with this initial knowledge. Furthermore, according to the research described in the Conceptual Change section and the Teaching Strategies for Diverse Learners section of Chapter 2, the model should include opportunities for metacognition,

instructional conversations, and authentic and culturally relevant experiences. The model should be culturally responsive by beginning with real-world experiences that are connected to students' initial knowledge and ways of knowing, progress towards formal understanding of science content and process, and return to real-world experiences in the manner described by Neslon-Barber and Turnbull (1995). The Inquiry for Conceptual Change model has these five components: Preparing, Wondering, Investigating, Constructing, and Connecting. Figure 12 illustrates the components of the Inquiry for Conceptual Change model. The circular nature of the illustration emphasizes the non-linear nature of science inquiry. Student learning and questioning may result in students and the teacher moving back and forth between components during a unit.

Figure 12. An Illustration of the Inquiry for Conceptual Change Model.

Preparing. In this component, the teacher tries to gain an understanding of her students' initial conceptions regarding the target concept. This will generally take place prior to the beginning of the unit. Students may complete a survey or some other type of activity to help the teacher illustrate their initial conceptions. From this basis, the teacher is able to generate activities for the "Wondering" phase and "Connecting" phase that will help to build student dissatisfaction with their initial conceptions and to find connections between their initial concepts and new scientific concepts. A "preparing" phase is also found in the following conceptual change instructional models: the Generative Learning Module (Osborne and Freyburg, 1985), Dual Situated Learning Model (She, 2002), and Conflict Maps (Tsai, 2000).

Wondering. In the initial portion of this component, students are introduced to the topic of study. This introduction can be made through stories, magazine articles, videos, demonstrations, etc. (Pizzini, Shepardson & Abel, 1989). Students should work individually and in small groups to identify their initial conceptions related to the topic. Whenever possible, students should be forced to commit to their initial conception in writing (Chin and Brewer, 1993). It is important during this step that students connect their initial conceptions and the topic to other situations that affect their lives (Padron, Waxman, and Rivera, 2002; Rodriguez and Berryman, 2002). Students should also work to identify disagreements between student initial conceptions and questions that can be researched. If applicable, the teacher should provide activities that build a sense of dissatisfaction with the students' initial conceptions (e.g. Posner et. al, 1982; Tsai, 2003).

Investigating. During this component, students working in small groups should refine their questions and develop a procedure for conducting research. Students should be encouraged to use multiple sources of information during their research. Additionally, opportunities should be provided for students to develop investigations that allow them to conduct experiments and collect data (e.g. Chin and Malhotra, 2002; Haury, 1995; Chang and Barufaldi, 1999; Krajick et. al, 1998).

Constructing. During this component, student groups analyze their data and begin to answer their research question. Students should be expected to develop some sort of "product" that they can share with the rest of the class (NRC, 2000). Students should work with the teacher to make sure that their conclusions are supported by evidence (NRC, 2000; Limon, 2001; Driver, Newton, and Osborne, 1998). At this point in Inquiry for Conceptual Change, students should return to the question of how their new knowledge is related to issues that affect their lives (Hennessey, 2003; Rodriguez and Berryman, 2002; Padron, Waxman, and Rivera, 2002).

Connecting. This component of the Inquiry for Conceptual Change model consists of building two specific connections. Visually, this component is found in the center of the circle to emphasize that connections should be made during each component of the model. The first connection is making sure that the activities and concepts are relevant to the students. Rodriguez (1998b) and Padron, Waxman, and Rivera (2002) argue that culturally responsive instruction will better help Hispanic students learn science. Culturally responsive teaching incorporates students' everyday concerns and

issues into the curriculum. These initial conceptions and ways of knowing act as an access point to learning new concepts. Culturally responsive teaching improves retention of new knowledge by working from students' existing knowledge base and improves self-confidence by emphasizing existing knowledge. Additionally, student interest promotes engagement in learning activities. Students should be given the opportunity in each component of Inquiry for Conceptual Change to explore how the topic under study is relevant and connected to their everyday lives.

The second connection is between the students' investigations and the curriculum. Curricular demands make it important that specific concepts are developed in a classroom. In Krajcik et. al.'s (1998) implementation of science inquiry, the teachers made use of "benchmark" activities to explicitly connect science concepts to the unit's driving questions. Interspersed throughout the student research, the teacher should include activities that focus on specific curricular needs. Student-centered discussions should help connect these activities to the context of their research. For example, during student investigations on motion, a teacher could include a benchmark activity that illustrates the importance of wearing seatbelts as a "hook" into Newton's Laws of Motion.

A proper classroom environment must be developed for successful use of the modified Circle of Inquiry. The environment should incorporate instructional conversations and metacognition.

Instructional Conversations. Padron, Waxman, and Rivera (2002) explain that cooperative learning influences Hispanic students by providing opportunities for students

to communicate with others, enhancing instructional conversations, decreasing anxiety, and developing social, academic, and communication skills. Padron, Waxman, and Rivera and Rodriguez (1998b) explain that students should engage in extended dialogue around academic concepts. Driver, Newton, and Osborne (1998) describe instructional conversation as discussions that identify different lines of thought and invite students to evaluate and refine these and move toward an agreed outcome.

Metacognition. Padron, Waxman, and Rivera (2002) and Rodriguez (1998b) explain that metacognition is an important aspect of helping Hispanic students learn. Students should ask themselves these questions throughout the inquiry process: "What am I meant to be doing?", "Do I know what to write or look for?" "What is the purpose of this task?" "Why am I learning about this topic?" "What control do I have in how to proceed?" Georghiades (2000) conducted a study that found that short "metacognitive instances" were enough to increase transferability of student learning and decrease conceptual decay. These metacognitive instances lasted 2-3 minutes and could be interspersed throughout instruction. Table 2 in Chapter 2 provides some examples of how to incorporate metacognitive instances.

The Professional Development Experience

The professional development design for this study closely followed the model employed by Krajcik et. al. (1994) and discussed in Chapter 2. The professional development experiences focused on collaborative conversations that resulted in specific classroom enactments and reflection. Participants met with the researcher on six

occasions over the course of two months. Each meeting lasted approximately 2.5 hours. Similar to Krajcik and his colleagues, I viewed these meeting as working sessions instead of workshops. Participants were treated as collaborators throughout the process. This collaborative process meets the criteria for effective professional development as described by Garet et. al. (2001) and discussed in Chapter 2. Garet and his colleagues found that effective professional development should emphasize sustained involvement and collective participation. Additionally, experiences should be aligned with teachers' goals and content and performance standards.

The participants were being asked to devote a significant amount of time and energy to this project. Therefore, it was important that they felt ownership over the professional development process and the products of the experience. I entered the project with the view that the participants were peers and we each brought significant experience to the table. I entered the process with a certain amount of expertise with ideal views of how science inquiry could be implemented with Hispanic students. Sam and John also had some experience with practical implementation of science inquiry. All of the participants had valuable experience with the practical conditions of their teaching environment and an understanding of how their students learn. I felt that it was important for me to be flexible in how the teachers approached the project. It was also important for me to be observant and responsive to the participants' experience and concerns regarding how this new method of teaching could be implemented in their setting. This respect for the participants' knowledge, flexibility, and responsiveness helped to build trust between the participants and me. The collaboration, trust and sense of ownership helped to

maintain a high level of engagement throughout the development and implementation process.

There were three goals for the first meeting. The first goal was to provide enough background so that the participants understood the scope of the project. The second goal was to have the participants determine the topic of their unit. The third, and most important, goal was to begin building a context for the professional development working sessions that would allow trusting, collaborative relationships to be built. All of the working sessions were conducted in the school's science laboratory. To help foster collaboration, all of us sat around a table, instead of a traditional workshop setting that places the facilitator apart from the participants. The meeting focused on providing an overview of the project and determining the topic for each of the three units. After the unit topic was determined, participants turned to the district's learning targets to identify specific knowledge and skills that the students would develop by the end of the unit. This freedom to choose the topic for their unit helped to build a feeling of collaboration instead of feeling that the professional development was "being done to them." Sam decided to focus on plants, Jason and Emma decided to focus on how water shaped the Earth, and Steve decided to focus on electric circuits. Since John does not have a specific class of students, he helped the other participants explore different topic options that fit with the district's learning targets. He also helped the participants identify specific learning outcomes for their topic. Participants were asked to read and respond to the article. "Shifting from Activity Mania to Inquiry" by Moscovici and Holdlund-Nelson (1998). This article describes how to differentiate between disconnected hands-on

activities that require little student thought and authentic science inquiry activities. This article was specifically chosen because it identified problems with the way that hands-on science is commonly taught. By reflecting on this articles, I hoped that participants would begin to become discontented with their current teaching practice.

The primary goal of the second meeting was to develop a pre-test that could be used to determine the initial knowledge of the teachers' students. During the meeting, I gave a very brief overview of the Inquiry for Conceptual Change model. I also provided more detail on the preparation phase and explained how the work done In the first session and the development of the pre-test would guide the remainder of the development process. The participants focused on creating a pre-test to determine their students' initial conceptions on the unit topic. The process of creating the pre-test also resulted in a refinement of the specific knowledge and skills that the participants found important. Participants were asked to read and respond to two articles. The two articles were, "An Inquiry Primer" by Colburn (2000a) and "Constructivism: A Grand Unifying Theory for Education" by Colburn (2000b). These two articles were chosen because they clearly describe the theory behind science inquiry. The articles also provide suggestions for incorporating science inquiry into the classroom. Participants were also asked to have their students complete the pre-assessments.

Three goals were planned for the third meeting. The first goal was for the participants to gain some understanding of teaching for conceptual change. The second goal was to more fully introduce the Inquiry for Conceptual Change model. The third goal was to have participants begin thinking about the context for their students'

investigations. This meeting began with a group analysis and discussion of the students'
pre-assessment responses. The discussion helped the participants determine the scope of
their units. The discussion also helped to foster discontent with the participants' current
teaching style as they realized the durability of some of the students' misconceptions. The
discussion was followed by an activity that modeled teaching for conceptual change. The
activity forces participants to identify their initial conceptions for the reason for Moon
phases and test at least two of these initial conceptions. By asking participants to test their
misconceptions, they become dissatisfied with their initial ideas. Then, when they test the
scientific model, they can see how it is intelligible, plausible and fruitful. This activity
was selected to provide a starting point for a discussion on conceptual change theories of
learning. One important part of this discussion was comparing how the phases of the
Moon are traditionally taught by having students model phases without confronting their
misconceptions. During this meeting, participants were introduced more fully to the
Inquiry for Conceptual Change Model. They were charged with the task of determining a
context for the unit that would be relevant to their students. The context selected needed
to lend itself to investigations that the students could perform.

The fourth session had two goals. The first, was to give the participants a glimpse
of how inquiry might look in the classroom. The second goal was to allow these teachers
to develop a draft outline of their units. In the reflections to the articles that the teachers
read after the second session, Jason, Emma and Steve expressed concern regarding what
inquiry would look like in the classroom. They also expressed that they did not realize
that inquiry could be done with different levels of teacher control. To help the

participants better understand these ideas, I introduced a series of activities that modeled different styles of inquiry. All three activities focused on the same content. The first activity presented the concept through an open investigation. The second activity presented the concept through a guided investigation. The final activity presented the concept through a structured investigation. After completing this activity, participants worked together to develop a focus for the investigations in their unit and to create a projected schedule of activities. I spent time during this session working with each participant or pair on their unit, with assistance from John.

The fifth and sixth meetings were definitely working sessions. I did not have any specific goals beyond helping the participants complete their units. During these two meetings and through e-mail conversations between meetings, we fleshed out the outline of the unit, identified resources, and developed specific benchmark activities. These meeting were very collaborative. I worked closely with each group as they developed their unit. John continued to work closely with Sam, Jason and Emma. He also helped Steve acquire materials for his unit.

Participants were interviewed before the professional development sessions began. The participants were also interviewed after they completed the design of their unit and after the implemented their unit. The researcher observed each participants class once during the implementation of the unit.

Data Sources

The constructivist paradigm demands that the researcher constructs an understanding of a phenomenon through the perspective of the study participants. This emphasis on participant perceptions guides the methodological choices. Patton (2002) describes three general types of qualitative data: interviews, observations, and documents. Data sources for this study include interviews, participant-created products, written reflections, observations of teaching, and student assessment products. Table 8 provides a summary of the focus questions, data sources, and timeline.

According to Patton (2002), interviews include open-ended questions and probes and "yield in-depth responses about people's experiences, perceptions, opinions, feelings, and knowledge." In this study, participant interviews took place on three distinct occasions. The first interview took place prior to the professional development experience. The second interview took place shortly after the professional development experience and after the participants completed the development of their unit. The final interview took place shortly after the participant has implemented the science inquiry unit in the classroom. I used an interview guide approach (Patton, 2002). An outline of issues and potential questions guided the interview with no formal interview protocol. The interview guides used in this study are included in Appendix C.

The initial interview began by asking descriptive questions about the participant's background. Next, participants were asked to describe their preferred method of teaching science and how they think their students learn best. These

underlying perspectives served as a starting point for discussion of more abstract educational philosophies. The participant was asked how they define science inquiry and to describe situations where they feel they have effectively used an inquiry approach. Additionally, participants were asked to discuss concerns that they have regarding the use of science inquiry approaches with their students.

Table 8. Summary of Focus Questions, Data Sources, and Timeline.

Focus Question	Data Sources	Timeline
1. What are teachers' perceptions of science inquiry and its implementation in the classroom?		
How does teachers' understanding of science inquiry change as a result of professional development and implementation of inquiry?	All Interviews and reflections	2/06 - Initial Interview 5/06 - 2nd Interview 6/06 - Final Interview 2/06 - First Reflection 3/06 - Second Reflection 6/06 - Final Reflection
How does teachers' understanding of science inquiry influence their implementation of inquiry in the classroom?	All Interviews, reflections, and implementation journal	2/06 - 6/06 05/06 - Implementation Journal
What challenges do teachers face when implementing science inquiry in a diverse classroom?	All Interviews and reflections	2/026 – 6/06
2. How does the use of the Inquiry for Conceptual Change model affect the learning of students in a predominantly Hispanic, urban neighborhood?		
Do science teachers observe any difference in student engagement between the inquiry model and their previous teaching methods?	Final Interview Final Reflection Implementation Journal Researcher Observation	5/06 - 6/06 5/06 - Researcher Observation
What types of research questions do students pose?	Final Interview Final Reflection Researcher Observation	5/06 - 6/06
Is there evidence of a conceptual change in students between the pre- and post-assessment?	Pre- and Post- Assessment	03/06 – Pre-Assessment 05/06 – Post-Assessment

Table 8: Continued.

Is there evidence of deep cognitive engagement on the part of the students?	Final Interview Final Reflection Implementation Journal Researcher Observation	5/06 - 6/06

The interview guide for the second interview involved three groups of questions. The first set of questions asked participants to describe science inquiry and discuss how their views of science inquiry had changed. The second set of questions were related to the school's science fair program. These questions provide insight into the participants views of open inquiry. The third set of questions examined the science inquiry unit that they developed.

The interview guide for the third interview included questions that focused on three different areas. Participants were asked to reflect on students' reactions to the unit. This included asking for evidence of student engagement, thinking, and learning. Participants were also asked about tensions related to using and developing science inquiry units. The third area tried to identify what participants thought were the most important aspects of the inquiry model and how they could be implemented more often.

Documents include materials such as publications, reports, personal diaries, photographs, and written responses to open-ended survey (Patton, 2002). Participants wrote three reflection pieces at different times during the study. The first reflection was assigned after the first working session. For this reflection, participants were asked to read the article, "Shifting from Activitymania to Inquiry (Moscovici & Holdlund-Nelson, 1998)." Participants then responded to a prompt that asked them to react to the article

after reflecting on their current teaching practice. A second prompt asked participants to identify roadblocks that they saw to implementing inquiry in their classroom.

The second reflection was assigned after the second working session. For this reflection, participants read the articles, "An Inquiry Primer (Colburn, 2000a)" and "Constructivism: A Grand Unifying Theory for Education (Colburn (2000b)." Participants responded to a prompt that asked them if they incorporated any of the author's suggestions into their current teaching practice. The participants also responded to a prompt that asked them if they had any concerns related to the suggestions made by the author.

The participants completed a lengthy final reflection at the end of the project. This reflection focused on their thinking about student learning during their unit, their teaching practice, and their thoughts about their teaching practice in the future. They were also asked to suggest recommendations for encouraging the use of science inquiry. The guidelines for this reflection are located in Appendix D.

The participants kept an implementation journal as they used the unit they developed with their students. In this journal, participants were asked to respond to three questions after each lesson: (1) What did the lesson look like today? (2) How did your students react to the lesson? Please include any evidence (questions, comments, student work) that shows students are thinking and learning. (3) What was your reaction to the lesson?

The effect of using the Inquiry for Conceptual Change model with these students was determined through three specific methods. First, teacher-participants were

specifically asked to record evidence of student learning in their reflections during implementation of their Inquiry for Conceptual Change unit. Second, my observations conducted during the implementation provided evidence of student engagement. Finally, the teacher-participant created pre-, post-, and formative assessments provided direct evidence of how students' conceptions changed during the implementation of the unit.

<u>Data Analysis</u>

Data analysis in qualitative studies is an iterative process of induction where themes emerge out of the data (Patton, 2002). Interviews, field notes and documents are coded and emerging themes are categorized. Patton (2002) explains that categories should be judged by two criteria. Internal homogeneity refers to the extent to which data in a specific category hold together in a meaningful way. External homogeneity refers to the extent to which difference in categories are bold and clear.

According to Patton (2002) the first decision to be made in analyzing qualitative data is whether to begin with intra-case analysis or cross-case analysis. Berkowitz (1997) states that "a case could be a single individual, a focus group session, or a program site. In this study, I will begin with intra-case analysis while defining each case as a specific data collection session.

The categorizing process is an iterative process that begins with getting to know your data. Bogdan and Biklin (1998) describe the following types of categories.

- Setting / Context
- Defining the Situation
- Respondent Perspective
- Respondents' Ways of Thinking about People and Objects

- Process
- Activity
- Events
- Strategies
- Relationship and social structure
- Method

Bogdan and Biklin (1998) suggest first ordering data sources and carefully reading them. Next, read them again and record your thoughts in the margins. Initial coding can then be conducted. During initial coding, numerous codes are generated without worrying about the variety of categories. A piece of information may be assigned several codes. After this initial coding is concluded, codes can be examined to find repeating ideas and emerging themes. During this process of focused coding, codes are eliminated and combined.

I began the data analysis process by ordering all of my data sources chronologically. The interviews were all digitally recorded and transferred to a computer. I transcribed each interview verbatim by using an audio program that allowed the playback speed to be reduced. I then read through all of the initial interview transcripts without taking notes. Next, I read the interview transcripts a second time and recorded notes in the margin. At this point, a colleague with a strong science education background reviewed the transcripts and confirmed that my notes were representative of the participant responses. The notes, including representative participant responses, were then categorized by hand into codes that reflected the types suggested by Bogdan and Biklin (1998). This process was repeated for the remaining interviews, reflections,

implementation journal and researcher observations. My colleague conducted an audit of my notes for each of these data sources.

The next step in the process is to identify patterns and connections in the codes. The development of a visual device can aid in this step. Miles and Huberman (1994) describe this as a data display that provides "an organized, compressed assembly of information that permits conclusion drawing…" Berkowitz (1997) describes a data display matrix that can be used for intra- and cross case analysis. Figure 13 illustrates a matrix for the initial interview.

Figure 13. A Data Display Matrix for the Initial Interview Case.

Participant →	John	Steve	Emma	Jason	Sam
Interview Categories ↓					
Background	Codes	Codes	Codes	Codes	Codes
Practice	Codes	Codes	Codes	Codes	Codes
Ideal	Codes	Codes	Codes	Codes	Codes

I created a data display matrix, similar to the matrix illustrated in figure 13, for each data source. Next, I looked across codes generated from the initial interview, first reflection, and second reflection. Codes were grouped by common themes and patterns between these codes were identified. I looked at these three data sources together because they all provided information on the initial knowledge, perceptions, and values held by the participants. Codes for the second interview were treated similarly. I then looked across the codes related to the unit implementation from the final interview, implementation journal, final reflection, and researcher observation. These codes were

grouped by common themes and patterns. I looked at these data sources together because they all provided insight into how the participants' units were implemented and information related to student learning. Finally, I looked across the codes related to the participants' thinking about science inquiry from the final interview, implementation journal, and final reflection. These data sources provided insight into the participants' reaction to their implemented unit and changes in their knowledge, perceptions and values since the beginning of the study. The same colleague that reviewed my notes in the previous step reviewed the groupings of codes for each data set for internal homogeneity.

The final step in the data analysis process is the interpretations of the data. The themes and connections that emerged from the analysis process can be used to explain findings and provide insight into the study's focus questions.

Credibility

Lincoln and Guba (1985) suggest that qualitative research focuses on credibility in place of internal validity as a measure of trustworthiness. Patton (2002) suggests that triangulation is one of the strongest methods to improve the credibility of a study. There are four types of triangulation: methods, sources, analyst, and theory/perspective. This study will use both methods triangulation and analyst triangulation.

In methods triangulation, combinations of interviewing, observation, and document analysis are used to provide cross-data consistency checks. Data collected from the written reflections provided by participants will be used to test the themes that emerge

from the initial interviews. The units of study produced during the professional development experience can be used to test the themes emerging from the second interview. Written reflections will be used to test and reinforce the themes emerging from the final interview. Classroom observations and participant interviews can be used to test and reinforce findings from the student pre- and post- assessments.

Patton (2002) explains that a great deal can be learned about the accuracy, completeness, fairness, and perceived validity of the data analysis by having the people described in the analysis react to the conclusions. I checked my data analysis conclusions with each of the participants to ensure that the conclusions are accurate.

Lincoln and Guba (1985) propose conducing an inquiry audit for increasing the credibility of a qualitative study. An inquiry auditor analyzes the process of the study as well as the data finding, interpretations and recommendations. I relied on two people to act as inquiry auditors. One of my committee co-chairs provided suggestions and revisions for my data collection and analysis process. This auditor reviewed each of my interview guides and reflection prompts. A colleague with a strong background in science education audited my data coding procedure to ensure that my groupings were reasonable and that my conclusions were justifiable. This two points at which this colleague audited my data analysis procedure was described in the previous section.

CHAPTER 4

RESULTS

Data Collection

During the Spring of 2006, I made several trips to work with the participants of this study. In late February, I conducted initial interviews of all of the participants. The following day, we began meeting for professional development sessions designed to help the participants develop science units based on the Inquiry for Conceptual Change model. At the end of the first session, participants were asked to read the article, "Shifting from Activitymania to Inquiry (Moscovici & Holdlund-Nelson, 1998)." Participants wrote a short reflection on their teaching after reading the article. After the second session, participants were asked to read the articles, "An Inquiry Primer (Colburn, 2000a)" and "Constructivism: A Grand Unifying Theory for Education (Colburn (2000b)." Participants wrote a short reflection on their teaching after reading these articles. The two reflections and the initial interview provided data to determine the participants' initial teaching practices and teaching beliefs.

The final professional development session was held in mid-April. Participants were interviewed in early May to determine how their understanding of science inquiry had changed. Shortly after that second interview, participants began implementing the science unit that they developed. Participants kept a daily journal of what happened in their classroom and how they reacted to the lessons. I observed each participant once in

late May. Students took a participant designed pre-assessment in March and a post-assessment upon completion of the unit. The daily journals, pre- and post- assessment, and observation provided data to determine how the inquiry unit was implemented and how students responded to the unit.

During the first week of June, I conducted a final interview with each participant. The participants also completed a written reflection of their teaching beliefs and impression of the implementation of their science unit. The interview and reflection provided data to determine the participants' understanding of science inquiry and teaching beliefs at the end of the study.

The data were divided into five broad categories. The data from interviews, artifacts, and the observation was then coded into themes. A detailed description of this process was described in Chapter Three. The rest of this section will discuss those categories and themes. First, data that provides insight into the participants' backgrounds will be discussed. Second, interview and reflection data that illustrates the participant's initial conditions (beliefs and practice) will be presented. Third, data from the second interview will show participant understanding of science inquiry as a result of the professional development sessions. Fourth, data from pre- and post- tests, observation, student work, and participant journals will be used to show how each participant implemented science inquiry in their classroom. Fifth, data from the final interview and reflection will be discussed. After the data has been presented, I will discuss the findings in terms of the two focus questions and sub-questions that guide this study.

There is a remarkable correspondence with individual participant responses across data sources within each of the broad categories. As a result of this consistency between methods, I will not explicitly discuss similarities between sources for each theme. However, I will note discrepancies in individual responses between data sources when they arise.

<u>Participant Backgrounds</u>

Five teachers participated in this study. Sam currently teaches fifth grade with a wide range of teaching experiences. Emma and Jason are sixth grade teachers with limited teaching experience. Emma speaks fluent Spanish and teaches in a bilingual classroom. Steve is an eighth grade teacher with a wide range of teaching experiences. John is the school's science laboratory instructor. He has a wide range of science teaching experience and provides science instruction for every student at the school.

<u>Sam</u>

Sam has been teaching for 22 years. He has nine years of experience focused on teaching science and math. Although he has little formal coursework in science, he has a strong personal interest in science that has lead him to developing a broad knowledge of science that he would classify as above average. Sam has been very involved professionally with science education at the district level. He has been involved in the district's science curriculum committee which includes responsibilities for textbook adoption and standards writing. In the late 1990's he was one of the district's science and math resource teachers who were part of an NSF Urban Systemic Initiative. In this

capacity, he received significant amounts of professional development related to math and science teaching. He was also responsible for doing on-site professional development for teachers throughout the district.

Sam describes good science teaching as being relevant, engaging and focused on the kids. A good science teacher should be comfortable with kids asking questions instead of lecturing. A teacher should ask questions that help students think and connect activities to the content. Sam also recognizes that there is a place in science instruction for more direct methods, "sometimes you have to be the sage on the stage (Sam Initial Interview, 2/27/06)." Before designing instruction, Sam feels that teachers really need to look at what they want to accomplish in terms of process and content. Sam has some concerns with student-centered teaching because of time demands presented by the breadth of the science standards and other subject demands. He states, "I would like to see a real inquiry-based classroom in the central city that successfully reaches all of the state and district targets. Until that classroom is found, maybe incorporating inquiry in small doses is the way to proceed (Sam 2nd Reflection, 3/13/06)."

Jason

Jason has been teaching in a general classroom for four years. He completed an accelerated alternative certification program that he admits did not focus much on teaching strategies for science. He has an undergraduate background in physical geography and geology, so he feels that his science knowledge may be more extensive than most elementary teachers, but is limited beyond physical geography and geology.

Jason has not participated in science related professional development since becoming a teacher.

Jason describes his science instruction as being teacher centered, with some "cookbook" style activities. As a result of conversations with John, he has been focusing this year on trying to use the "activity before content" method more often. This method places an activity at the beginning of the unit to provide some engagement and give students a place to "hook" the content to. Jason sees the ideal of science teaching "as being more hands-on experimentation, more student-centered, and more self discovery. Students should be engaged by their own inquiry (Jason Initial Interview, 2/27/06)." However, he admits that he, "has "crashed and burned in the past when I have tried more open-ended discovery activities. I am not sure if I am setting them up wrong or if my students lack the basic process skills and fundamental scientific knowledge to do it (Jason 1st Reflection, 2/28/06)." He states, "It (science inquiry) sounds so simple, but so did installing a water pump on a Subaru – I hope this endeavor goes more smoothly (Jason 1st Reflection, 2/28/06)."

Emma

Emma has been teaching in a general classroom for three years. As an undergraduate, she took courses in astronomy, plants, and environmental studies. She also took Advanced Placement biology and chemistry in high school. In addition to this coursework, Emma has practical experience with environmental science through the Peace Corps. She has no professional development experiences in science education.

Emma feels comfortable teaching all of the science content covered in the sixth grade curriculum, but often has to review specific laws or vocabulary for a chapter.

Emma sees good science instruction as "assessing students' initial knowledge, picking out the big ideas, and stressing vocabulary. It is important for students to see the concepts in action through demonstrations and hands-on activities (Emma Initial Interview, 2/27/06)." Since becoming a teacher, Emma has learned that her students "love structure. They do not get a lot of structure at home, so at school it is important that they know what is happening next and what is expected of them (Emma 1st Reflection, 2/28/06)."

Steve

Steve has been teaching general education for 11 years. He only completed the minimal science requirements as an undergraduate student and feels more comfortable with mathematics and social studies. The only significant professional development experience that Steve has in science was a full semester online astronomy course that I taught during the Fall of 2005. Steve describes his science content knowledge as limited. It may be good in some areas, but is very low in others. He feels most comfortable with space science and botany.

Steve recognizes that his science instruction has leaned more towards the lecture format during his career. Currently he places a large emphasis on reading in science. He states, "the activities that I use are ones that have been either successful or easy to implement in prior years (Steve Initial Interview, 2/27/06)." When asked in his initial interview how he would describe good science teaching to a student teacher, he

responded, "Honestly, I would ask what she thinks because I am looking for a different way to teach science. I'm pretty stuck in the way I teach, so I would be looking for a new way to do it (Steve Initial Interview, 2/27/06)."

John

John has 15 years of classroom teaching experience and two years as a professional development leader. Besides one year as a general fifth grade teacher (last year) and his current science laboratory teacher position, he has taught exclusively science. In his current position, he is responsible for teaching science laboratory activities to every student in the school. He meets with students in grades one to five once every six days. He meets with sixth to eighth grade students twice every six days. Each session is approximately 45 minutes long. He attempts to match the laboratory activity to the classroom teacher's needs and often suggest activities for them to use. Although his undergraduate coursework in science was minimal, just the basic requirements, he has participated in extensive professional development experiences in science over the past 15 years, including formal college courses, workshops, and trips. Similar to Sam, John spent time at the district's central offices as a middle school science support teacher through an NSF Urban Systemic Initiative. In this position, he received extensive professional development related to science and led on-site, science professional development opportunities for teachers throughout the district. John feels that his science content knowledge is adequate for what he is doing, but he also states, "I am still learning. It isn't just the content, it is pedagogy. It is amazing how different teaching is in first grade compared to eighth grade (John Initial Interview, 2/27/06)."

Initial Conditions

Participants were interviewed before the professional development sessions began in order to gauge their initial beliefs about science teaching. Participants also wrote reflections to three science inquiry related articles early in the project. These reflections provide additional insight into their initial beliefs on science teaching. Their responses can be summarized in the following themes: student factors; current practice; understanding of science inquiry; challenges of using science inquiry; the promise of science inquiry; and questions about science inquiry. Unless otherwise noted, the quotes in this section are from the participants' initial interview conducted on February 27, 2006.

Teachers' Thoughts About Student Factors

The participants described a number of student factors that they take into account when leading instruction for their students. All of the teachers stated that their students' prior experiences with science were generally limited. This necessitated the use of scaffolding and remediation strategies during instruction. Additionally, the participants felt it was important to show how science content is relevant to their students. The participants use a variety of adaptations to help their students learn.

Students' Life Experiences. Sam noted that his students generally do not come to the classroom with the same life experiences as other students. He states, "They have been exposed to fewer ideas and concepts." Sam adds, "I do not think that my students are taught to be as critical and skeptical of information as other students might be." All of

the other participants seem to agree with these beliefs. All five participants also felt that although the students have the support of their parents, many of the parents do not have the expertise necessary to provide help. Jason adds, "They (students) do not have much in the way of role models for (school) learning, except for teachers."

The lack of exposure, ideas and parental help leads these teachers to the belief that their students need significant scaffolding and remediation. Sam states, "I don't lower the bar, I just have to give them what they haven't had in other places. Steve emphasizes the importance of scaffolding since he sees frustration setting in quickly when students do not understand concepts.

Importance of Relevancy. Participants mention identifying relevancy as one characteristic of instruction that is important to their students. As discussed in Chapter Two, relevancy is specifically important for Hispanic students because it improves self-confidence, motivation and engagement (Padron, Waxmon & Rivera, 2002; Ginsberg & Wlodkowski, 2000). Emma comments, "I try to find a way to connect concepts to their real lives." This statement is typical of what each participant believes. Jason explains, "good science teaching should relate to our students' lives and get them engaged in learning." He also states that the best way to engage students is through a "little bit of flash." However, only Sam mentions that he explicitly thinks about relevancy as he plans for instruction.

Instructional Adaptations. Each teacher has specific adaptations that they make for their students. Steve addresses students' need for scaffolding by providing them with

guided reading packets and very structured hands-on activities. In addition to connecting the concepts to their lives, John states that he does, "all kinds of crazy stuff; jokes, dancing, and voices. We try to have fun." Since students may have little help at home, Emma "provides all of the materials for projects in class and gives students time to work on them in school." Jason emphasizes engagement and student interest. In addition, he realizes that he may be one of his students' only role model for school learning, so he tries to build personal relationships with them.

Current Practice

The participants' descriptions of their current teaching practice can be summarized through seven themes: design and resources; reading emphasis; prior knowledge emphasis; discussion structure; group work; assessment; and activity structure.

Design and Resources. Emma and Jason explain that they generally start a unit by using a "KWL" chart to determine their students' initial ideas on a concept. Sam mentions that he occasionally uses this strategy. A "KWL" chart asks students to brainstorm what they already "know" about a topic and what they "want to know" about the topic. Later in the unit, the KWL chart is revisited and students brainstorm a list of things that they have learned about this topic. After the KWL, Jason and Emma introduce the big ideas of the unit by having students read the text. They also both mention that they occasionally introduce a concept by having students conduct a short activity, instead of reading. This "Activity Before Content" strategy was recommended to them by John.

Jason states, "this is a useful strategy and I have been focusing on ways to use it more (Jason 2nd Reflection, 3/13/06). As students are introduced to the content, Emma focuses on vocabulary and attempts to demonstrate concepts in a variety of whole group activities.

Emma, Jason, Steve and Sam all mentioned that their primary source for instructional guidance and materials is their textbook. As the science laboratory teacher, John tries to provide the other teachers with activities that are not found in the book. He has an extensive collection of resources and is adept at using the Internet to find activities. He notes that most of the textbook suggested activities are not of a very high quality. As an example, he describes one activity, "sitting and watching a piece of ice melt under a lamp…for an hour…that's not going to do it!" All of the teachers are aware of the district's learning targets for their grade level. They keep these targets in mind, but their textbook provides the structure for their instruction. Sam states, "The learning targets are not very useful. They are kind of inconsistent. In some places they are very broad and then in other cases they are too specific."

Emphasis on Reading. All of the classroom teachers describe a heavy emphasis on reading during their science instruction. Steve's description of what you would see if you visit his classroom is illustrative of this emphasis.

> You would see science text books out, see notebooks open and usually guided reading packets that go along with the text. You would see me walking around the room, reading along with the students, guiding them through the text and stopping very frequently to discuss what we have learned. Very often, I am learning at the same time (Steve Initial Interview, 2/27/06).

Emma and Jason also state that students spend a lot of class time in science reading, usually together as a class. Jason notes, "ten pages of reading can take an entire week of science time." Sam identified an emphasis on reading, but spends more time on whole class discussions.

Prior Knowledge. Each of the participants identify and react to their students' prior knowledge in different ways. Steve states, "I am so guided and structured by what I have to teach that I rarely try to find out what my students are thinking." Emma uses a KWL chart to identify students' prior knowledge when she thinks that her students have some familiarity with a concept. However, she notes, "it often does not help to identify their prior knowledge, because they still have the misconception even after re-teaching (Emma 2nd Reflection, 3/13/06)." Jason also uses a KWL chart at the beginning of instruction. When he identifies a misconception he, "hits the breaks, blows it apart, and tries to right the ship." Jason states, "this is usually done in a lecture format by trying to look at the thought process behind the misconception." In his second reflection, Jason notes, "Students really need to clarify their initial conceptions before they can explore why they are not consistent with the scientific community." He adds, "I'm starting to doubt that me standing in front of the class talking and explaining has an impact on my students' misconceptions (Jason 2nd Reflection, 3/13/06).

John uses "questioning, introductory activities, stories, discrepant events, and demonstrations" to find out students initial knowledge of a specific concept. He believes that instruction, "should start with students' prior knowledge and how it applies to their life." John explains that when he identifies a misconception, he often "won't tell my

students right away. Instead, we use experiences from the activities and discussion to counter the misconception." His consistent emphasis on starting "where the students are at" throughout the initial interview and reflections shows that identifying and building from students' initial ideas are very important to his instructional style.

Sam also uses questioning, demonstrations, and activities to identify his students' initial conceptions. He sees that identifying initial conceptions can set the stage for them to learn new content by providing them with experiences that they can attach labels and vocabulary to. He notes that, "sometimes student misconceptions can be corrected by helping them understand that it isn't right, but on other occasions, I use a more direct method to correct misconceptions." Sam provided an example of how an activity can be used to identify students' prior knowledge.

> Instead of reading about energy, we introduced the topic by conducting an activity. Student groups were given different materials that demonstrated a different form of energy. Each group had to determine how their materials generated energy. They presented their findings to the whole class. The experience gave students knowledge that allowed for deeper understanding when concepts were formalized in later lessons (Sam 2nd Reflection, 3/13/06).

Although most of the participants identified strategies for determining their students' prior knowledge, only John seemed to hold this as a central organizing principle during instruction. However, none of the teachers, including John, used their students prior knowledge while planning before instruction.

Discussion Structure. All of the participants provide time in class for discussion. The vast majority of this discussion is teacher centered, where the teacher asks questions

and follows up with more questions. All of the participants stated that student cross-talk is not common in their classrooms and may not be specifically encouraged. Additionally, Emma notes a frustration with classroom discussions, "I give wait-time, but I think it often gives them time to tune out and not think (Emma 2nd Reflection, 3/13/06)."

Group Work. In general, the teachers use a small amount of group work in their classrooms. Emma and Jason primarily use groups during hands-on activities. Jason estimates that this occurs during 25% of class time. Sam also indicates that group work only accounts for about 20% of class time. Steve uses group work sparingly in class and focuses mostly on whole group reading. His special needs students are allowed to read in pairs. John is the exception to this. Since he is the laboratory instructor, nearly all of his time with students is spent doing hands-on activities. All of these activities use group work, with some whole class and individual work.

Assessment. All of the classroom teachers use traditional formal summative assessment measures. They use written tests that they develop and tests provided by the textbook. None of the classroom teachers formally assess science process skills. John does not give grades to students, so he does not conduct summative assessments.

Jason, Steve, John and Sam also use informal formative assessments. Both Sam and Jason describe a method of gauging student understanding by having students give a "thumbs-up, -down, or –sideways" depending on how well they understand the content. Steve and John specifically mention that they informally assess their students through observations and discussion.

Activity Structure. All of the classroom teachers participating in this study admit that they use hands-on activities infrequently. Hands-on activities are rarely used more than once or twice per week and are usually confined to John's laboratory session. Sam states, "this year hands-on activities are conducted in the laboratory session and rarely during regular class time." Steve also explains that "the hands-on stuff is done in science lab, not in here (his classroom)." This laboratory session occurs once every six days for Sam's class (grade 5) and twice every six days for Emma and Jason (6th grade) and Steve (8th grade). Although it isn't true with every teacher in the building, those participating in this study work closely with John to make sure that the laboratory session is connected to what they are doing in their classroom. Additionally, writing conclusions and follow-up from the activities are usually the responsibility of the classroom teacher after the laboratory session.

Although students are often encouraged by all of the participants to describe what they know about a specific topic before an activity begins, the central question for the activity is almost always given to them. Students are almost always provided with a detailed procedure to follow. Quite often, the activity is demonstrated for the whole class before they are allowed to begin work. John provides a simple rationale for this, "If it is too open ended, they (students) really freak out." Students are also provided with data tables and are guided in how to collect and record data.

John states that he tries to pull the class back together after the activity so that they can discuss their conclusions. However, usually there is not enough time left in the laboratory session and it becomes the classroom teacher's responsibility to do this. Sam

and Jason provide a specific format and guidance for students as they write their conclusion. Steve also has students write a conclusion to summarize what they learned. All of the teachers try to engage their students in a discussion of their results. John, Jason and Steve all attempt to have their students generate new questions as a result of the activity. However, because of time constraints, they also admit that they rarely provide opportunities for students to actually investigate these new questions.

Understanding of Science Inquiry

Each of the participants has a unique definition of science inquiry. All of their definitions overlap regarding the understanding that science inquiry is more student led and involves students investigating questions. Emma states, "science inquiry is different from traditional science teaching because it is more student led. Students should be in groups asking and working on questions and spending long intervals investigating." Sam states, "science inquiry involves going with student questions instead of sticking with a rigid set of objectives." He describes two "levels" of science inquiry, "In guided inquiry, the teacher provides a situation that confines the students' questions. In open inquiry, the students investigate their own questions." Jason explains, "science inquiry involves students investigating their own questions, not mine. It is more student led. It needs to stay within the guidelines of the curriculum, but students should be able to steer the learning toward their interests." Steve says, "science inquiry should have less teacher guidance. Students should look for answers and want to discover on their own." John explains that inquiry is what "kids do when they are born. They ask questions about the world and experiment with it to find answers. Science inquiry involves a more

methodical approach so that the answers can be confirmed by others. Science inquiry should be about students asking questions, finding their own answers, and coming up with new ideas."

Challenges of Using Science Inquiry

The participants in this study identified four challenges to using science inquiry in the classroom. First, students may lack the ability and background knowledge to conduct science inquiry. Second, providing a more student centered environment may create classroom management problems. Third, teachers feel pressure to address many different topics in science. This is confounded in a general classroom where teachers also have to prioritize multiple subjects. Finally, teachers may not feel comfortable implementing science inquiry.

Student Ability. John, my students generally do not have the skills that they need to conduct science inquiry." He sees specific problems with measuring and math skills, "I see kids in 8th grade that can't use a ruler. I have kids in 5th grade that can't multiply. I have kids in 4th grade that can't add." Without these skills, John contends that you can not do inquiry, "if you don't make measurements, all you are doing is having fun." Jason adds that since students are not introduced to science process skills throughout the year, "they panic when they have to use them."

Classroom Management. Jason and Emma are concerned about how science inquiry will disrupt the classroom and make management difficult. Jason sees a problem of trying to give each group attention to keep them engaged, "Without engagement, they

will be unfocused and off task." In both of Emma's reflections, she commented on her concerns of how moving towards student centered instruction will cause classroom management problems. She states, "I have a great group of students, but it has remained that way because I provide a strong structure by giving clear explanations and expectations. I don't know if you can do that during science inquiry (Emma 2nd Reflection, 3/13/06)" She explains that often her biggest worry is often not, "how can I teach this to my kids, it is how can I handle my students while we get through this subject (Emma 1st Reflection, 2/28/06)?" She states that providing structure makes it, "easier to control and handle squirmy children. I have had problems when students were given more freedom or choice (Emma 1st Reflection, 2/28/06)."

Curriculum Pressure. All of the participants identified curriculum pressure as a major challenge to using science inquiry. This pressure is felt from two different sources. First is the vast amount of science content that students are expected to learn. Second is the pressures placed on science in a general classroom from other subjects.

In his second reflection, Sam states that inquiry is time consuming. He asks, "if schools using traditional teaching methods are having difficulty achieving state and federal goals, where does that leave those that want to teach science using inquiry (Sam 2nd Reflection, 3/13/06)?" Sam explains that it needs to be clear what teachers are expected to teach, "we need a reasonable number of content objectives (Sam 2nd Reflection, 3/13/06)." Jason and Emma echo Sam's concerns about the pressure to cover a large amount of content. Steve doesn't feel this pressure. He has come to the realization that he can not get through the entire textbook, If I can finish one-half of the book, I feel

comfortable with what I have done." Steve states that the way past this roadblock is to, "define clear conceptual goals and developing inquiry activities that will meet them (Steve 2nd Reflection, 3/13/06)."

The pressure to address a large amount of science content is confounded by the fact that these classroom teachers also teach all of the other core subjects. "I'm not a science teacher, I teach everything," said Steve, "I have to get to almost every subject every day. I'm comfortable with social studies and math, so it is easy to prioritize those over science (Steve 2nd Reflection, 3/13/06)." Steve adds:

> This prioritization is prevalent at all grade levels. I believe it turns into a runaway train or epidemic when it comes to poor prioritization of science. It leaves many students with an inferior foundation of science content knowledge and almost no process skills. Frankly, with all of these factors present, it becomes easier for a teacher to turn his back on science and not even consider any kind of inquiry model at all (Steve 2nd Reflection, 3/13/06).

Sam shares these frustrations. He notes, "I love science, but I have given it a low priority because of my students' needs in mathematics and reading." He states, "I value science so much, but I've reprioritized because I see a greater need to focus on reading and writing." He continues to explain, "this has influenced his decision to use more teacher-centered pedagogy in science."

Teacher Comfort. Steve, Sam, John, and Jason all identified a teacher's low comfort with science content and science inquiry as a challenge to using science inquiry. Steve states, "The biggest restraint is the philosophy of the teacher or the comfort level of the teacher. It is a difficult and scary thing for some teachers to try to do that." Since Steve does not have a strong science background, he puts himself in that category.

Because of his lack of science background, Steve thinks that he may have a "longer road to travel than some," when it comes to using science inquiry. Jason explains in his first reflection that he is a relatively new teacher and was trained in an accelerated program that didn't spend much time on how to teach science. Therefore, he sees his understanding of science inquiry as a barrier to implementation. In both his interview and first reflection, John explained that a lot of professional development opportunities focus on using hands-on activities to make science fun without connecting the activity to learning. This either convinces the teacher that the point of science in middle school is to entertain students, or they are turned off from using hands-on activities. Sam explains, "No teacher would admit that they don't know how to teach reading, but no one is afraid to admit that they don't know how to teach science." He continues to explain that it is difficult to ask teachers to use science inquiry when they do not have a handle on the standards, do not have a general comfort level with science, and do not have easy access to resources.

Science Inquiry Shows Promise

In their reflections, Steve and Jason both see the potential for science inquiry to have a positive impact on their students. Jason explains, "science inquiry appears to be more engaging because it uses their experiences to help guide their learning. It makes science relevant to them, which should get them excited and increase conceptual understanding (Jason 1st Reflection, 2/28/06)." Steve remembers activities that he has done in the past that allowed students to produce questions, "Those activities were engaging for the students and it was engaging for me because I could see their

motivation." Steve believes that, "science inquiry can produce better scientific thinkers (Steve 1st Reflection, 2/28/06).

Initial Questions about Science Inquiry

Three specific questions emerged from the reflections that the participants completed during the first stage of this study. Sam is interested in which concepts and skills are best taught through science inquiry. Emma wonders, "What is the balance of inquiry needed to maximize learning? I want students to feel comfortable with new information, but I do not want to linger on topics too long (Emma 2nd Reflection, 3/13/06)." She wants students to feel comfortable with new information, but she does not want to linger on topics too long. Jason, Sam and Emma all wonder what science inquiry will look like in their classroom.

Summary of Initial Conditions

In this section, the participants described their views of what good science teaching should look like and their current science teaching practices. The participants also shared their understanding of science inquiry and their concerns about using science inquiry in the classroom. Table 9 provides a matrix that summarizes this section.

Table 9. A Summary of Responses from the Initial Interview and Participant Reflections.

	Sam	Jason	Emma	Steve	John
Good Teaching					
	Good teaching is relevant, engaging and focused on kids. Connect activities to content, some direct instruction is needed, focus on outcomes	Current – teacher centered, focusing on ABC to help engage. Ideal should be more student centered, but he has "crashed-and-burned" when he tried.	Good teaching is assessing prior knowledge, picking out vocabulary, see concepts in action, structure is very important	Leans towards lecture format, looking for better ways to teach science	Believes instruction should start with what the students know and how it is connected to their lives. It takes more than content knowledge, pedagogy is important.
Student factors					
	Prior experiences limited, scaffolding, relevancy	Prior experiences limited, scaffolding, relevancy	Prior experiences limited, scaffolding, relevancy	Prior experiences limited, scaffolding, relevancy	Prior experiences limited, scaffolding, relevancy
	Not as critical and skeptical as they should be.	Teachers are only role models for valuing education, tries to build personal relationships	All materials and time to complete projects are provided at school	Adaptation – guided reading packets	Engagement through "crazy stuff"
	Specifically plans for relevancy	Emphasizes engagement and interest,			

Table 9. Continued.

	Sam	Jason	Emma	Steve	John
Current Practice					
Design and resources	Textbook is primary source for instructional guidance, resources and course structure	Often start with KWL, big ideas through reading text, occasionally intro with a short activity (recommended by John) ABC is useful and a big focus for him this year Textbook is primary source for instructional guidance, resources and course structure	Often start with KWL, big ideas through reading text, occasionally intro with a short activity (recommended by John) Stresses vocabulary, demonstrate concepts in whole group settings Textbook is primary source for instructional guidance, resources and course structure	Textbook is primary source for instructional guidance, resources and course structure	Vast collection of resources and adept at locating resources online. He provides these resources to all teachers.
Emphasis on reading	Emphasis on reading, but more time on class discussion	Heavy emphasis on reading,	Heavy emphasis on reading,	Heavy emphasis on reading,	
Discussion structure	Majority of discussion is teacher-centered, student "cross-talk" is not common.	Majority of discussion is teacher-centered, student "cross-talk" is not common.	Majority of discussion is teacher-centered, student "cross-talk" is not common. Often sees "wait-time" as an opportunity for students to tune out.	Majority of discussion is teacher-centered, student "cross-talk" is not common.	Majority of discussion is teacher-centered, student "cross-talk" is not common.

Table 9. Continued.

	Sam	Jason	Emma	Steve	John
Prior knowledge	Uses a variety of means to identify students' initial conceptions. Views initial conceptions as a way to set the stage for learning new content. Sometimes he addresses misconceptions through activities, but often he takes a more direct approach. Does not use initial knowledge for unit planning.	Uses KWL to identify prior knowledge, addresses misconceptions immediately in a lecture format. By the second reflection, notes the importance of students clarifying initial conceptions and begins to doubt that his approach to changing misconceptions is effective. Does not use initial knowledge for unit planning.	Uses KWL to determine prior knowledge, but thinks that it isn't always useful since ideas sometimes don't change after instruction Does not use initial knowledge for unit planning.	Generally too structured and rarely attempts to find students' prior knowledge Does not use initial knowledge for unit planning.	Uses a variety of techniques to determine initial conceptions. Often won't tell students when a misconception is identified. Later, he can use their experiences to confront the misconceptions. Consistently states that identifying and building off of students' initial ideas are very important to his instructional style. Does not use initial knowledge for unit planning.
Group work	Small amount of group work, mostly during hands-on activities.	Small amount of group work, mostly during hands-on activities.	Small amount of group work, mostly during hands-on activities.	Uses group work sparingly. Special needs students are allowed to read in pairs.	Students work in groups extensively
Assessment	Traditional summative assessment, informal "quick" formative assessment	Traditional summative assessment, informal "quick" formative assessment	Traditional summative assessment,	Traditional summative assessment, informal "quick" formative assessment	Not responsible for grading so summative is not important, informal "quick" formative assessment

Table 9. Continued.

	Sam	Jason	Emma	Steve	John
Activity structure	Infrequently use hands-on activities, usually confined to John's laboratory sessions	almost always given question, detailed procedure, data tables and guidance in how to collect and record data.	almost always given question, detailed procedure, data tables and guidance in how to collect and record data.	almost always given question, detailed procedure, data tables and guidance in how to collect and record data.	almost always given question, detailed procedure, data tables and guidance in how to collect and record data.
	almost always given question, detailed procedure, data tables and guidance in how to collect and record data.	Activity is usually demonstrated for the class before students do it for themselves	Activity is usually demonstrated for the class before students do it for themselves	Activity is usually demonstrated for the class before students do it for themselves	Activity is usually demonstrated for the class before students do it for themselves
	Activity is usually demonstrated for the class before students do it for themselves	Guidance in how to write the conclusion	Guidance in how to write the conclusion	Guidance in how to write the conclusion	Guidance in how to write the conclusion
	Guidance in how to write the conclusion	Attempt to have students ask new questions from results, but rarely followed-up on.		Attempt to have students ask new questions from results, but rarely followed-up on.	Attempts to provide opportunities for students to determine their own procedures on a regular basis
					Attempt to have students ask new questions from results, but rarely followed-up on.

Table 9. Continued.

	Sam	Jason	Emma	Steve	John
Understanding of Science inquiry					
	More student led, involves students investigating their questions.	More student led, involves students investigating their questions.	More student led, involves students investigating their questions.	More student led, involves students investigating their questions.	More student led, involves students investigating their questions.
	Going with student questions instead of sticking to rigid outcomes, realizes that inquiry exists on a continuum of teacher control		Groups asking and working on questions, spending large intervals of time investigating	Less teacher guidance, looking for answers and want to discover on their own	It is what kids do when they are born – ask questions about the world and find answers, science inquiry is more methodological – asking questions, finding answers, and coming up with new ideas.
Challenges of using Science Inquiry					
Student Ability					Students lack process skills, specifically measurement
Classroom Management		By making the classroom more student centered, classroom management will become a problem	By making the classroom more student centered, classroom management will become a problem, she has a good group of students because of the structure of her classroom, problems arise when students are given more freedom or choice		

Table 9. Continued.

	Sam	Jason	Emma	Steve	John
Curriculum pressure	Science inquiry takes time that makes it harder to balance all of the learning targets	Science inquiry takes time that makes it harder to balance all of the learning targets	Science inquiry takes time that makes it harder to balance all of the learning targets	Doesn't feel pressure to get through all of the learning targets because it simply isn't possible	
	Generalist teachers are responsible for more than science, reading and mathematics are given a higher priority	Generalist teachers are responsible for more than science, reading and mathematics are given a higher priority	Generalist teachers are responsible for more than science, reading and mathematics are given a higher priority	Generalist teachers are responsible for more than science, reading and mathematics are given a higher priority, prefers math and social study – so those naturally get more attention	
Teacher comfort	States, no teacher would admit that they don't know how to teach reading, but no one is afraid to say that they don't know how to teach science.	Accelerated certification program did not focus on science pedagogy, lack of knowledge of inquiry is a barrier.		The biggest constraint is the philosophy and comfort level of the teacher. Science inquiry is foreign and scary to many teachers	
	It is difficult to ask teachers to teach science inquiry when they don't have a handle on the standards, are not comfortable with the content, and do not have easy access to resources			My background may give me a longer road to travel than others when it comes to science inquiry	

Table 9. Continued.

Sam	Jason	Emma	Steve	John
Science inquiry shows promise				
	Potential to have positive impact on their students		Potential to have positive impact on their students	
	Appears to be more engaging because student experiences drive their learning, it makes science more relevant.		Remembers past activities that allowed students to produce questions, they were engaging and motivating for his students.	
			Science inquiry can produce better science thinkers	
Initial questions about science inquiry				
What concepts are best taught through science inquiry	What will it look like in my classroom?	How to balance inquiry to maximize learning, spend enough time so students are comfortable but not too much time		
What will it look like in my classroom?		What will it look like in my classroom?		

Post Professional Development Conditions

Participants were interviewed after the professional development sessions were complete. The participants had completed the development of their science inquiry unit and were preparing to implement the unit with their students. This second interview was used to gauge participants' change in understanding of science inquiry. Participants were asked a series of questions related to their definition of science inquiry. Participants were also asked about the school's science fair program. These questions were important because it was a recent example of science inquiry that all of the teachers participated in. Finally, the participants were asked to describe their unit, their reactions to the unit and how they thought their students would react to it. All of the quotes in this section come from the second interview conducted on May 1, 2006.

Defining Science Inquiry

Participant responses in this category of interview questions can be summarized in five themes. First, participants' general definition of science inquiry will be discussed. Second, the participants' understanding of the continuum of teacher control in science inquiry will be described. Third, I will discuss how participants see that their understanding of science inquiry has changed since the beginning of the study. Fourth, participants' beliefs about how science inquiry will work with their students are presented. Finally, concerns about science inquiry that were given by participants will be discussed.

What is Science Inquiry? A comment by Sam summarizes the basic definition of science inquiry given by the participants, "Science inquiry is the process of asking questions and finding answers." All of the participants explained that science inquiry is more student-centered and involves students asking questions, conducting experiments to answer those questions, and communicating the results of those experiments. All of the participants identified the importance of determining what the students already understand about a topic and trying to use that as a starting point for generating questions. Emma stated, "In science inquiry, teachers do not plan a project from beginning to end. Instead, they think about what they want students to discover and plan experiences to help them find what they already know, generate questions, and determine an experiment to answer those questions." Jason stated, that inquiry involves "turning over the reigns to the kids a bit. If they can incorporate their background knowledge to start forming concepts and questions, maybe it will have more meaning for them."

All of the participants stated that the most important aspect of science inquiry is students generating a good question. "Without a good, researchable question, you can't do inquiry," stated Steve. Sam noted that science inquiry can be facilitated by teacher scaffolding and questioning. Specifically, he noted that students can generate an experiment through class discussion by "teachers asking what do we have to do; what kind of measurements and data should we collect; and what should we do with that data?" Jason explained, "there needs to be a structure to collect data related to the question. Students also need to be able to communicate their results to other people." John indicated, "discussion is a very important component of science inquiry. Students

should share what they are wondering and what they are finding." Emma felt that it is important to assess, "how well students stay focused on the question and how they apply the scientific method to get good results."

A Science Inquiry Continuum. Science inquiry can be viewed on a continuum of teacher control. In structured inquiry, the teacher determines the specific questions, procedures, and reporting mechanisms that the students will use. In open inquiry, these are all determined by the students. Guided inquiry lies somewhere between the two (Bonstetter, 1998; Colburn, 2000). "I was a little worried about inquiry because I saw it as almost totally open inquiry, which would be difficult for our students at this point," said John. This idea of science inquiry as being almost totally student-centered, or open, was held by all of the participants before this study began. "I thought it had to be open discovery, but I discovered that there can be some structure," said Emma. Jason states that he did not understand that there were different levels of science inquiry, "I saw it as binary, either it is open inquiry or it is not inquiry." Jason describes the level of teacher control as, "is it more in the students' hands or is the teacher a script writer?" Steve notes that it is possible for there to be inquiry in a more guided approach. He adds, "What is important is that there is thinking going on all the time. There has to be some guidance going on to make sure that kids are getting what they need to know."

Other Changes in Understanding. In addition to the participants gaining an understanding of the science inquiry continuum, they identified other areas where they had changed their thinking. Sam gained a new appreciation for the importance of a pre-

assessment. He stated that he usually does quick assessments by using a "thumbs up, thumbs down" approach to gauging understanding. However, he states, "now I see the importance of developing a pretest to both clarify what the learning outcomes are and to see what my students initial understandings are." The other participants place similar value on the pre-assessment and planning process. Steve mentions that a lot of things have been clarified in his mind. He also recognizes that some topics may not be more difficult for implementing inquiry. Steve comments that it is a bit more difficult to prepare for science inquiry, but it feels great when the kids start doing it. John gained an understanding of the importance of metacognition, of having students think about how their thinking has changed and why it changed.

Will it Work With My Students? Sam, Steve and John are confident that a science inquiry approach will work with their students. John states, "I think it is going to work. There is excitement (from the participants) in what we are doing." Jason and Emma are more skeptical of how well science inquiry will work with their students. Jason explains that they should be more engaged with this process, but he does worry that they won't be interested. Emma states that it will work very well for some of her students. They will become the leaders in their groups. However, others will struggle without having a list of procedures to follow. Emma anticipates, "it may not be successful initially, but as my students get used to the process, it could be a good thing."

Concerns About Implementing Science Inquiry Units. Sam is not concerned about using science inquiry with his students, "There will be some 'hiccups' along the way, but

I am confident that I can deal with them." Steve has a similar feeling, although he does have some specific concerns that students, "will have problems staying focused on their questions." Emma and Jason share a few concerns. They are apprehensive that their students will have difficulty coming up with questions. They also see problems maintaining their students' interests late in the school year. They both hope that investigating water, something familiar to their students, will help keep interest high. Jason and Emma are also concerned with the "unscriptedness" of science inquiry. They are both used to designing the lessons and activities that students will do. In science inquiry, they won't be able to prepare with a great level of detail. Jason states, "I don't know how to teach inquiry yet. I'll learn while I am doing it."

Science Inquiry and the Science Fair

Every year, the students and faculty at Becker School hold a science fair. It provides a chance for students to investigate science questions that interest them and showcase their science process abilities. Unfortunately, the experiences of the students and teachers may not be as strong as it could be. In this section of the second interview, participants discuss the science fair, struggles that students have with developing questions for the science fair, their perception of student success, and comparisons between the science fair and the science inquiry unit that they developed.

The Science Fair. All of the participants worked with their students as they developed their science fair projects. John acted as the science fair coordinator for the entire school. Overwhelmingly, the participants described situations where students

needed significant guidance in order to complete their projects. Emma explained, "I had to help all of my students because they did not know how to proceed." This comment was similar to statements from the other participants. Steve states, "We (teachers) hope that by eighth grade the students will be able to complete a project on their own, especially the students who have been at the school for six years. However, only two or three students in my class were able to work independently." Jason commented, "I got students materials and had to hold their hands through the entire process."

The participants noted that their students lacked the base knowledge and skills, even measurement skills, to be able to conduct investigations. Steve acknowledges that this is "probably because the teachers don't focus on independent investigations during the year, just during science fair." Steve explained, "most of my students are so used to structure that it is almost impossible for them to work alone. They have a need to know if they are doing things correctly at every step in the process." Emma noted, "I had to teach my students how to identify variables and help students step-by-step to map out their experiment."

Developing Questions. All of the participants agreed that having students develop their own question for the science fair was the hardest part of the process. "Of the twelve groups in my class, all of the questions came from my head. The questions were not theirs," stated Jason. Sam explained that he provided a lot of help to students as they developed their questions. Emma adds, "I do not think that too many of my students ended up with questions that they were really interested in." Steve notes, "My students

either chose questions that were too simple or chose questions that were so difficult that they cannot answer them."

Was Science Fair Successful? "If you use the criteria of having students being able to work independently and having the background and skills needed to do their own inquiry, I would say that we were not very successful," stated Sam. All of the participants in this study shared this comment. However, they also all realized that this lack of background was a result of not emphasizing science inquiry throughout the school year. Steve commented, "They (students) have never done anything on their own before in science. They do not have a comfort level." John echoed this sentiment when he said, "We don't do it (inquiry) enough. When we get to the science fair it is too overwhelming because we have not done anything like it during the year." Jason explains that he should have spent time teaching what an experiment looked like, "I assumed that my students knew more than they did."

Comparing the Science Fair and the Science Inquiry Unit. Steve stated, "Comparing science fair to the unit I developed is almost like comparing apples to oranges. I am hoping that it will be a lot more student led. I am hoping that they can go farther on their own." Jason and Emma feel that their students should be more successful in their unit because it is more focused, so the students won't be overwhelmed. Emma stated, "We will be able to build background knowledge with students so that when we give them the opportunity to do open inquiry they can succeed." Sam describes a similar approach, "I am looking at being more structured. They will be grouped and will come up

with a few questions to investigate as a group." He also adds that since he will know in advance the types of things that his students will be investigating, "I will be able to do benchmark work. I can provide scaffolding so that students can practice the skills that they will need to complete their investigation." John adds that "students should be more comfortable with these units because they just went through the process with science fair." He stated, "If we relate this to science fair, the kids won't be freaking out."

Inquiry for Conceptual Change Units

In the final part of the second interview, participants were asked questions about the units that they developed. The themes in this section describe the participants' thoughts and feelings related to the development of their unit just before the units were implemented. This section will begin with a brief overview of the units that were developed. Then, four themes that emerged from the interviews will be discussed. The first theme is the challenge of determining the scope for the unit. The next theme involves concerns that the participants have with implementing their unit. The third theme discusses their willingness to do more science inquiry in the future. The final theme identifies time as a major constraint for using more science inquiry based instruction.\

Unit Overview. This section will only contain a thumbnail sketch of the units that were developed by the participants. The units will be described in detail in the unit implementation portion of this chapter. As the science laboratory teacher, John had a unique role in the development of these units. Although he was not responsible for a

specific unit, he did provide support to all of the other participants. He spent most of his time working on the units developed by Sam, Jason and Emma.

Sam developed a unit for his fifth grade class with a primary objective of understanding how pollution affects plant growth and a secondary objective of having students understand the lifecycle of plants. He began by focusing students' attention on their ideas about pollution and its affect on plants. He then provided background through direct teaching methods on pollution. As a class, students generated questions on how specific types of pollution could affect plants. Students then grew control and treatment Wisconsin Fast Plants. Wisconsin Fast Plants are commonly used in education because they can complete a full life cycle in just over one month. Sam provided students with benchmark activities to help them understand protocols for making observations, data collecting, and data reporting. The unit concluded with a presentation of the students' findings to a class of third grade students that are also studying plants.

Emma and Jason worked together to develope a unit for their sixth grade classes with the primary objective of having students understand how water shapes the Earth. The unit focused on how water changes the surface of the Earth and how it sustains life. Students went on a field trip led by a geologist from a local university. During the field trip, they saw examples of how water shapes the land and how humans try to influence the flow of water. Students visited a water treatment facility and saw where their household water originates. Students also conducted an activity to review the water cycle. After the students gained this background knowledge, they developed investigations that

could be conducted using stream tables. Some student groups investigated how filters could be designed to clean water.

Steve developed a unit for his eighth grade class with the primary objective of students understanding the difference between series and parallel circuits and the flow of current in circuits. The unit began with a very guided exploration in which students were asked to use a set of materials to make a light bulb light. Next, students discovered series and parallel circuits by completing a structured inquiry activity that had students build circuits that allowed a light to be turned on and off with a sequence of switches. Finally, students investigated the direction of current flow in different types of circuits using a compass and ammeter.

Deciding on a Scope for the Unit. The participants found that one of the most challenging aspects of developing their unit was to decide on what should be taught. Steve explains, "Deciding what I wanted them to know and how far to take it was very challenging." John made similar comments regarding deciding what the major topics and subtopics of the unit should be. Sam and Emma also found this step difficult. John added that the collaboration between participants helped to determine the scope of the units, even when participants were not working on the same unit.

All of the participants agreed that designing a pre-test, while challenging, was very valuable in further refining the scope of their unit. Results from the pre-test will be discussed in the unit implementation portion of this chapter. John stated, "I thought it was great that we had to write expectations, what we wanted kids to know. Generating the pretest helped us define what we wanted the kids to know." John added, "We say that we

do that (start with what the kids know), but we don't really do it. It may affect small portions of what we teach, but it doesn't regularly affect how we organize our units." Steve explained, "Developing the pretest was very valuable for me. It clarified what I would be teaching. You couldn't develop a unit without it….well, you could, but you would not be addressing the issues that needed to be addressed." Sam added that the pre-assessment design compelled him to consider the following questions:

1. What knowledge and skills are indicated by the standard?

2. What do I really want students to know?

3. What scaffolding will be necessary so that students will meet the standard?

4. In what context are the knowledge and skills usually found in the students' lives?

Sam stated that that last question caused him quite a bit of frustration, "You (the researcher) pressed me to place my questions in a context that the students were familiar with. It was frustrating and difficult, but I think it paid off in the student responses."

Emma commented, "The results of our (Emma and Jason) pretest showed us where we could start, so that we do not have to repeat topics that the students were comfortable with." Jason added, "The responses were valuable because I knew what content we needed to address." Sam explains, The gaps between actual student responses and ideal responses are beneficial in two ways. First, it forced him to consider the validity of specific questions included in the instrument. Second, the identified gaps that were not due to poor questions provided the objectives for the unit lessons." Sam states, "Without this process, I might have developed lesson objectives that did not address my student

needs, which probably often happens when a teacher blindly uses a textbook scope and sequence."

    <u>Concerns About Implementing the Science Inquiry Unit.</u> The participants identified three major concerns and one coping mechanism for the implementation of their unit. Jason, Emma and Steve have concerns about classroom management as they implement their unit. The unit is being implemented near the end of the school year, so they are concerned that students will not be engaged and will not stay on task. However, they are hoping that the open-ended nature of science inquiry will help them stay focused. Jason is specifically concerned about how the high level of absenteeism in his class will affect the implementation of his unit, "On any given day, nearly one-quarter of my students could be absent." At this point in the project, neither Jason nor Emma could picture what science inquiry will look like in their classrooms.

    Emma and Jason are concerned that their students will not have the necessary background knowledge to be successful in the investigation portion of the unit. John hopes that the implementation of this unit will help teachers get past wondering if their students are capable of conducting science inquiry.

    Emma and Jason are also concerned with the lack of structure in their unit. Emma states, "I have a map of how the lessons might progress, but not a step by step plan for what will happen. I learned to teach by developing very detailed lesson plans." Emma states, "I don't have a clear idea of how to order the lessons because I have to wait for the kids to come up with ideas. That is a challenge for me." She sees that this unit "is much less focused on the textbook and vocabulary and more focused on the topic. It is more

active instead of reading and note taking. Students will also go out into the community to see things outside of the classroom." Emma explains, "I am concerned with how much guidance to give students." Jason states, "I feel apprehensive because this unit is totally different from what I have done in the past. I feel disorganized, chaotic and out of control." John understands that this unit is very different from how Jason and Emma normally teach, but he "hopes that the implementation of the unit will give them the confidence that they can teach in a more student centered manner."

Sam and Steve do not feel any strong concerns about implementing their units. Steve has some issues with obtaining the materials for the unit, but once that is resolved, he does not see any problems. He stated, "I guess there may be some forks in the road that could mess me up, but we will deal with it as it happens." Sam shares a similar comment, "I am comfortable being a little unsure of how it is going to unfold. I am not afraid of kids not following a linear progression." Sam and Steve's lack of concern is because they are comfortable being flexible. As Sam states, "I am willing to take what comes, so I don't have any concerns."

Doing More Inquiry. During the interview, each participant was asked if they saw themselves developing more science inquiry units for their classroom. John, Sam and Steve were confident that they would do something like this again. John stated, "I will do this again, especially if kids come out learning. I'll be spending my time doing this because it really opened my eyes at looking at planning ahead of time with a pretest." Steve mentioned that he would like to try to do some planning for next year during the summer. Sam explained, "I am used to showing teachers bits and pieces of things

(inquiry) and doing things here and there, compartmentalizing them in a day or two. I have not done any long term investigations. I think this unit is going to open me up more to longer investigations."

Emma and Jason were not as confident about their future using science inquiry. Emma sees herself slowly working toward more inquiry. She stated, "I might like to include more of the book, or more activities from the book, but also include something that really has kids come up with questions. It will take some time for me to become comfortable with it." Jason has not made a decision on his future with science inquiry, "I haven't conquered my fears yet, so we will see how this goes."

Time Constraints. All of the participants agree that time is a major stumbling block to implementing more science inquiry. "Why can't we do this all of the time? We can, we just don't have time," stated John. "We are crazy here, you hear those teachers out in the hall (during the interview)? It is 5:30 and they are still working. It isn't desire, it is just that we get to the point where we don't have any left to give." Steve adds, "We went through more than five weeks of preparing for a ten lesson unit. Preparing for a full year would be a heck of a lot of time!" Sam explains that implementing science inquiry takes work "You have to focus your energy on getting it done and getting it into your class schedule."

Emma notes that time within the curriculum is also a constraint. She stated, "Science inquiry is more time consuming than traditional lessons. I feel if I use inquiry I would get through even less…although they would probably learn more. I'm feeling pressured by other science topics and other subjects." Sam echoes this feeling when he

stated, "It relates to bang for your buck. How does it tie in to what you have to teach. I'll do more next year, but I won't be able to do it all of the time. Having it fit into the learning targets is a big obstacle, probably even more so for people that have less comfort with it than I do."

Summary of Post-Professional Development Conditions

In this section, participants described their new understanding of science inquiry and how their views have changed during the professional development sessions. The participants explained how students performed in the school's science fair and compared that event to the type of science inquiry used in their unit. Finally, the participants described the unit that they developed, their reactions to the development process and their concerns about implementing science inquiry. Table 10 provides a matrix that summarizes this section.

Table 10. A Summary of Participants' Interview Responses Prior to Implementing a Science Inquiry Module.

	Sam	Jason	Emma	Steve	John
Defining Science Inquiry					
What is science inquiry? / Characteristics of science inquiry	it is student centered and involves asking questions, conducting experiments, and communicating results	it is student centered and involves asking questions, conducting experiments, and communicating results	it is student centered and involves asking questions, conducting experiments, and communicating results	it is student centered and involves asking questions, conducting experiments, and communicating results	it is student centered and involves asking questions, conducting experiments, and communicating results
	it is important to identify what students already understand about a topic and use that as a starting point for generating questions	it is important to identify what students already understand about a topic and use that as a starting point for generating questions	it is important to identify what students already understand about a topic and use that as a starting point for generating questions	it is important to identify what students already understand about a topic and use that as a starting point for generating questions	it is important to identify what students already understand about a topic and use that as a starting point for generating questions
	The most important part of science inquiry is generating good questions	there needs to be a structure in place to collect data related to the question	it is important to assess how well students stay focused and apply the scientific method.		discussion is an important part of science inquiry, students should share what they are wondering and finding
	Science inquiry can be scaffolded by questioning students about the steps				
Science inquiry continuum	Has a strong technical background in science inquiry and was familiar with the continuum of teacher control.	I didn't understand there were different levels of science inquiry, there needs to be some guidance so students get what they need to know	I thought it had to be open discovery, but learned that there can be some structure		I saw science inquiry as almost totally open, which concerned me because it would be difficult for our students at this point

Table 10. Continued.

	Sam	Jason	Emma	Steve	John
Changes in understanding	Gained an appreciation for the importance of a pre-assessment, it really forces you to clarify your learning outcomes and identify the gaps between what students know and what you want them to know.	Knowing what you want students to get out of the unit and where they are at are very important. The pre-assessment is a good tool	Knowing what you want students to get out of the unit and where they are at are very important. The pre-assessment is a good tool	Knowing what you want students to get out of the unit and where they are at are very important. The pre-assessment is a good tool Some topics, like the human body, may not be appropriate for science inquiry	Knowing what you want students to get out of the unit and where they are at are very important. The pre-assessment is a good tool Metacognition is important because students are explicitly thinking about how their knowledge changed
Will it work?	Confident that the inquiry approach will work.	Somewhat skeptical of how well it will work Students should be engaged, but he is worried about what will happen if they are not interested	Somewhat skeptical of how well it will work It will work well for some students, but others will struggle Initially it may not be successful, but as her students get used to it, it could be a good thing	Confident that the inquiry approach will work.	Confident that the inquiry approach will work.
Concerns	Not concerned, problems will arise, but confidence in ability to deal with them	Students will have problems coming up with questions, problems maintaining interest late in the year The unscriptedness of science inquiry is very different from their usual method of lesson planning	Students will have problems coming up with questions, problems maintaining interest late in the year The unscriptedness of science inquiry is very different from their usual method of lesson planning	Not concerned, problems will arise, but confidence in ability to deal with them Concerned that students may not stay focused on their questions	

Table 10. Continued.

	Sam	Jason	Emma	Steve	John
Science Inquiry and Science Fair					
The science fair	Students need significant guidance during most stages of preparing for the science fair. Students lack base knowledge and skills needed to conduct investigations, because these skills are not a focus during the rest of the year	Students need significant guidance during most stages of preparing for the science fair. Students lack base knowledge and skills needed to conduct investigations, because these skills are not a focus during the rest of the year	Students need significant guidance during most stages of preparing for the science fair. Students lack base knowledge and skills needed to conduct investigations, because these skills are not a focus during the rest of the year	Students need significant guidance during most stages of preparing for the science fair. By 8th grade, only 2-3 students are able to work independently on their project Students lack base knowledge and skills needed to conduct investigations, because these skills are not a focus during the rest of the year Students are so used to structure that it is almost impossible for them work alone.	Students need significant guidance during most stages of preparing for the science fair Students lack base knowledge and skills needed to conduct investigations, because these skills are not a focus during the rest of the year.
Developing questions	Getting students to develop their own questions was the hardest part of the process.	Getting students to develop their own questions was the hardest part of the process. All of the questions ended up coming from my head, not theirs.	Getting students to develop their own questions was the hardest part of the process. Most students settled for questions that they were not interested in.	Getting students to develop their own questions was the hardest part of the process. Students often choose questions that are either too simplistic or too difficult.	Getting students to develop their own questions was the hardest part of the process.

Table 10. Continued.

	Sam	Jason	Emma	Steve	John
Student success in the science fair.	If the criteria for success is students being able to work independently to conduct an investigation, then we are not successful.	If the criteria for success is students being able to work independently to conduct an investigation, then we are not successful.	If the criteria for success is students being able to work independently to conduct an investigation, then we are not successful.	If the criteria for success is students being able to work independently to conduct an investigation, then we are not successful.	If the criteria for success is students being able to work independently to conduct an investigation, then we are not successful.
	Lack of success is a result of not prioritizing student-centered investigations during the school year.	Lack of success is a result of not prioritizing student-centered investigations during the school year.	Lack of success is a result of not prioritizing student-centered investigations during the school year.	Lack of success is a result of not prioritizing student-centered investigations during the school year.	Lack of success is a result of not prioritizing student-centered investigations during the school year.
Comparing science fair and ICC units	Students should be more successful because the topic is constrained, we can build background knowledge that the need before they begin their investigation	Students should be more successful because the topic is constrained, we can build background knowledge that the need before they begin their investigation	Students should be more successful because the topic is constrained, we can build background knowledge that the need before they begin their investigation	Because the topic is constrained, students should have an easier time generating questions and answering them	Students should be more comfortable because they just went through the science fair process.
Inquiry for Conceptual Change Units					
Unit overview	How does pollution affect plants? What is the lifecycle of a plant?	How does water shape the Earth? How does water sustain life (pollution, drinking water)?	How does water shape the Earth? How does water sustain life (pollution, drinking water)?	What makes a complete circuit? What is the direction of current flow in a circuit? What are series and parallel circuits?	John provided development support for the water and plant units.

Table 10. Continued.

	Sam	Jason	Emma	Steve	John
Deciding on the scope	Deciding the scope and specific learning outcomes for the unit was challenging	Deciding the scope and specific learning outcomes for the unit was challenging	Deciding the scope and specific learning outcomes for the unit was challenging	Deciding the scope and specific learning outcomes for the unit was challenging	Deciding the scope and specific learning outcomes for the unit was challenging
	Designing the pre-test was challenging, but very valuable, it helped participants define what was important for students to understand	Designing the pre-test was challenging, but very valuable, it helped participants define what was important for students to understand	The pretest results showed us where we could start.	Designing the pre-test was challenging, but very valuable, it helped participants define what was important for students to understand	Collaboration between participants and the research helped to determine the scope of the unit.
	Gaps between responses and what students should know provided focus to the learning outcomes			Gaps between responses and what students should know provided focus to the learning outcomes	Designing the pre-test was challenging, but very valuable, it helped participants define what was important for students to understand
Doing more inquiry	Confident that he will do more science inquiry in the future	Undecided. Fears have not been conquered, so it will depend on how this unit goes.	It will take time for me to be comfortable with it. I would like to include more of the book and activities from the book, but also provide an opportunity for generating questions.	Confident that he will do more science inquiry in the future	Confident that he will do more science inquiry in the future

Table 10. Continued.

	Sam	Jason	Emma	Steve	John
Other Concerns	Not overly concerned because he is comfortable being flexible.	Classroom management is a concern, especially with our high rate of absenteeism What is this going to look like? Concerned that students do not have the necessary background knowledge to do investigations. I feel disorganized, chaotic and out of control.	Classroom management is a concern, especially with our high rate of absenteeism What is this going to look like? Concerned that students do not have the necessary background knowledge to do investigations. Normally develops very detailed lesson plants, can't do that with science inquiry because it depends on choices that students make, the lack of structure goes against everything that I was taught about how to teach	Classroom management is a concern, especially with our high rate of absenteeism Not overly concerned because he is comfortable being flexible.	I hope that the implementation of these units will help some of the participants get past wondering if their students are capable of conducting science inquiry. Hopefully implementation will give the participants confidence
Time constraints	Time is a major stumbling block for implementing more inquiry Having it fit into the learning targets is a big obstacle, especially for teachers that have less comfort with them than I do.	Time is a major stumbling block for implementing more inquiry	Time is a major stumbling block for implementing more inquiry Science inquiry is more time consuming than traditional lessons. If I use more inquiry, I will get through less content…although they would probably learn more.	Time is a major stumbling block for implementing more inquiry	Time is a major stumbling block for implementing more inquiry

<u>Unit Implementation</u>

Three units were developed during this study. Sam developed a unit based on how pollution affects plants for fifth grade. Jason and Emma collaborated to develop a unit on how water shapes the land for sixth grade. Steve developed a unit on electric circuits for eighth grade. The units were based on the Inquiry for Conceptual Change model presented in Chapter Three. However, participants had the flexibility to design their unit in a manner that they felt would work best for their students. I provided assistance and resources during the development of the units, but the majority of the work was done by the participants. As the laboratory science teacher, John was not responsible for a specific class of students. Therefore, he was free to assist any of the participants as they developed their units. He played a large role in the development of the plant and water units.

This section of Chapter Four will provide a description of each unit, as well as teacher and student reactions, and evidence of student learning. The description of the unit and teacher and student reactions were compiled from data collected from the final interview, final reflection and implementation journals that participants were asked to keep. Evidence of student learning is provided by the final interview, final reflection, researcher observations, and the pre-and post-assessments.

<u>Grade 5: Effects of Pollution on Plants</u>

Sam's unit had the primary goal of helping students understand the affect of pollution on the growth of plants. The secondary goal was for students to become

comfortable with the lifecycle of plants. In the "Wondering" phase of this unit, students were introduced to sources of pollution and began developing questions about how different types of pollution might effect plants. In the "Investigating" phase, student groups conducted an experiment to determine how a specific pollutant affected the growth of Wisconsin Fast Plants. In the "Constructing" phase, students drew conclusions from their investigations and presented their findings to a class of third grade students. Sam used benchmark activities to connect specific curriculum goals, specifically skills needed to conduct investigations and plant lifecycles, to the unit. Additionally, this unit grew directly from the initial knowledge of students and the topic of the investigation was relevant to their lives.

Plant Unit Detail. This description of Sam's unit was compiled from his implementation journal. The plant unit included 18 distinct lesson spread over a four week time period. During the first lesson, students were asked in a "think, pair, share" activity to focus on what they knew about plants, pollution and the effects of pollution on plants. Students reported out to the entire class and their responses were recorded on chart paper. Sam noticed that most of the students shared their ideas the class. Their comments showed some prior knowledge of plants and pollution, but little knowledge of how pollution might affect plants. Sam saw that the students were somewhat hesitant during the brainstorming and reporting of ideas, but attributes that to his students' lack of experience doing these types of activities.

The next lesson was a benchmark activity with the purpose of improving students' skills with making and recording data. Students used observation skills with a partner to

match creature drawings with descriptions. They also individually practiced observing details and recording results by copying a drawing of a plant. Sam noted that the students were engaged, but some became frustrated with their lack of artistic ability. He thought that the lesson prepared them for making plant observations during their investigations.

The next lesson was another benchmark activity with the purpose of increasing students background knowledge of pollution sources. Students read a chapter in a general science book and viewed a video on pollution. Sam facilitated a discussion on what they saw and read. Sam noted that several of the students seemed to be intrigued by landfills and incineration methods of garbage disposal.

Students then watched a second video on biodiversity and were asked to individually respond to the question, why is it important that I learn about the effects of pollution on plants. Students had to share their answer with the class and were not allowed to "pass." Sam noted that students were reluctant to offer their thoughts on the question. However, he felt that it reinforced the relevancy of the unit.

Sam felt that students were now at the point where they were ready to begin the core investigation for the unit. As a class, students developed a graphic organizer about pollution and began thinking about how pollution might affect plants. Sam noted that the students were engaged and most of the students were willing to share their knowledge. Next, students generated a list of types of pollution that could be tested on plants. Initially, Sam had planned on only using two types of pollutants. However, students demanded to be allowed to test a greater variety of pollutants! Groups of students selected a pollution to test on their plants. Groups selected road salt, ammonia, acid rain

(created by Sam), laundry detergent, smoke, gasoline, antifreeze, and motor oil. Students wrote their investigation question and hypothesis in their journals. Then, groups planted their seeds. Sam noticed that the students were highly engaged in group discussions when selecting a pollution to test. He feels that this lesson went well because of the scaffolding he used to focus students knowledge of pollution.

As another benchmark activity, Sam integrated measurement into his math teaching time. Students practiced measuring using centimeters and millimeters. More competent students helped those that were struggling and all students were able to accurately measure by the end of the period.

Students then discussed what types of data would be useful in investigating the effects of pollution on plants. Student ideas were incorporated into a data collection protocol that would be used by all groups. Sam introduced students to the idea of a control group and a treatment group. He felt that the students were somewhat engaged, but not excited by this lesson. Sam saw that this was a lot of work, but felt that it helped students get their investigations going in the correct direction.

The plants had now germinated and were growing. Students collected their initial data set for both their control and treatment and then applied the pollution to their treatment plants. Sam noticed that his students were excited to see their plants growing and highly engaged when applying the treatment. Students continued to collect data from their control and treatment plants. Students were highly engaged while collecting data. They often stopped by the room before school to check on their plants. Some of the students were dismayed that their plants died very soon after applying the treatment.

Students participated in a benchmark activity where they identified parts of a plant. Students read about plants in their science text and watched a video on plants. Students then examined, drew and labeled parts of plant specimens prepared by third grade students from the school. Sam noted that student engagement was moderate during the reading and high while they were examining plant specimens. Sam focused on parts of plants later in the unit because students felt ownership over their plants and could connect what they were learning to their plants.

Students prepared presentations from their journals on how their selected pollution affected their plants. Students were given a format and worked in their groups to prepare their presentation. Since third grade students were also studying plants, they were invited to Sam's room for the presentations. Sam's students gave their presentations to at least 5 groups of third grade students. Sam noticed a high level of engagement in both the older and younger students. He noticed that his students generally stopped referring to their note cards after the first few presentations and were just able to talk to the students about what they had done. Sam thought that the activity was effective at bringing the unit together for the students. He is convinced that cross grade-level presentations enhance learning.

The fifth grade students completed their investigations of how pollution affects plants by watching the Dr. Seuss video, "The Lorax" and discussing its relevance. Sam was amazed at how intensely students watched the video. He was also excited how students were able to identify the causes and effects of pollution on the environment when they discussed the video.

Sam completed his unit on plants by introducing plant reproduction and having students pollinate their Wisconsin Fast Plants by using bees on a stick. Sam felt that students were engaged when using the bee stick and that the activity really cemented their knowledge of the pollination process.

After reflecting on the implementation of his plant unit, Sam feels that some of the benchmark lessons could have been improved by encouraging students to share their ideas more often. For example, students could demonstrate how they would measure a plant leaf. This would allow for more student ideas to be incorporated into the data collection protocol.

Evidence of Learning Provided by the Teacher and Researcher Observations. Sam teaches 21 students. Of these, 16 are Hispanic and 2 are White. Sam and John were both excited by the amount of learning that they witnessed during the implementation of this unit. John commented that, "The investigations with Wisconsin Fast Plants and experimentation with pollution made the subject matter come alive – or dead, depending on the experimental treatment(John Final Interview, 6/01/06)." John also noticed that they were very engaged and able to apply knowledge from previous lessons when they came in for their weekly laboratory session. Sam explained, I can tell that the kids were really thinking about what they were doing because of the high level of engagement. I rarely had to refocus students during the unit, especially during the hands-on portion of the unit (Sam Final Reflection, 6/05/06)." Sam also felt that students had much more ownership over what they were doing. They responded and asked questions about their observations. During my observation of this unit, I noticed that many of the kids referred

to the control and treatment plants as "our plants" and some of the groups had decorated the containers. I also observed two students ask Sam if they could delay going to gym class so that all of the third grade students could visit all of the fifth grade groups (Field Notes, 5/23/06). They really wanted to share what they learned.

I had the opportunity to observe the class while they were presenting to the third grade students. The student groups were confident when speaking and helped each other answer questions that I posed. When I asked the "laundry detergent group" if they were surprised by what happened, they responded that they were very surprised when their plants started dying right away. The "road salt group" was able to show me in their journals that their plants began to wilt and turn yellow shortly after the treatment was applied. The "ammonia group" concluded that their pollutant was not harmful to their plant. They immediately pointed out that their treatment plant was a darker green than the control plant. They also showed me data in their journals that illustrated that both plants had comparable growth after the treatment was applied (Field Notes, 5/23/06). Figure 14 shows an observation and data section in a student's journal. Figure 15 shows the "road salt group" and "ammonia group" control and treatment plants

Figure 14. A Student Journal Entry for the Plant Unit.
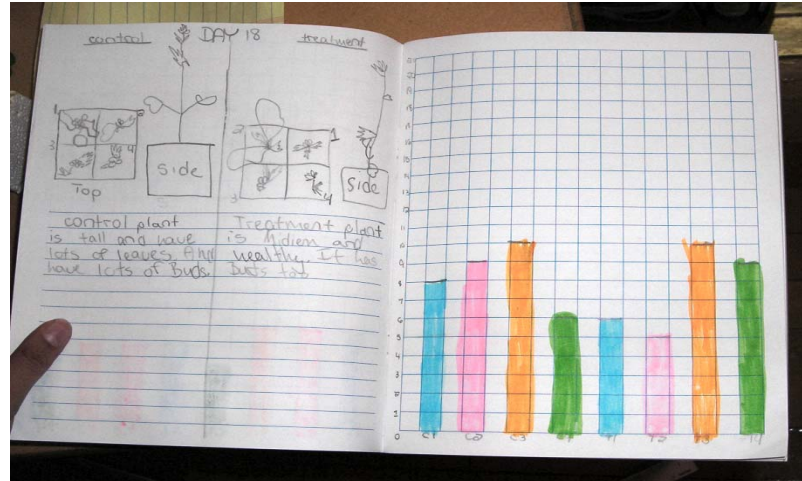
Figure 15. The "Road Salt Group" Plants are on the Left and the "Ammonia Group"
Plants are on the Right.

Sam saw additional evidence that students were learning by the quality of student
discussion and spontaneous questions, "During data collection sessions, students often
gave unsolicited suggestions as to why some plants died quickly. Some students
suggested that the plants were not receiving an equal amount of water. Other students
said that the seedlings might be more fragile than older plants (Sam Final Reflection,

6/05/06)." At other times, student comments showed Sam that his students were thinking deeply about what they were doing, "They were noticing things without being prompted. For example, one group of students suggested that these are small plants and the results might be different if they were testing larger plants (Sam Final Interview, 6/01/06)." During my observation, one group of students said that they were curious to find out what happens to all of the chemicals that they use when they do chores. They are interested in finding out where they go and if they will affect plants. Sam commented to me that that question would never have been asked if it wasn't for this style of inquiry (Field Notes, 5/23/06). Another student commented to me that it was important to know how pollutants affect plants because if we kill off all of the plants, we won't have enough oxygen to breathe (Field Notes, 5/23/06).

Evidence of Learning From the Pre- and Post-Assessment. Before looking at the post test, Sam did not think he would see much growth. However, after analyzing the assessments he stated, "I must say that I was pleasantly surprised at what the students learned. The pre and post tests are significantly different and show good learning (Sam Final Reflection, 06/05/01)." He added, "As a whole, the class showed improvement on each question on the test (Sam Final Interview, 06/01/06).

When compared to the pretest, students were able to label more parts of a plant, identify more needs for a plant to continue to grow, described more causes for unhealthy plants, drew more detailed life cycle diagrams, and had a dramatic increase in the understanding of why bees are important to flowers. Figure 16 shows evidence of how two students ability to identify parts of a plant changed from the pre-test to the post-test.

The top left drawing shows one students' idea of the parts of a plant before the unit. She identifies the "middle part" as a place where bees take honey. This misconception for the importance of bees was the most common response in the pre-test. Only one student indicated that bees take honey from flowers in the post-test. Four students also indicated on the pre-test that plants needed wind to survive. No students indicated wind on the post-test as a need for plant growth in the specific question that asks for needs. However, one student still mentioned a lack of wind as a reason for a plant getting sick.

Figure 16. Student Pre- and Post- Test Sketches of the Parts of a Plant.
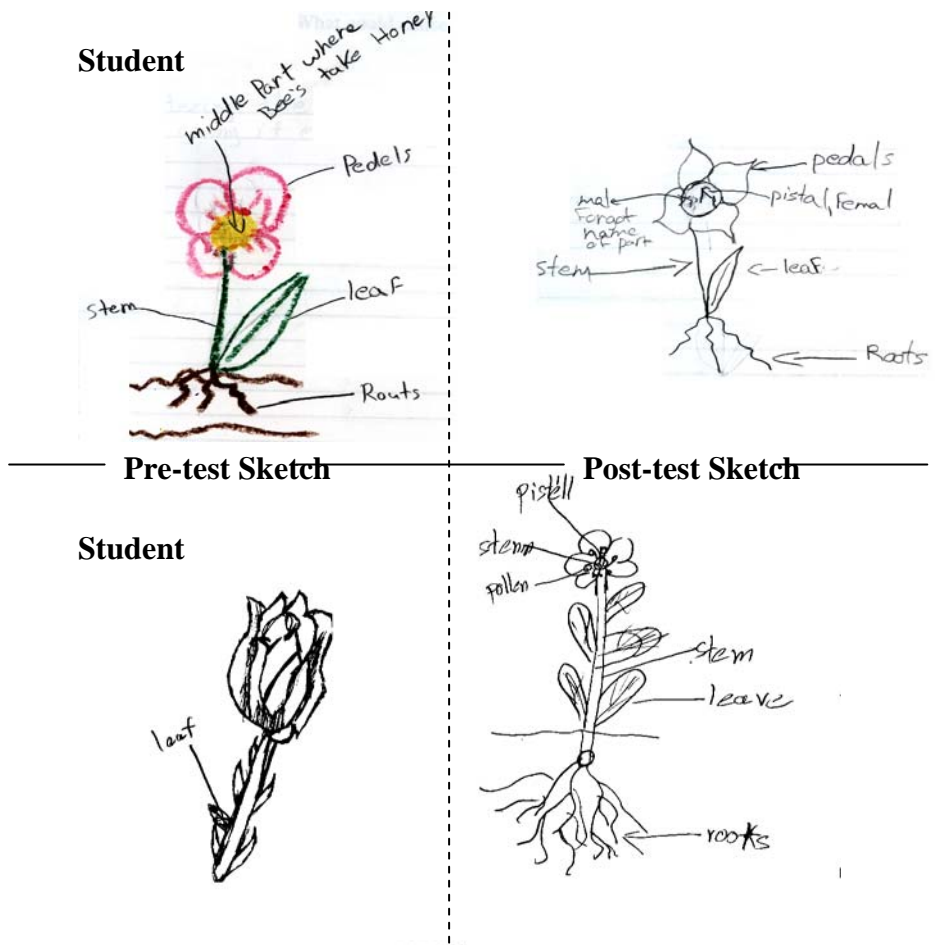
Sam indicated that this data shows that "the unit was effective, but provides some insight into what he could do differently next year to improve the wording of questions and tweaking the focus of the unit." Sam stated, "This really energizes me and makes me enthusiastic about the experience. After looking at the post test results, it looks like the kids gained a lot (Sam Final Interview, 6/01/06)." Table 11 summarizes the student responses for the pre- and post- test.

Table 11. A Comparison of Pre- and Post- Test Responses for the Plant Unit.

Question	Response Categories	Pre-test Responses	Post-test Responses
A. Draw a plant and label its parts.	Pedal / flower, leaf, stem or less	3	0
	Roots and parts listed above	10	9
	Seeds and parts listed above	5	2
	Pistil, Stamen and parts listed above	0	10
B. List the things that a plant needs to grow.	Unknown (leaves, stems, growth, etc.)	2	4
	Water, sunlight	5	4
	Food/soil, water, sunlight	7	5
	Air, food/soil, water, sunlight	4	8
	Insects, air, food/soil, water, sunlight	0	2
	Above plus indicate that the items should be clean.	0	3

Table 11. Continued.

Question	Response categories	Pre-test responses	Post-test responses
C. What could cause the leaves of a house plant to turn brown?	Do not know	1	0
	Not enough sunlight / water	14	11
	Seasons	2	2
	Dying	1	1
	Not enough sunlight / water and pollution	0	7
D. Draw and label the life cycle of a plant.	Could not decipher	3	2
	Seed – little plant w. flower – big plant with flower	4	2
	Seed – roots – little plant w. flower – big plant with flower	7	3
	Seed – roots – stem – flower	1	9
	Seed – roots – stem – flower – pollinate	1	5
E. Why are bees good for flowers?	I don't know	2	1
	They make plants grow	4	2
	They take bad stuff away	4	0
	They take honey from the flower	6	1
	They collect pollen	2	4
	They move pollen to the pistil	0	13

Table 11. Continued.

Question	Response categories	Pre-test responses	Post-test responses
What might make trees sick / leaves turn yellow in the summer?	I don't know	1	1
	Could not decipher	2	0
	Seasons	1	2
	Not enough water	2	0
	Too hot / too much sun	8	5
	Takes time for leaves to turn green	0	1
	Pollution	3	11

Grade 6: How does Water Shape the Land?

Jason and Emma's unit focused on two of the district's learning targets for sixth grade. The first target states that students should be able to conduct scientific investigations, which involves posing questions, making predictions from results, comparing the behavior of models to the behavior of natural things, recording results accurately and writing reports. The second target stated that students should understand how forces, such as weather and geological movement, change the surface of the Earth. Students should be able to distinguish between forces that change things quickly and slowly. Students should also be able to describe the water cycle. Emma and Jason specifically wanted their students to be able to explain the steps of the water cycle and how that cycle impacts their life. They wanted students to understand where they got their drinking water from and how it was cleaned. They wanted their students to know

how water is continually shaping the Earth's surface. Finally, they wanted their students to be able to come up with their own investigation that included asking questions, designing and conducting an experiment, and communicating their conclusions to their peers.

The unit focused on water use and examples of water as a shaping force in the students' community. This helped to make the unit relevant to the students. The unit contained two "trips" through the Inquiry for Conceptual Change Model. In the first two lessons, students' focused on their initial knowledge and asked questions about how a model of the water cycle worked (Wondering phase). In the "Investigating" phase, students conducted informal experiments to answer their questions about the water cycle model. In the "Constructing" phase, students connected what they saw to their initial knowledge and discussed their findings with the class. In the remaining lessons, students investigated how water can be cleaned and how it shapes the land. In the "Wondering" phase students took a field trip to sites that showed how water shapes the land and how drinking water was obtained and cleaned. Students also were introduced to a variety of images that showed water features. Students discussed how these features may have been formed. This led to the generation of questions that could be investigated. During the "Investigating" phase, students either investigated how water shaped the land or how filter systems cleaned water. In the "Constructing" phase, students prepared presentations so that they could share their results with the entire class. The field trip served to strongly connect this unit to the students' lives. Additionally, a few benchmark activities connected specific curriculum goals to the unit.

Water Unit Detail. The description of the water unit was compiled from Jason and Emma's implementation journals. The water unit included 10 lessons spread over a two week period. Each lesson lasted approximately one hour. In the first lesson, students worked independently to develop a KWL chart on water. The teacher then compiled the individual KWL's into a master chart for the class. Students then discussed the chart and categorized the questions. Emma was disappointed with the difficulty that her students had coming up with things that they knew and questions about what they wanted to know. Emma's students made statements similar to: we need it to live; we drink it; and it is a liquid. Jason was impressed with his students' questions and their interest in the subject. He noted that spontaneous discussion arose as they reviewed the chart. His students asked questions related to how water gets on the outside of a soda can (condensation), to what would happen if all of the water on Earth gets dirty?

In the second lesson, students followed directions to build a model of the water cycle in a jar. Students were not told what they were making, but instead were instructed to try to figure it out by referring to their KWL chart. Emma stated that her students were engaged and asked good questions. She gave them time to experiment with the model to try and answer those questions. Emma's students struggled with writing down explanations of what happened. Jason stated that this lesson exceeded his expectations. He explains that his students were highly engaged, used vocabulary from the KWL chart and were able to correct their initial incorrect conceptions about the water cycle. Jason provides one example of how students were able to use technically correct explanations,

"One group explain that the smoke from the match dropped in the jar are little particles that the evaporating water can cling on to form a cloud."

In the third lesson, students worked in groups to communicate their results to the entire class. Jason felt that once the students got over their apprehension of public speaking, they performed well. They often compared their conclusions to those of others and asked questions of other groups when their results disagreed. Jason felt that his students were able to connect their observations of the water cycle model to real-world examples. Emma's students had difficulty communicating their results, so she had to provide them with specific questions to answer. She was pleased with how they answered those questions.

During the fourth lesson, students viewed images of landforms and waterways and attempted to explain how they were developed. The landforms and waterways included meanders, rapids, deltas, canyons, alluvial fans, river beds, damns, irrigation, and polluted areas. Jason felt that his students were inquisitive and actively shared their beliefs about how the features were formed. Emma stated that her students commonly said that the features were caused by flooding, hurricanes and glaciers. She struggled with how to phrase her questions as they went through the images. Neither Emma nor Jason felt that the students became dissatisfied with their ideas of how these were formed.

Following the images, the students took a field trip to do field work at a park with a river and one with a lake. Students also visited a local university laboratory that is dedicated to river and lake research. Jason was pleased with the fieldwork and the level of engagement of his students. They pointed out many of the features that they saw in the

images and asked many good questions. Students also collected data, including flow rate, direction and temperature. In hindsight, Jason wishes he had had his students spend less time collecting data and more time observing features. Emma did not feel that her students were actively engaged in the fieldwork. She stated that they asked very few questions during the experience.

In the next activity, students reviewed their KWL and generated questions that could be tested in the laboratory. Jason, stated, "I am getting happier by the lesson. Although I helped the students refine their questions, they posed excellent, testable questions that I hope will be answered." Questions included, what happens to a river when a dam is built on it, and how do you clean dirty water so that we can use it? Emma was concerned that her students did not understand what a testable question was. She helped them generate a list and then rephrased questions so that they could be tested. The final questions for Emma's students were very similar to the questions for Jason's class.

After breaking into groups and selecting questions, the students designed an experiment to test their question and used stream tables to begin investigating their question. Jason was pleased with the level of engagement, but frustrated that they were not applying knowledge from other sources (the textbook, fieldtrip, etc.). Jason was pleased with the attention that his students paid to their question, but noticed that they were becoming frustrated by their inability to answer their question from the stream table. Jason too was frustrated by the logistics for the investigation. Students had to spend just as much time with set up and clean up as they did exploring. He explained, "…fifty pounds of sand plus gallons of water equal a heavy mess." Emma had a hard time

watching her students struggle. They didn't seem to know what to do besides play with the materials. She tried to guide them, but they were not able to apply knowledge.

Emma and Jason took different approaches to how they constructed the investigation during the second day. Emma continued to let her students work with little guidance. Although her students were engaged, they were frustrated that they were not answering their questions. When Jason's students returned to their lab, he provided them with some additional guidance. His goal was to help them better model what happened in nature. He told students that they should not pre-cut channels to form their rivers and should try to pour their water at a constant rate. He saw that his students were excited to better understand the process and were able to make connections between the model and the real world. Jason stated:

> Watching students attempt to test their theories about a particular process and not seeing it occur in the model, becoming dissatisfied, was enlightening for the students and rewarding for me. Watching students take different approaches as a result of this dissatisfaction and discovering correct cause and effect relationships was exciting for both the students and me. This lab went well (Jason Implementation Journal, Lesson 8).

In the ninth lesson, student groups reflected on what they learned and prepared a presentation that they would share with the class. Jason was encouraged to see that most of the members of each group were engaged. This showed him that everyone participated during the stages, because members within groups had differing initial beliefs about the processes. Jason noted that some of the groups had difficulty putting their thoughts and records into words, but with support were successful. Emma noticed that most of her students were not engaged and she had to redirect them multiple times. Her students

resorted to the standard science fair format for their presentation and frequently asked her if their conclusions were correct. The difference between Jason and Emma's students at this point in the unit may be because of Emma's bilingual students having a lack of confidence communicating in English.

Students orally communicated their new understandings to their classmates in the final lesson. Emma continued to be discouraged that her students were not able to effectively communicate what they did in their investigations. Many of them were not able to retell what they did during the investigation. Emma felt that students learned during the investigations, but, since they have difficulties communicating, she is not sure how she can assess their work. Jason felt that his students enjoyed the oral presentations more than past ones because they were knowledgeable and confident about the subject matter. Jason observed that students were enthusiastic presenters and active listeners. Some students in the audience asked questions to the presenting group and some presenters engaged audience members by asking them questions.

After reflecting on the implementation of their unit, Emma feels that she would model the investigation portion more so that her students felt more comfortable working with the materials. Emma does not know what she could do to increase student engagement, because students were given plenty of opportunities to generate questions, investigate those questions, and work in groups. Jason would like to give students more time to investigate the next time he does this lesson. He thinks students would have gotten to where he wanted them with less assistance from him, but he was running out of time and had to accelerate their work. One of the biggest challenges for this activity was

the logistics of using stream tables. In each lab session, students only had about 20 minutes of actual work time, with 40 minutes of set-up and clean-up. Jason, Emma and I did not anticipate this. Jason commented, "I would have loved more time. It was so messy, we just ran out of time and cleaning materials."

Evidence of Learning Provided by Teacher and Researcher Observations (Jason). Jason teaches 28 students. Of these, 21 are Hispanic and 4 are White. Overall, Jason felt that the students met his expectations, but they needed "guidance with fundamental skills of inquiry: identifying and controlling variables, collecting data, and communicating results (Jason Final Interview, 6/01/06)." Jason was frustrated by the students' lack of recording data, "As much as we stressed drawing pictures and writing notes about their observations, when the water came out the pens went away (Jason Final Interview, 6/01/06)." With guidance, the students were able to pose questions, test questions and generate new questions from their results. Jason stated, "the unit was wonderfully effective from a student learning perspective. The students were actively engaged and asked great questions. Students were on task and there were very few discipline problems (Jason Final Interview, 6/01/06)." Jason explained, "The students' line of questioning and discussion was the main evidence that they were thinking deeply about the content. They were asking each other questions and engaging in spirited debate about differing hypotheses, sometimes too spirited (Jason Final Reflection, 6/05/06)." Almost all of the students were engaged in the final presentation. Students in the audience asked questions of the presenters and the presenters could answer them with examples from their investigation. Jason stated, "The questions were popping and in here it is usually painful

to get them to ask a question (Jason Final Interview, 6/01/06)." When Jason took the master 'KWL' chart off the wall at the end of the unit, his students were disappointed, "They were proud of it. They were in to it. We went back to it and they were able to answer most of their questions. The chart was much more complete and student driven than what we have done in other units (Jason Final Interview, 6/01/06)."

At the end of the unit, Jason asked his students to draw and label the water cycle. Twenty of his students correctly drew the diagram. Three students obviously misunderstood the directions because they drew other water related cycles and two students did not respond. Eighteen of the 20 students that drew appropriate diagrams correctly identified evaporation. Ten of the students that drew appropriate diagrams correctly identified condensation and fourteen of the students correctly identified precipitation. Jason was pleased with these results, I was somewhat disappointed with many of my students' difficulty explaining condensation, but it is still an improvement over the number of students that understood condensation at the beginning of the unit (Jason Final Interview, 6/01/06)." Figure 17 shows an example of student drawn water cycles.

Figure 17. Student Drawn Water Cycle.

it is a normal
cloud

it [
put

it is evaporating
it is going to
the clouds.
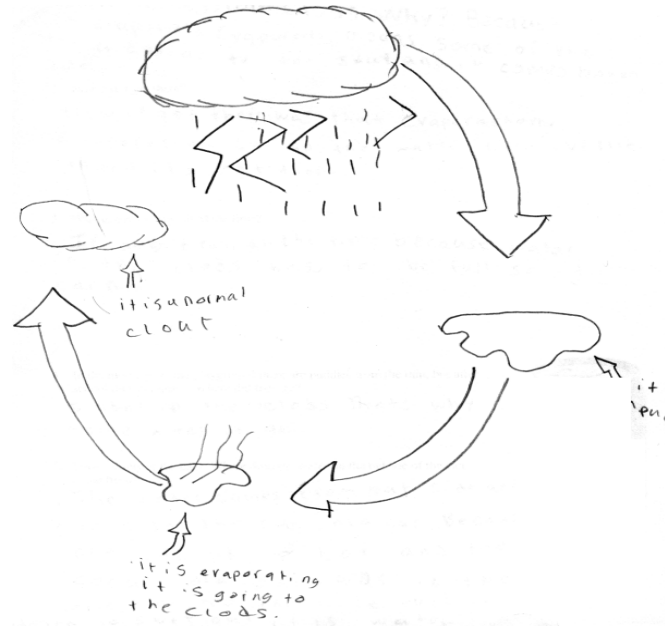
The students incorporated concepts that they saw in the field trip to what they were doing in the lab. John stated, "You could see the lights come on as they made connections between the field trip and the lab (John Final Interview, 6/01/06)." Students generally approached their questions in a logical manner and tested multiple hypotheses to try and find an answer. Jason provides one example:

> One group set out to answer the meandering vs. rapids question in numerous ways except for the correct one. They first divided their stream table in half and formed different landscapes (sandy and rocky). They tried to place rocks strategically to change the course of the river. Eventually they discovered the answer on their own. All of the time, they were questioning their strategies, observations and conclusions (Jason Final Reflection, 6/05/06).

Initially, this group pre-made their river. Jason and Emma both found that it was common for students to begin their exploration by using their hands to carve a pathway for the river. Some groups required intervention from Jason and Emma to allow the river to form

naturally. John noted, "The first thing they did was cut a path in an 'S' shape because that is what meanders look like (John Final Interview, 6/01/06)." Figure 18 shows a student pouring water into a pre-dug channel.

Figure 18. A Student Pours Water in a Pre-Dug Channel.

A group that I observed asked the question, how do you stop the water in order to build a dam? Each time they tried to block the water in order to build the dam, they found that the water found a way around. It took them a while to realize the flaw in their logic, they were trying to build a dam to stop the water so that they could build a dam. Eventually, one of the girls in the group stated, "Maybe you can't build a wall big enough to keep water from everything. Instead, we could build little streams so water will go away from what you want to keep dry." Figure 19 shows an image of this process. Unfortunately, her partners did not listen to her advice and continued to struggle. However, by the end of the period, her idea won out and the group realized that they needed to divert the water to build their dam (Field Notes, 5/23/06).

Figure 19. Students Dig a Channel (Left) to Divert Water From the Area Where They Want to Build a Dam (Right).

Jason also found evidence that the unit worked well with students who had been struggling in class. He described one group of students that were all enrolled in the exceptional education program. Their goal was to determine the effect of a dam on the land. On their first trial, they were frustrated that the water did not flow through their river. One of the students commented, "Maybe we can jack the end up so the water goes downhill." Once the students got the water to flow downhill, they quickly observed that the water began to form a pool behind the dam. Jason helped them expand on what they were observing and gave them the appropriate vocabulary, the term reservoir. He was surprised to find that most of the students in the group were able to use the term and explain its formation many days after the discovery (Jason Final Reflection, 6/05/06). These students were also very confident in their final presentation. Jason commented, "About 25% of my students are in the exceptional needs program and they often tune out with most of the stuff we do. That wasn't the case here, they were in front of the class giving a presentation. You just don't see that (Jason Final Interview, 6/01/06)." This led

Jason to conclude, "student-led science inquiry yields results for all of my students, the low achievers, high achievers, and the students in the middle (Jason Final Interview, 6/01/06)."

Evidence of Learning Provided by Teacher and Researcher Observations (Emma).
Emma teaches 27 students. Of these students, 26 are Hispanic. Emma observed many of the same things with her bilingual students as Jason saw with his students. Her students were engaged and actively explored multiple solutions to their questions. There were very few discipline issues. Emma saw a lot of collaboration while they were working in groups, "Students were talking to each other and asking questions of each other in order to determine what was happening. I was impressed with the ability of the groups to work independent of me (Emma Final Reflection, 6/05/06). She saw many "instances of students trying to problem solve, but she also saw instances where students were not building from their observations (Emma Final Interview, 6/01/06)." Emma also stated, "When I asked my students why they were trying certain things, I felt that many of them were very confident in how they answered (Emma Final Interview, 6/01/06)."

Student groups asked a variety of questions: why do rivers meander; how do you change the course of a river; how can you build a dam in the middle of a river; and how can you clean dirty water? During my observations, I spent a significant amount of time watching the group of students that were trying to determine how meanders were formed. This group spoke almost exclusively in Spanish during their investigations. Like all of the other groups in Jason and Emma's classes, they began by creating a river by hand. Unlike the groups that carved rivers into the sand with their hands, this group built an 'S'

shaped river by placing small rocks to create banks. When they poured water, the river found a way to flow outside of the banks (Field Notes, 5/23/06). Figure 20 illustrates this. Each time that they added more rocks to the banks and poured more water, they came to the same results.

Figure 20. This Group Pre-Made a River by Building Rock Banks.
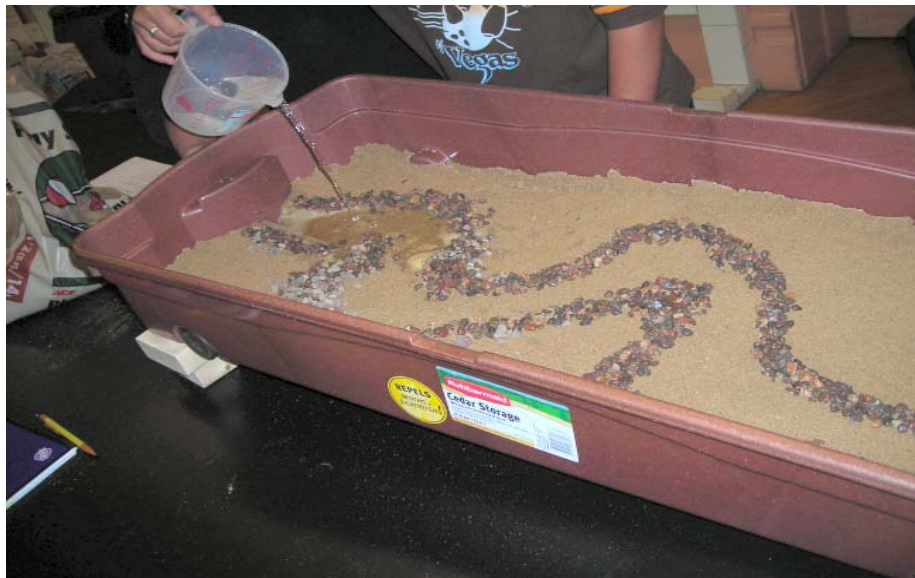
At one point, one of the students noticed that a lot of sand was collecting at the bottom of the tray as shown in figure 21. I asked the group where they though the sand came from and they responded, "The water carried it down there. Just like we saw at the river on the field trip (Field Notes, 5/23/06)."

Figure 21. Students Noticed that Water Carries Debris Downstream. The Image on the Left Shows the Stream Table Before Water was Poured and the Image on the Right Shows the Stream Table After Water was Poured.

Eventually, one of the students said to the group, "Let's just take all of the rocks out and see what happens." Instead of picking all of the rocks out, the students decided to just mix the sand and rocks together to form a random landscape. One student commented, "Maybe these rocks will get in the way of the water." After the landscape was created, the students poured water into the top of the stream table. Figure 22 illustrates this. As they watched the water flow around rocks to the bottom of the tray, Emma pointed to some of the streams that were being formed and said, "What are these?" One student said, "Those are places where it is easier for water to go, paths for it." The student that commented on the rocks being in the way of the water responded, "It is like what we said, the rocks get in the way so the water takes a different path." As they poured more water into the stream table, they began to notice that the little streams were carving channels in the sand. "Look," said one student, "we are making rivers!" Emma asked them if this helped them answer their question about the formation of meanders. One student commented, "Maybe meanders are formed when water goes around rocks or hard earth (Field Notes, 5/23/06)."

Figure 22. Pouring Water Over a Natural Landscape. The Dashed Black Line Identifies the Beginning of a River Channel that the Students Noticed.

A different group took as their question the problem of designing a filter to clean water samples that they took from the lake. Figure 23 shows a drawing of one of their designs. The students applied what they saw during the field trip by designing a system with multiple filters. They used a microscope to observe living organisms and other contaminants in their water. After some frustration with the materials at hand, they changed their question from "How can we clean water?" to "Can we clean water with these materials?" The students in this group provided some interesting observations. At one point, I asked them about their field trip and asked what water does to the beach. One of the students replied, "It brings in junk!" That wasn't the answer that I expected, but it is definitely true and something that you would not get from a textbook. Later, I asked them what they think they have learned so far in their investigation. A student responded, "We shouldn't pollute water so much because it is really, really hard to clean!" (Field Notes, 5/23/06)

Figure 23. One Group's Sketch of How to Build a Water Filtration System.
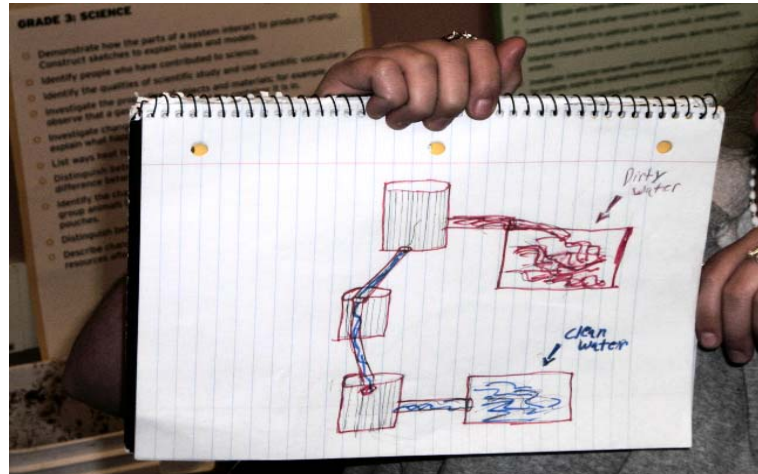
Although Emma saw evidence that students were learning during their investigations, she was not as enthusiastic about the effectiveness of the unit from a student learning perspective as Jason was. She stated, "It was very difficult to asses my students because of the poor quality of their presentations (Emma Final Interview, 6/01/06)." Her students were very reserved when in a whole class situation. She stated, "Even when I asked them specifically about things I saw them do in the lab, they couldn't talk about it. My students were uncomfortable and wanted to read directly from their prepared note cards during their presentations (Emma Final Interview, 6/01/06). She feels that their lack of confidence may be a result of them doubting that they have the correct answer, "They probably have it, but they don't have the confidence in their knowledge since I didn't give them the information (Emma Final Interview, 6/01/06)."

Evidence of Learning From the Pre- and Post-Assessment (Jason). When comparing the pre- and post- assessment, Jason sees lots of growth in his students, "It is apparent that they made significant improvements in their understanding due to this unit (Jason Final Interview, 6/01/06)." Jason stated that some parts of the pre-test were surprising. For example, he though that all of the students would know that they got their drinking water from the lake because he said, "We talked about the lake a lot. When I say 'we' I guess I mean that I talked about it (Jason Final Interview, 6/01/06)." The post-test showed significant improvements in this area. Jason stated this about those results, "I thought I was doing all of this great teaching, but perhaps the one that was really getting it was me. Maybe for them to explore on their own is the way to go (Jason Final Interview, 6/01/06)." Jason also saw on the pre-test that most of his students had a general grasp on the water cycle, but struggled with condensation. They were able to focus on that during the unit. That focus seemed to have been successful as many students showed an increase in understanding of condensation. Jason also noted that they deepened their understanding of other things related to water. For example, one question tried to get at evaporation. On the post-test, students said that the water may have ran into the sewers, into the groundwater, and other things that they did not mention before. Jason stated, "They would not have learned those things from just reading the textbook (Jason Final Interview, 6/01/06)."

Jason realized from the pre-test that students did not have an accurate understanding of water as an agent of change. He had taught about how water changes the surface of the Earth on other occasions, but realized that those lessons may not have

had much of an effect. Since students had the opportunity to visit land formations and explore how water creates these formations in a stream table, they were able to show improvement in this area on the post-test. Jason feels that his students will remember the content better too, "because they learned much of it from exploration and were able to connect their learning to things in the real world (Jason Final Interview, 6/01/06)." Figure 24 shows examples of how students' drawings of rivers changed from the pre-test to the post-test. In almost all cases, students were able to show more detail in their post-test diagrams. One area of concern that Jason noticed was the number of students on both the pre- and post-test who believed that rivers flowed towards the south. He attributed this, not to student failure, but to a mistake on his part, "We visited two rivers on their field trip and both flowed south. I was surprised, but I understand how students could make that generalization (Jason Final Interview, 6/01/06)." Table 12 summarizes the student responses for the pre- and post-test.

Figure 24. Examples of Jason's Students' Pre- and Post-test Drawings of Rivers.

Student A

———— **Pre-test Sketch** ———————————— **Post-test Sketch** ————

Student B

Table 12. Jason's Students' Responses on the Pre- and Post- Test for the Water Unit.

Question	Response categories	Pre-test responses	Post-test responses
Where does rain come from?	Clouds	20	18
	The Sky	3	3
	Condensation	0	1
	The water cycle	0	4
	Evaporation	0	4
	Other answers that could be viewed as correct	0	2
	Outer Space	1	0
How did it get there?	Evaporation	11	11
	Water Cycle	0	7
	Concept of evaporation, but did not use the term	5	0
	Other, partially correct	7	3
	Incorrect	7	6
Why doesn't it rain all of the time?	Clouds need to fill up	7	5
	Lack of moisture in the air	2	8
	It takes time for evaporation	4	8
	Temperature or seasons	4	3
	Other incorrect	12	4

Table 12. Continued.

Question	Response categories	Pre-test responses	Post-test responses
In the morning, there are puddles on the playground. By the end of school they are gone. Where did they go?	Evaporation	15	17
	Up to the clouds	9	2
	To the sewer	1	3
	It dried up	0	1
Where does the water on the outside of a can come from? (a picture of a "sweating" soda can was provided)	Condensation (term and explanation)	0	6
	Condensation (term only)	4	7
	Concept of condensation but did not use the term	3	6
	Evaporation	1	2
	Melting	1	1
	Other incorrect response	15	2
Which way do rivers flow?	Downhill	6	6
	Down	4	7
	Cardinal direction	5	13
	Other, incorrect	4	2

Table 12. Continued.

Question	Response categories	Pre-test responses	Post-test responses
What does water do to a beach?	Erodes it	0	4
	Forms a coastline	0	6
	Changes the beach	0	5
	Makes more sand	2	1
	Makes waves	2	0
	Pollutes it	1	3
	Incorrect Response	20	4
Where do you think beach sand comes from?	Rocks weathering or eroding	0	13
	Rocks and shells that are smashed	8	3
	Water deposits it	0	5
	Incorrect response	18	7
Draw and label as many parts of a river system as you can.	Drew a river with tributaries	4	16
	Drew a meander	0	4
	Drew rapids	0	3
	Drew a dam	0	2
	Drew a delta	1	5
	Labeled the mouth and/or banks	3	2
	Drew a lake	2	0
	Drew a single featureless river	17	8

Table 12. Continued.

Question	Response categories	Pre-test responses	Post-test responses
How do you think the Grand Canyon was formed?	River erosion	4	16
	Water, rocks and nature	0	3
	Other Incorrect response (including glaciers, meteors, earthquakes, humans, etc.)	27	5
Look at the picture (alluvial fan) and describe how you think it was formed.	Identified as an alluvial fan	0	7
	Water deposited sand on dry land	0	10
	Formed by a river	0	4
	Water coming down a hill	1	2
	Incorrect response (ie: humans, avalanche, tornado, volcano, etc.)	22	4
What happens to a river when it rains a lot?	Overflows	8	2
	Floods	6	17
	Increases erosion	0	2
	Gets bigger	4	3
	Moves faster	3	2
	Other, incorrect	5	2
Where does the water you drink come from?	Lake (correct)	6	17
	Sanitation plant	3	2
	Other, incorrect	14	7

Table 12. Continued.

Question	Response categories	Pre-test responses	Post-test responses
List sources of water pollution.	Humans	11	5
	Ships	2	4
	Factories	7	7
	Cars, oil / gas	6	9
	Trash	0	21
	No Response	6	2
How do you think the water you drink gets cleaned?	Multi-staged process	0	10
	Water treatment plant	10	10
	Mechanical system (chemicals, machines, etc.	8	3
	Filters	4	7
	Nature	3	0
	No response	3	3

Evidence of Learning From the Pre- and Post-Assessment (Emma). Emma noticed many of the same things in her evaluation of the pre- and post-test data from her students that Jason observed. Emma, like Jason, was surprised by how many of her students did not know where they got their drinking water. Also, she noticed that her students often thought that things happened quickly. She stated, "It shows that they don't have the life experiences about how water shapes the Earth (Emma Final Interview, 6/01/06)." Emma's pre-test results for the water cycle were similar to Jason's. Her

students struggled with understanding condensation, but the unit helped improve that understanding. Additionally, students were able to provide more detail for their river drawings and had an improved understanding of how water shaped the surface of the Earth. Figure 25 shows examples of students' pre- and post-test drawings of rivers. Overall, Emma felt that her students showed fairly significant improvements on the post-test. Table 13 compares her students' pre- and post-test scores.

Figure 25. Examples of Emma's Students' Pre- and Post- Test Drawings of Rivers.

Student A

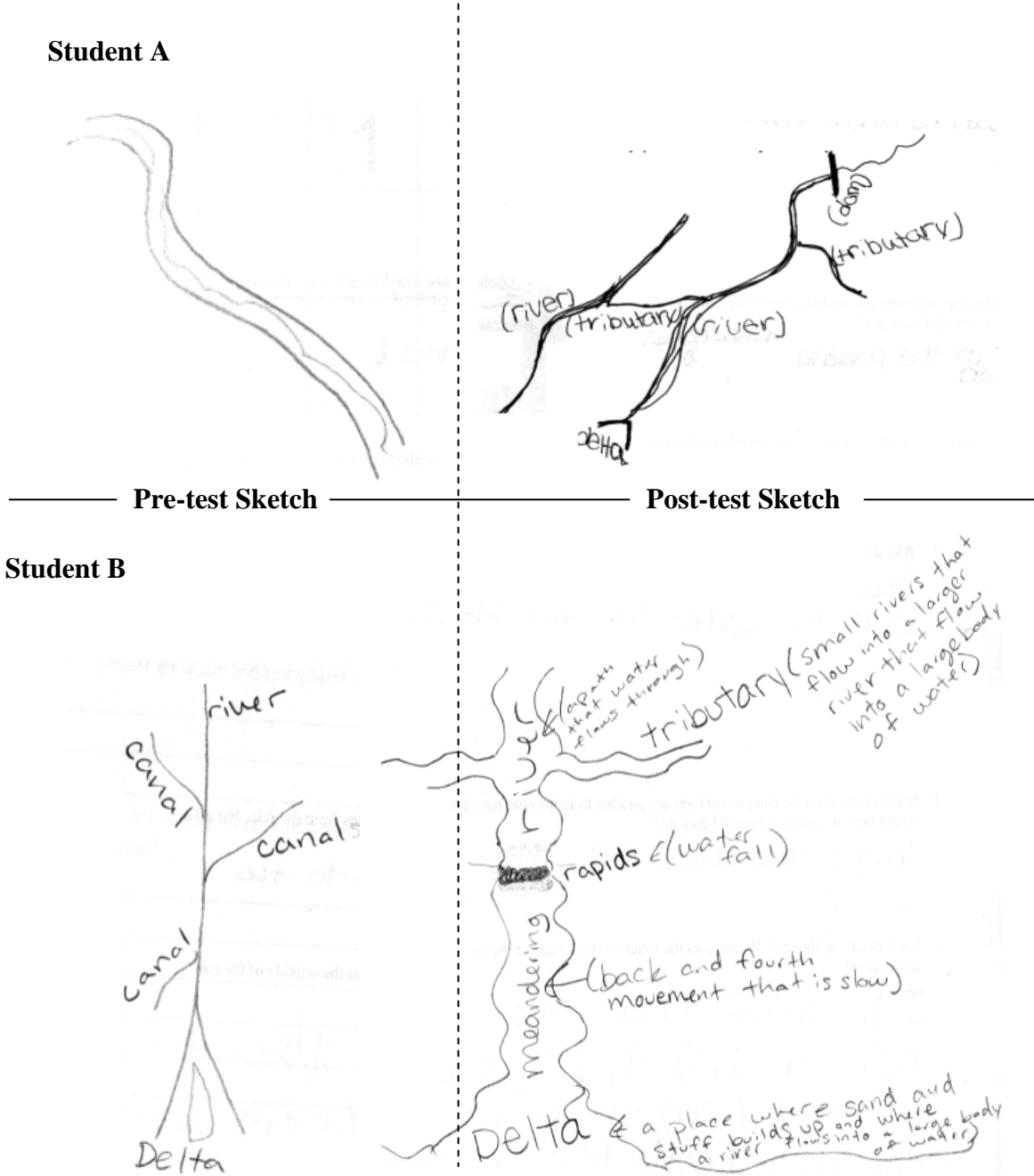**Pre-test Sketch**   **Post-test Sketch**
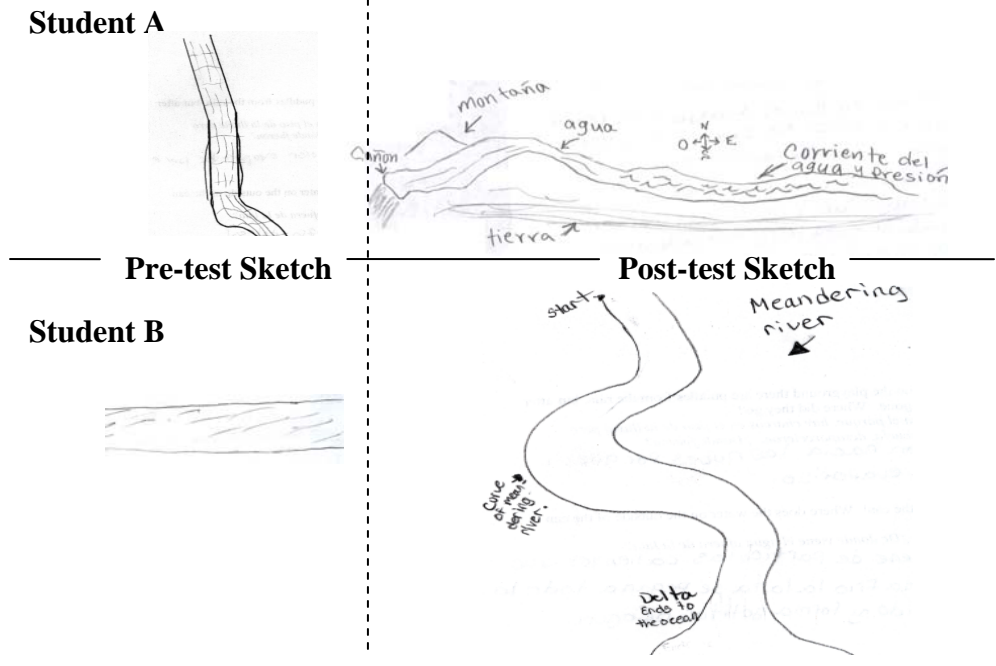
Student B

Table 13. Emma's Students' Responses to the Pre- and Post- Test for the Water Unit.

Question	Response categories	Pre-test responses	Post-test responses
Where does rain come from?	Clouds	21	17
	The Sky	3	3
	The water cycle	0	5
	Evaporation	0	2
	Other answers that could be viewed as correct	3	0
How did it get there?	Evaporation	14	15
	Water Cycle	0	5
	Concept of evaporation, but did not use the term	2	3
	Other, partially correct	4	2
	Incorrect	7	2
Why doesn't it rain all of the time?	Clouds need to fill up	8	9
	Lack of moisture in the air	0	6
	It takes time for evaporation	10	9
	Temperature or seasons	1	1
	Other incorrect	7	2
In the morning, there are puddles on the playground. By the end of school they are gone. Where did they go?	Evaporation	18	20
	Up to the clouds	3	4
	To the sewer	2	1
	It dried up	0	2

Table 13. Continued.

Question	Response categories	Pre-test responses	Post-test responses
Where does the water on the outside of a can come from? (a picture of a "sweating" soda can was provided)	Condensation (term and explanation)	0	3
	Condensation (term only)	0	5
	Concept of condensation but did not use the term	7	10
	Evaporation	0	1
	Other incorrect response	15	7
Which way do rivers flow?	Downhill	0	5
	Down	11	13
	Cardinal direction	6 (mostly south)	8 (mostly south)
	Other, incorrect	2	1
What does water do to a beach?	Erodes it	2	5
	Forms a coastline	0	3
	Changes the beach	0	1
	Makes more sand	6	7
	Makes waves	3	0
	Pollutes it	2	2
	Other, Incorrect response	12	6
Where do you think beach sand comes from?	Rocks weathering or eroding	0	12
	Rocks and shells that are smashed	12	9
	Water deposits it	0	3
	Incorrect response	10	3

Table 13. Continued.

Question	Response categories	Pre-test responses	Post-test responses
Draw and label as many parts of a river system as you can.	Drew a river with tributaries	3	14
	Drew a meander	0	5
	Drew rapids	1	3
	Drew a dam	0	6
	Drew a delta	0	2
	Labeled the mouth and/or banks	6	8
	Drew a lake	1	0
	Drew a single featureless river	13	5
How do you think the Grand Canyon was formed?	River erosion	5	10
	A lot of water	1	3
	Water, rocks and nature	9	8
	Other Incorrect response (including glaciers, meteors, earthquakes, humans, etc.)	11	6
Look at the picture (alluvial fan) and describe how you think it was formed.	Identified as an alluvial fan	0	0
	Water deposited sand on dry land	1	5
	Formed by a river	8	10
	Water coming down a hill	2	4
	Water drying up	2	0
	Incorrect response (ie: humans, avalanche, tornado, volcano, etc.)	7	6

Table 13. Continued.

Question	Response categories	Pre-test responses	Post-test responses
What happens to a river when it rains a lot?	Overflows	1	4
	Floods	11	14
	Increases erosion	1	
	Gets bigger	6	4
	Moves faster	3	4
	Stays the same	0	0
	Other, incorrect	1	0
Where does the water you drink come from?	Lake (correct)	6	15
	Sanitation plant	1	8
	Other, incorrect	18	4
List sources of water pollution.	Humans	3	2
	Factories	2	4
	Cars, oil / gas	8	9
	Trash	15	18
	Animals	6	9
	No Response	6	0
How do you think the water you drink gets cleaned?	Multi-staged process	0	0
	Water treatment plant	3	3
	Mechanical system (chemicals, machines, etc.	14	13
	Filters	4	3
	Nature	1	0

Grade 8: Electric Circuits

The learning goals for Steve's unit were focused on helping students understand the direction and amount of current in a circuit and understanding the differences between series and parallel circuits. Steve notes that his first thoughts about an electricity unit were more ambitious, but the pre-assessment results showed that his students held significant misconceptions in these areas. Steve explains, "A traditional unit on circuits would instruct students to connect wires in various arrangements and then tell students what they built. I want my students to be able to build their own circuits and discover the direction of current flow on their own (Steve 2nd Interview, 5/01/06) ." Steve embedded the components of the Inquiry for Conceptual Change model at different points in the unit. In the "Wondering" phase, teachers are expected to help students focus on their initial conceptions and become dissatisfied with them. Students should also generate questions that they can investigate. Steve had students generate a "KWL" chart and used this as a starting point for student investigations. In the "Investigation" phase, students conduct experiments or other investigations to answer questions. During the electric circuit unit, students completed a structured inquiry activity (written by the researcher) that allowed students to discover series and parallel circuits. Students also developed and conducted investigations to determine how current flowed in a circuit. In the "Construction" phase, students should develop conclusions from their investigations and communicate them. Steve did this at multiple times during the unit through whole class discussions. Steve intended to connect the unit to the students' lives by focusing on

electricity use at home. However, this connection was not strongly emphasized during the implementation of the unit.

Electric Circuits Unit Detail. This section was compiled from Steve's implementation journal. The electric circuit unit included four extended lessons that involved approximately ten hours of instructional time. Steve started the unit by generating discussion focused on the pre-test. He changed the normal presentation of a "KWL" chart to a "TWL" chart so that it focused on what students think. From this, they generated a list of things that they wanted to know about electric circuits and then started an open exploration using a variety of materials. Steve noticed that the students enjoyed being able to work freely with the materials without having to follow a rigid set of directions. They were highly engaged. He did have to remind students to make drawings of what they built. At the end of the lesson, students reported out on what they learned. Steve enjoyed focusing on student misconceptions without actually telling them that they were wrong. He did tell them that many of the things on their "T" chart were misconceptions, but they needed to find out which ones worked and which did not.

In the second lesson, students completed the Redundant Circuit activity. In this activity, students had to build circuits that could turn a light on and off if one or two switches failed. Students were given specific tasks to accomplish as a guide to discovering series and parallel circuits. For example, students were asked to build a circuit that would still work if two switches failed in the closed (on) position. This is only possible if you have at least three switches in series. Later, students were asked to build a circuit that would still work if two switches failed in the open (off) position. This is only

possible if you have at least three switches in parallel. Steve noted that all of the groups were excited by their successes at the beginning of the activity. Some of the groups became frustrated as the tasks became more complicated (discovering parallel circuits). However, Steve felt that he only had to provide intensive guidance to a few groups, the rest were able to complete the tasks on their own. Both Steve and the researcher noticed that students who held the misconception that current flows out of both ends of the battery had difficulty discovering parallel circuits (Field Notes, 5/23/06). Figure 26 shows a student sketch that indicates this misconception.

Figure 26. A Sketch that Indicates that the Student has a Misconception that Current Flows out of Both Sides of the Battery. The Arrows in the Sketch Indicate the Direction of Current Flow.
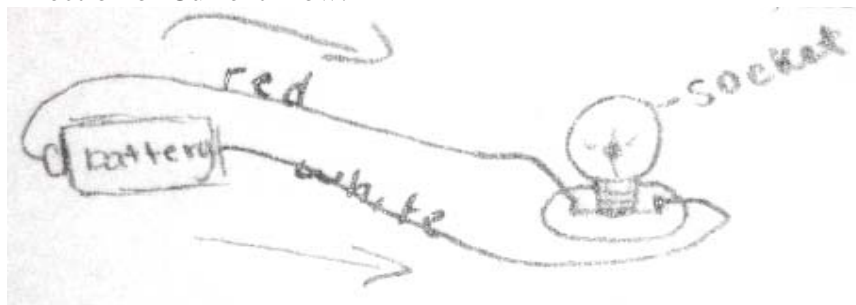
In the third lesson compasses were used to determine the direction of current flow in a circuit. Steve demonstrated how current flowing through a wire deflected the compass needle in a specific direction. If the battery was reversed, the compass needle was deflected in the opposite direction, indicating that current was flowing in the opposite direction. Students practiced until they were comfortable using the compass and then tested their hypothesis for multiple circuits. Students were able to make circuit

diagrams to correctly show the proper direction of the current. Steve was pleased that his students were able to figure out the concept and learned proper directions on their own.

In the fourth lesson, students used multimeters to measure the amount of current in different circuits. They were given the opportunity to explore using a variety of materials and report out what they learned. Steve was excited to see that all of his students were engaged and testing different hypotheses. Steve stated, "It is great when all I have to do is facilitate, sometimes I don't have to do much of that. Often, I was barely guiding them towards different questions to explore."

After reflecting on the implementation of the unit, Steve does not think that he could do anything different to increase student engagement (Steve Final Reflection, 6/05/06). However, changing the order of lessons so that students discover current direction before trying to discover series and parallel circuits may help more students be successful (Steve Final Reflection, 6/05/06). Also, additional opportunities for students to formally record and share their findings may help students focus on what they are learning (Steve Final Interview, 6/01/06).

Evidence of Learning Provided by Teacher and Researcher Observations. Steve teaches 21 students. Of these students, 15 are Hispanic. Steve felt that the unit was effective from a student learning perspective. He admits that students, "did not get all of the concepts in the unit, but they definitely learned (Steve Final Interview, 6/01/06)." He stated that he was pleased with what they learned. In his third interview, John mentioned that Steve exclaimed after class one day, "Yeah, wow! They really got it!"

Steve commented, "The students were extremely engaged throughout the entire unit. They truly enjoyed working with the materials. They were much more engaged than with all previous science units (Steve Final Reflection, 6/05/06)." He felt that not only did they enjoy the unit more, "they learned more than they did in other science units (Steve Final Interview, 6/01/06)." Steve stated, "Their enjoyment was a result of the inquiry approach, because I can't see my students thinking that electricity is any more exciting than other topics that they covered (Steve Final Interview, 6/01/06)." Steve said that it was easy to tell that the students were engaged just by walking around the room, they remained engaged in the tasks. Although most of the students stayed focused on their tasks, occasionally, students would become frustrated and go back to simple things that they discovered. His students kept asking if they would be able to do electricity that day.

Steve stated that another way that he could tell that students were thinking deeply about the content was that,

> The students were asking good questions about the content. They usually just ask if they can go to the bathroom. They asked themselves multiple questions as they were exploring: what happens when we add more wires to a circuit; what happens when we add more batteries; how can we add switches to create redundancy; will the bulb stay lit if we flip the battery? Many of the students were thinking beyond just what I asked of them (Steve Final Interview, 6/1/06).

While I was observing the class, I saw two examples that support Steve's conclusion that students were thinking deeply about the content. At first glance, one student seemed to be off task. He was busy connecting every wire that he could find to create a giant circuit with one battery and one wire. When he connected the last wire, he

noticed that the bulb lit as he expected. However, he noticed that it was much more dim than in his smaller circuit. He looked at me and said, "I wonder why that happened?" I asked him what he thought and he responded, "Maybe the battery has a harder time pushing electricity through all of that wire." (Field Notes, 5/23/06) If this unit had gone into resistance, this student would have an example that he discovered on his own to illustrate the concept. The second example involved a group struggling to determine how to create a circuit with two switches that could still turn a bulb off and on if one of the switches became stuck in the open position (off). They tried different arrangements of switches to no avail. Then, I saw one of the girls in the group get quiet and sketch something on scratch paper. She quickly grabbed the materials and built a circuit. It worked. She had discovered a parallel circuit, without knowing the term and without being told what to do. Figure 27 shows the circuit that she built. I asked her how she did it and she responded, "All I did was make another way for the electricity to go." (Field Notes, 5/23/06) When the class is introduced to parallel circuits, she will already have a good idea of what they are and why they work the way they do. Steve noticed that she was "flying high" about her discovery and commented to me at the end of the day, "You have to look for that and cherish it, you don't get a lot of that when you tell them to open the book to page 25 and read. It is what makes the job fun." While observing, Steve and I noticed that almost all of the groups were able to discover parallel circuits without extensive guidance from either of us (Field Notes, 5/23/06).

Figure 27: A Student Attempting to Construct a Circuit that will Allow a Light to be Turned On and Off if Either of the Switches Becomes Stuck in the Off Position (a Parallel Circuit).
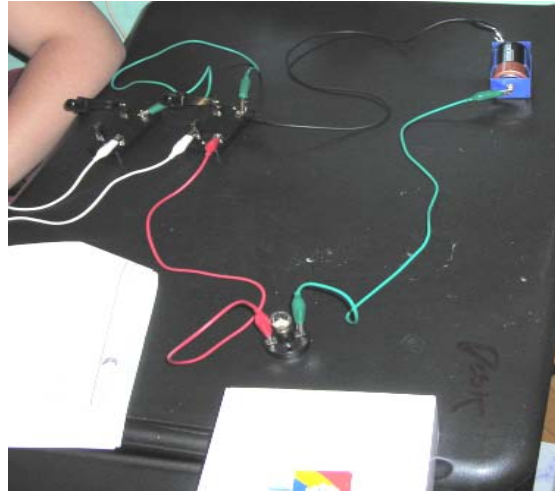
Evidence of Learning from the Pre- and Post-Assessment. Steve explained that his expectations for student learning were not fully met, "All students were proficient in some areas, but not all (Steve Final Reflection, 6/05/06)." Steve explained that the pre-test results did not surprise him too much, "Student responses were all across that board and a lot of misconceptions were prevalent." Steve determined criteria for being proficient as "only missing one or two of the things that were covered in the unit." Based on this criteria, the class went from 0% proficient on the pre-test to 72% proficient on the post-test. A comparison of pre- and post- test responses show that students had a much better understanding of what constitutes a complete circuit at the end of the unit. Before the unit, nearly one half of the students held the misconception that current flows out of both ends of the battery towards the light bulb. This misconception was also observed by Steve and I during the implementation of the unit (Field Notes, 5/23/06). All of the students were able to correctly identify the direction of current flow on the post test.

Nearly one half of the students still were unable to draw a series and parallel circuit on the post test. However, the vast majority of students were able to properly explain what would happen to a light bulb if another bulb was removed from a parallel or series circuit. This shows that although they struggle with drawing these circuits, they have an understanding of how they function. . Figure 28 provides examples of how two students' drawings of series and parallel circuits changed as a result of the unit. Note how student 'A' almost has a correct diagram for a parallel circuit in the post-test. The light bulb should have two wires connecting to the rest of the circuit. These drawing also show examples of how students are beginning to draw their circuits using circuit diagram symbols. On the post-test, 17 of the students used at least some circuit diagram symbols in their drawings. None of the students used the symbol for a battery, which is not surprising considering that the diagrams provided in the test did not either. No students used circuit diagram symbols on the pre-test. The fourth question asks what would happen if a wire was added as a short circuit. Students actually scored worse on this item on the post-test than on the pre-test. However, short circuits were not covered in this unit. Additionally, the student rationales for selecting incorrect answers (dimmer because more wires decreases current, or no change because no additional power was added) do make sense within the scope of the unit. Voltage and resistance were not covered, so it is not fair to assume that students will understand that current follows the path of least resistance. Table 14 summarizes the student responses for the pre- and post-test.

Figure 28. Student Pre- and Post-Test Drawings of Series and Parallel Circuits.

——— Pre-test Sketch ——— | ——— Post-test Sketch ———
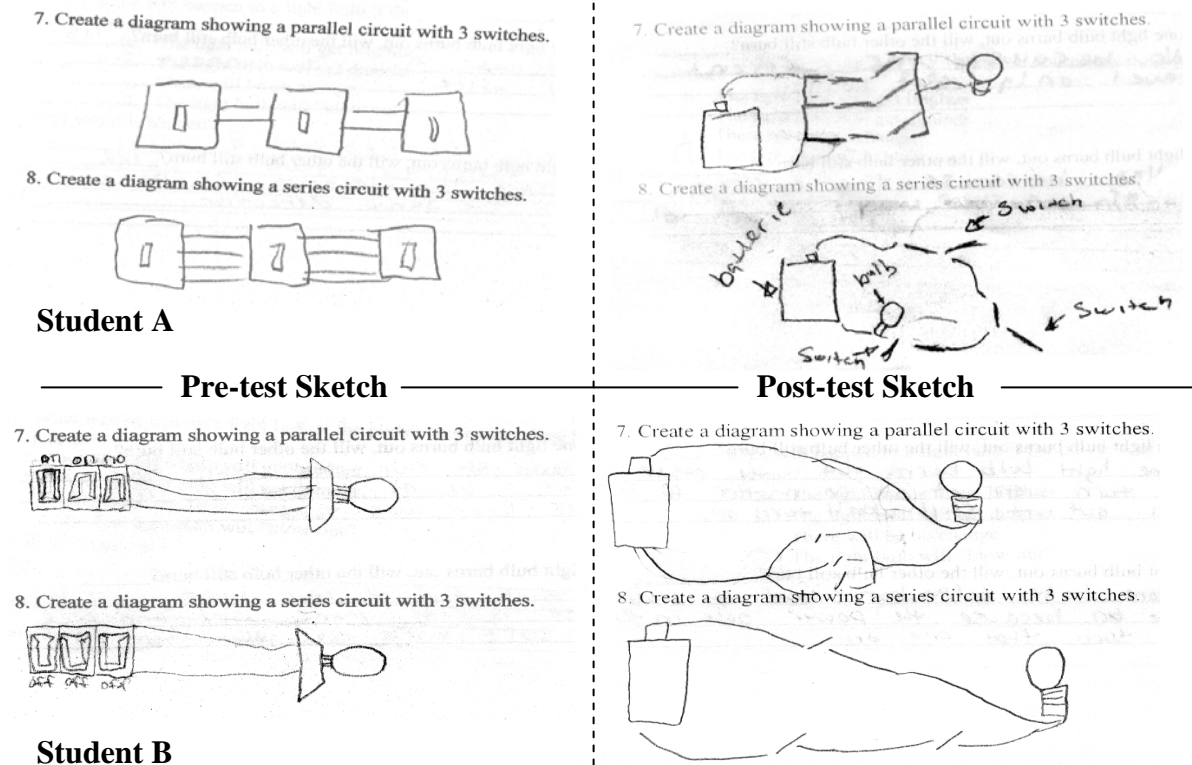
Student A

Student B

Table 14. Student Responses on the Pre- and Post- Test for the Electric Circuits Unit.

Question	Response categories	Pre-test responses	Post-test responses
Which circuit will light a light bulb? (Figure 29)	A or B	2	0
	C	6	0
	C and D	12	0
	D (correct)	3	21
Is the amount of current the same or different before and after the light bulb?	No answer	0	1
	Different	10	4
	The Same (correct)	13	16

Table 14. Continued.

Question	Response categories	Pre-test responses	Post-test responses
What is the direction of current flow in the circuit?	No answer	2	0
	From both ends of the battery towards the light bulb	10	0
	From the light bulb towards both ends of the battery	1	0
	From one end of the battery, through the light bulb and towards the other end. (correct)	10	21
What will happen to the bulb if a short circuit wire is added?	No answer	1	0
	The bulb will get brighter	3	3
	The bulb will get dimmer	9	9
	The bulb will stay the same	5	7
	The bulb will go out (correct)	5	2
Create a diagram showing a parallel circuit with three switches	No answer	2	0
	Incorrect	20	10
	Correct	1	11
Create a diagram showing a series circuit with three switches	No answer	2	0
	Incorrect	21	9
	Correct	0	12
In a series circuit with two bulbs, if one bulb is removed will the other remain lit?	Yes	17	5
	No (correct)	6	16

Table 14. Continued.

Question	Response categories	Pre-test responses	Post-test responses
In a parallel circuit with two bulbs, if one bulb is removed will the other remain lit?	Yes (correct)	7	19
	No	16	2

Figure 29.   Diagrams for the First Question on the Pre- and Post- Test. The Circled Answers Show the Most Commonly Selected Response for the Pre-Test.

1. Circle the diagram, or diagrams, that will produce a lighted bulb.

A   B   D   C
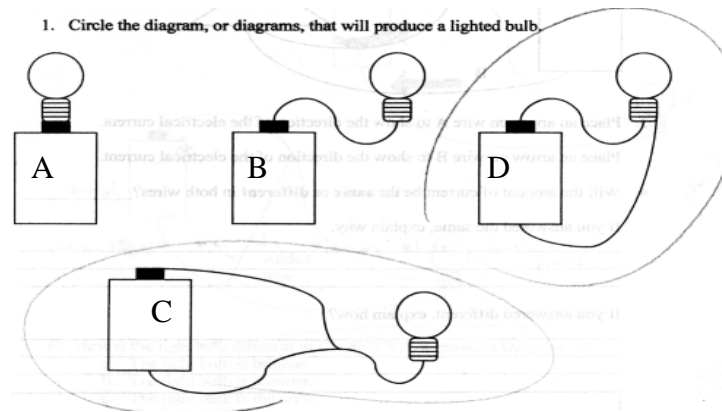
Summary of Unit Implementation

The structure and implementation of the participant designed units was described in this section. Additionally, evidence for learning provided by teacher and researcher observations and the pre- and post- test were discussed. Table 15 provides a matrix that summarizes this section.

Table 15. A Summary of the Unit Implementation Section.

	Sam	Jason	Emma	Steve	John
Unit Detail	The primary focus of the unit was for students to discover the effect of pollution on plant growth. The secondary focus was for students to understand the lifecycle of plants. The unit contained an extensive combination of benchmark activities and an extended guided inquiry. The benchmark activities served two purposes. The first purpose was to help students build specific background content knowledge. The second purpose was to help students develop skills needed for inquiry. An explicit connection was made between the unit topic and the students' lives.	The primary content goal of this unit was to help students understand how water shapes the land. Secondary content goals included increasing student understanding of the water cycle (specifically condensation) and increasing understanding of the local water supply and pollution. An additional primary goal was to improve students' abilities to conduct scientific investigations. The unit consisted of a structured inquiry activity for the water cycle, a field trip to local sites impacted by water, and a lightly guided inquiry activity using stream tables or construction of a water filtration system. .	The primary content goal of this unit was to help students understand how water shapes the land. Secondary content goals included increasing student understanding of the water cycle (specifically condensation) and increasing understanding of the local water supply and pollution. An additional primary goal was to improve students' abilities to conduct scientific investigations. The unit consisted of a structured inquiry activity for the water cycle, a field trip to local sites impacted by water, and a lightly guided inquiry activity using stream tables or construction of a water filtration system.	The primary goals of this unit involved helping students understand how to construct a simple circuit, understand the direction of current flow in a circuit, and understand differences between series and parallel circuits. The unit began with a brainstorming session on what students were thinking about electricity and what they wanted to know. Students conducted an open inquiry with a variety of materials (wires, bulbs, batteries, switches, etc.) as a starting point for the unit. Students completed a structured inquiry activity where they discovered series and parallel circuits.	Provided support during the implementation process. Initially felt that Jason and Emma were skeptical of science inquiry and their students' ability to conduct inquiry. The implementation of the unit showed Jason and Emma that they were capable of teaching in a student-centered manner and that their students had the potential to conduct science inquiry.

Table 15. Continued.

	Sam	Jason	Emma	Steve	John
Unit detail continued	Students communicated the results of their investigation to their peers and to a group of younger students. Possible change includes allowing for more student ideas to be incorporated into the data collection protocol.	The unit was connected to the students' lives by visiting examples in the community and focusing on the local water supply and pollution. Students were expected to communicate the results of their investigation to their peers. Heavily guided students in the generation of questions, but little guidance during the actual investigation and preparation for communication. The logistics of using stream tables for relatively open investigations proved to be very difficult	The unit was connected to the students' lives by visiting examples in the community and focusing on the local water supply and pollution. Students were expected to communicate the results of their investigation to their peers. Heavily guided students in the generation of questions and communication of results, but little guidance during the actual investigation The logistics of using stream tables for relatively open investigations proved to be very difficult.	A benchmark activity showed students how to use a compass to measure the direction of current flow. Students used this knowledge to determine the flow of current in a variety of circuits. A benchmark activity showed students how to use a multimeter to measure current. Students then measured current at different points in multiple circuits.	

Table 15. Continued.

	Sam	Jason	Emma	Steve	John
Evidence of learning provided by observation	Students felt ownership of the investigation and their plant. Students were highly engaged during the guided inquiry lessons and at least moderately engaged during the benchmark activities. Students asked insightful questions and made comments that showed thinking beyond that of textbook knowledge.	Met learning expectations, but needed guidance with fundamental skills of inquiry. Students were actively engaged and asked insightful questions. Students questioned each other and debated alternative hypotheses. Students connected concepts from the field trip to their investigations. Students began by pre-making rivers, but eventually began investigating with more natural processes. Students were very inquisitive and engaged when peers presented the results of their investigation.	Students were actively engaged and explored multiple solutions to their questions. Students discussed ideas with each other. Impressed by students' ability to collaborate. Students connected concepts from the field trip to their investigations Difficult to assess student knowledge through group presentations. Students were not engaged, needed lots of guidance, and had difficulty communicating their results. Communication difficulties may be a result of a lack of confidence because they were not told correct answers by the teacher or textbook.	The unit was effective from a student learning perspective. Students didn't get all of the concepts, but they definitely learned. Students were very engaged throughout the unit and they asked good questions related to the content. Students that held the misconception of current leaving both ends of the battery struggle when trying to discover parallel circuits.	

Table 15. Continued.

	Sam	Jason	Emma	Steve	John
Evidence of learning from pre- and post-test	Students were able to label more parts of a plant, identify more needs for a plant to grow, describe more causes for unhealthy plants, drew more detailed life cycle diagrams, and had a dramatic increase in their understanding of the role of insects in pollination.	Students made significant improvements. Realized that his past teaching may not have caused a change in students' ideas. Students had an increased understanding of their local water supply and sources of pollution. Students increased in their ability to provide multiple solutions to questions and increased their understanding of condensation as part of the water cycle. Students provided more detail in their drawings of rivers and increased understanding of how land features were formed by water. Many students held the misconception that rivers flow to the south because of the two river sites chosen for the field trip.	Students made significant improvements. Students had an increased understanding of their local water supply and sources of pollution. Students had an increased understanding of the water cycle, specifically condensation. Students provided more detail in their drawings of rivers and increased understanding of how land features were formed by water.	Although expectations were not fully met, most students showed a dramatic improvement. All of the students were able to correctly identify the direction of current in a circuit, this compares to slightly less than 50% of students before the unit. There were improvements in the number of students that could correctly draw series and parallel circuits. However, many students still struggle with this. The vast majority of students were able to explain what would happen to a light bulb if a second bulb was removed from a series or parallel circuit. This shows that most students understood how the different circuits function even if they could not draw them. Most students are beginning to use circuit diagram elements in their diagrams.	

<u>Post Unit Implementation Conditions</u>

Participants were interviewed for a third time after they completed the implementation of their science inquiry units. Participants were also asked to write a final reflection on their experiences in this study. The responses that were specific to the science inquiry units were already discussed in the Unit Implementation portion of this chapter. Participants were also asked to comment on their understanding of science inquiry, how they saw themselves using science inquiry in the future, and recommendations for educators on how to increase the amount and quality of science inquiry taking place in the classroom.

<u>Understanding Science Inquiry</u>

Participant responses to the interview and final reflection questions related to science teaching can be divided into four themes. The first theme is the participants' definition of science inquiry. The second theme includes benefits that the participants see coming from science inquiry instruction. The third theme describes the frustrations that the participants have with science inquiry. The final theme describes how participants see their understanding of science inquiry changing since the beginning of the study.

<u>Defining Science Inquiry.</u> John describes science inquiry as, "a formalized extension of natural human inquiry. We naturally ask questions about how things work, but science inquiry adds a rigorous approach to how we answer those questions (John Final Reflection, 6/05/06)." Emma explains that, "Science inquiry is a student oriented

way of learning. Students ask questions about a topic and design experiments to answer those questions. Students create their own procedures, analyze their data and communicate the results. Inquiry is open-ended and sometimes unpredictable (Emma Final Reflection, 6/05/06)." All of the participants described the importance of determining what the students already know and helping them become dissatisfied with their initial knowledge. Steve stated, "One of the big ideas is to get a pre-test out there and design lessons based on their knowledge, lessons that allow students to explore (Steve Final Interview, 6/01/06)." They mentioned the importance of students asking questions and finding their own way to answer those questions. All of the participants also mentioned that science inquiry includes a continuum of teacher control, it is not necessary, and may not be desirable, to turn control completely over to the students. Sam provides a statement that is consistent with the comments of the rest of the group, "It isn't about letting kids do 'whatever.' It isn't totally open inquiry, especially when it is new to them. It is about structuring things so that they can learn and have some success. It is OK to have structure and benchmark activities Sam Final Interview, 6/01/06)."

Benefits of Science Inquiry. The benefits to the approach used in this study can be viewed as benefits to the teacher and benefits to the student. One of the biggest benefits identified by the participants was the value of a systematic approach to planning the unit. John stated, "I think we really benefited from sitting down and deciding what it is we want kids to know. Writing it down, having a pretest, and knowing how we will be able to determine if the kids get it. As teachers, we teach things, but we really don't sit down and think of the scope of a unit before we get started (John Final Interview, 6/01/06)."

Sam and Steve echoed these comments. Sam stated, "The planning seemed like the key thing. It was probably the first time that I have done it like this, and I see it as being very valuable (Sam Final Interview, 6/01/06)." Emma found the development of her unit as beneficial to her teaching because, "…it caused me to think about how I can get my students to think more deeply and critically about science, how I can get them into groups more often, and how I can help them become more capable expressing their observations and ideas (Emma Final Reflection, 6/05/06)."

Jason found the most beneficial aspect of the unit to be the high level of engagement of his students. He states, "Students have their beliefs and they have to find it within themselves to change. I remember being a teenager, you don't learn what people tell you, you learn by discovering it (Jason Final Interview, 6/01/06)." Jason adds, "Normally, I have my top 15% that improve, the middle of the road students that might gain a bit, and the bottom that doesn't move forward at all. With this unit, everyone made gains, especially my Special Education students. I was very pleased with how well they did (Jason Final Interview, 6/01/06)." Comments similar to these were made by the other participants, specifically when asked about the implementation of their unit.

Frustrations with Science Inquiry. Sam was primarily frustrated at the initial point of the development of the unit, "It was difficult to determine what the big ideas should be because the learning targets for the district are too vague and not helpful (Sam Final Interview, 6/01/06)."

Jason was frustrated by not being able to give groups and individuals as much assistance as he would have liked. He was also frustrated that students needed significant

guidance at times to get to the big ideas. Although he does think that "the inquiry got them ready to learn the big ideas (Jason Final Interview, 6/01/06)." Jason and Emma were both frustrated by the logistics of the student explorations, "It took 10 minutes of set-up and 30 minutes of clean-up for 20 minutes of exploration (Jason Final Interview, 6/01/06)."

Emma was frustrated by her students' difficulties communicating what they learned, "I saw them learn it, but I was not able to get it back from them (Emma Final Interview, 6/01/06)." She perceived her bilingual students as "more reserved and that it was a struggle to get them to open up (Emma Final Reflection, 6/01/06)." She states, "It may be that they couldn't tell me what they learned because they didn't know what to focus on. It may also be that the students are conditioned to get the right answer from their teacher and since this didn't happen in the unit, they did not have confidence (Emma Final Interview, 6/01/06)." Emma did not feel that the unit went smoothly for her students and if she did it again she would model some things that they could do with the equipment instead of just sending them off to explore. She stated:

> It was frustrating some times, but I don't mind trying new things. I'm early enough in my career where I will give it a try – even if it goes against what I learned about being a teacher. I learned that it was important to always model, always structure, always show kids what they are supposed to do before they do it. I struggled with trying to let kids do it on their own (Emma Final Interview, 6/01/06).

Changes in Understanding of Science Inquiry. Each participant found that their understanding of science inquiry changed in different ways. Emma stated that she now understands that there are different levels of science inquiry, "some are structured and

supportive of the students and others are more open-ended (Emma Final Reflection, 6/05/06)." Steve felt much more comfortable with science inquiry than he did at the beginning of the study. He stated, "I feel I understood what inquiry learning was, but I learned that students and teachers need to come up with more questions throughout a unit. There needs to be more investigations going on throughout the unit (Steve Final Reflection, 6/05/06)." John found that a lot of what he already did in the classroom was verified by this study. He said, "The study reaffirmed his commitment to use science inquiry as often as possible in his lesson planning (John Final Reflection, 6/05/06)." Sam stated that "because of my prior experiences, I probably have not changed much in terms of my paradigm. However, the experience has reinforced the value of making sure that I knows what I expect of students (Sam Final Interview, 6/01/06)." He adds, "This unit was much more than a lone inquiry piece. It was a long term project. Prior to this experience, I didn't consider developing longer term units. Now I see the value in them (Sam Final Reflection, 6/05/06)." Jason describes perhaps the greatest change in understanding of all of the participants when he stated:

> My understanding of how science inquiry "looks" changed from the beginning of this project to now because, to be honest, I had no idea how it was going to play out. I was pleasantly surprised by the questions raised by my students, but I was disappointed by their inability to discover the big ideas on their own. This project definitely changed the way I look at students' initial ideas. When I used to do a KWL, the "K" was what I knew, if they said something wrong I didn't put it up. Instead, I should let them confront and explore it. Getting dissatisfied with your ideas is important and I overlooked that. This project didn't go smoothly, but it was just as rewarding as that Subaru pump (mentioned in the Initial Conditions portion). It was a good end result (Jason Final Reflection, 6/05/06).

The participants were also able to describe where they fit on a continuum between teacher centered and student centered instruction. John stated that he is towards the student centered end, "I don't think it is good to go all the way in that direction. I see the value in being more teacher centered in situations (John Final Interview, 6/01/06)." Jason sees himself more on the teacher centered side, "I would like to turn loose a little more and I am sure that my students would learn more that way. I'll get there over time (Jason Final Interview, 6/01/06)." Steve also sees himself as being more teacher centered, but would like to move towards student centered instruction. Sam states, "The continuum really depends on your goals. I am a mix. There has to be some freedom, but there are also places for more direct instruction. For example, when we did journaling in this unit, I could have had students collect a lot of data and look at each other's journals and slowly determine what works best. But that would take a really long time (Sam Final Interview, 6/01/06)!" Emma felt that during the implementation of the unit she was student centered because, I purposefully stepped back. Normally I lean more towards teacher centered. Maybe I will give students an experiment where they could do a few things on their own, but with less variation. I might give them some opportunity, but give them more structure (Emma Final Interview, 6/01/06)." Emma added, "I think kids react better to teacher centered instruction, that is where her students put themselves (Emma Final Interview, 6/01/06)." When pressed on this comment, she admits, "students have probably been conditioned to prefer teacher-centered instruction throughout their schooling (Emma Final Interview, 6/01/06)."

As the science laboratory teacher, John was not directly involved in implementing any of the units. This gave him a unique perspective to observe how his colleagues changed during the course of this project. During the first few weeks of the project, he felt that his colleagues were really frustrated, "They couldn't see what they were supposed to be doing because they had never done it before (John Final Interview, 6/01/06)." He commented that Jason and Emma were very hesitant to go through with the project, "They had experiences where they let things get loose and the kids chose to do inappropriate things. The reality we live in is insane, if you are not on top of things it will go bad fast (John Final Interview, 6/01/06)." John stated, "Emma was also very concerned that her students wouldn't be able to do it. I am hearing that less from her now, she is willing to keep trying it (John Final Interview, 6/01/06). He noted, "Even though the logistics of their water unit were miserable, they see that their kids were engaged and learning. Now, they are thinking that inquiry isn't so bad (John Final Interview, 6/01/06)."

Using Science Inquiry in the Future

Participants were asked in the third interview and in the final reflection to look at the future of science inquiry within their classroom. Participant responses can be divided into four themes. In the first theme, participants explain how worthwhile they thought their investment in developing an inquiry unit was. In the second theme, participants discuss their willingness to develop additional science inquiry units. In the third theme, participants revisit the tension brought on by time constraints. In the final theme,

participants discuss possible ways to ease the time constraint tension by incorporating specific elements of science inquiry.

The Project was Worthwhile All of the participants indicated that the time that it took to develop and implement the unit was worthwhile. Steve stated, "Inquiry is worth the time. We can't afford not to take the time to let students learn for themselves. It is obviously harder than telling kids to open to page 25 and read and do this worksheet, but anything that is good for kids is a little harder (Steve Final Reflection, 6/05/01)." Jason stated, "it was as much work as he feared it would be, but feels that it was still worth it (Jason Final Reflection, 6/05/01)." He explains, "The bigness and messiness of our unit didn't sour me, but it made me more apprehensive. Also, I felt lost all the way up to and even in the beginning of implementation. Once we got going, it was cool (Jason Final Interview, 6/01/06)." He believes that students gained valuable experience and took some enduring understandings from the unit. He stated, "Bottom line, I will try to implement other inquiry units because of the success of this one (Jason Final Reflection, 6/05/06)." Emma was a little more reserved in her comments about the value of her inquiry unit. She was "frustrated by her students' inability to communicate what they learned (Emma Final Interview, 6/01/06)." However, overall she felt, "It was worth my time. I will use components of inquiry again in the future (Emma Final Reflection, 6/05/06)." Sam stated, "I am really enthusiastic about what we accomplished, it was interesting seeing the growth in kids learning. I am energized by the unit. It gave me a push and renewed my interest in how we educate our students in science (Sam Final Interview, 6/01/06)." He stated:

The unit was worth the time and effort. Students learned organizational skills, presentation skills, teamwork, and citizenship. They have developed a sense of the role humans play in the fate of our planet. Oh, did I mention that they learned a lot about plants, too? It was definitely worth the time (Sam Final Reflection, 6/05/06).

Designing Full Units. John, Sam, Steve and Jason all say that they are likely to develop multiple science inquiry units next year. Steve explains, "Even though it takes time to develop a big unit, it is something you can use year after year. So, you spend a little time and you get the benefits of kids being engaged. It is worth it (Steve Final Interview, 6/01/06)." John stated that he is "now more inclined to attempt larger inquiry projects (John Final Interview, 6/01/06)." Sam provides a similar willingness to attempt longer term science inquiry, "Even though I taught a lot of science, most of it was showing teachers things that could be done in a class period or two. This is the first time in my career that I have taken a bigger idea and stuck with it for a long period of time. I would like to do more of these, but the actual number will depend on how many standards I can connect to the units (Sam Final Interview, 6/01/06)." Jason is more conservative than his colleagues, I see myself developing one or more units next year, but on a smaller scale than the unit we did this year (Jason Final Interview, 6/01/06). Emma stated, "I do not see herself developing more complete units. Instead, I see trying to incorporate elements of science inquiry into existing units. It should only add a day or two to the length of the unit but can have a real impact on student understanding (Emma Final Interview, 6/01/06)."

<u>Revisiting Time Constraints.</u> Two distinct time constraints exist. The first is a balance between personal time and time spent developing lessons. The second is the tension of trying to cover all of the district's learning targets for multiple subject areas within the curriculum. The participants feel both of these tensions. John suggests that the development time tension can be minimized by "planning with a cohort of teachers during common planning time. It may be possible to plan with teachers at different grade levels that cover the same topic so that units at different grade levels can reinforce each other (John Final Reflection, 6/05/06)." Steve explains, "Knowing that I will see successful results helps to ease the tension. Knowing that the unit can be used multiple times after being developed can also help to ease the development time tension. Getting rewarded, possibly financially, for personal time spent developing units would help ease the tension (Steve Final Reflection, 6/05/06)." Sam stated that he didn't feel too much of a development time constraint because "I had a high interest in developing the unit (Sam Final Interview, 6/01/06)." Jason explains, "The amount of prep time and time away from family might limit his ability to develop units to three or four times per year (Jason Final Interview, 6/01/06). However, he adds:

> I have already minimized some of the tension between designing inquiry units and having the personal time available by actually getting one under my belt. I'm uncomfortable when I don't know how something is going to look in the classroom. That was a time consuming hang-up for me. That has lessened. However, developing a science inquiry unit is still a big consumer of time and energy. I certainly will do this unit next year and look to implement others. I will hopefully be able to find out how to improve my efficiency (Jason Final Reflection, 6/05/06).

The participants also feel a tension in how to fit science inquiry into their tightly packed curriculum. Sam suggested keeping the number of full science inquiry units down to two or three per year, "I felt comfortable with the time spent on this unit because I could tie in a variety of standards in science and other subjects. However, there are so many standards that I do not think it is possible to map all of them into inquiry units (Sam Final Interview, 6/01/06)." Jason is apprehensive about the time that science inquiry takes. He states, "This was cool, but reading and writing took a back seat for a while, now we need to catch up (Jason Final Interview, 6/01/06)." He feels guilty because it is his job to cover the learning targets, and they will probably only hit three-quarters of them. Sam, Emma, John and Jason feel that No Child Left Behind adds to this tension. John and Jason feel that the tests used in Wisconsin focus more on recapitulation of facts and vocabulary. Sam and Emma see that standardized tests are a sampling of standards that are too broad for schools to realistically teach. Since science inquiry takes more time than traditional methods, this will confound that problem. Steve feels much less tension over No Child Left Behind, any tension with NCLB should be ignored and teachers should simply focus on student learning. If kids are learning, NCLB will fall into place (Steve Final Reflection, 6/05/06)."

Incorporating Science Inquiry Elements. All of the participants feel that it is important to incorporate elements of science inquiry on a regular basis. Emma explains, "The way I usually teach does not encourage higher level thinking. It may be successful at keeping lower lever learners on tasks and giving them some level of achievement, but it doesn't help them think at a higher level. I believe that science inquiry is one way to do

this (Emma Final Interview, 6/01/06)." As an example, she sees "eliminating the procedure from our contour mapping exercise. After instruction on the concepts of topographic mapping, I could have the students create a map using clay and draw a map from the model. Students will have the opportunity to try different methods of mapping contour lines and will be able to compare methods with other students (Emma Final Interview, 6/01/06)." John explains, "It is important to engage students' prior knowledge at the beginning of any lesson. This can be done through questioning, discrepant events and activities (John Final Interview, 6/01/06). Sam suggests, "A short inquiry lesson can be based on student questions generated through a KWL or other means. It would be realistic to include a guided inquiry activity every other week (Sam Final Interview, 6/01/06)." Jason describes the 'activity before content (ABC)' method that he has been trying to use more this year, "Before this project, these activities had a detailed procedure to follow. I would like to move away from that (Jason Final Interview, 6/01/06)." Jason provided the following example for the water cycle:

> I gave the students materials and instructions on how to build the model, but I did not tell them what they were modeling. When we were done building it, the students began to get it. They realized that they were seeing the different aspects of the water cycle. They were talking about condensation, using proper vocabulary and making connections to the real world. I didn't let them 'cop out' of the thinking part of the activity by telling them what they were going to see. It was a great springboard to discussion. It took one hour and they went through the entire inquiry cycle, they got dissatisfied, explored and presented, all within one class period (Jason Final Interview, 6/01/06).

Steve admits that he has been "taking the easy way when looking at units. I have been doing it a certain way for years, but he will look at it differently now. If I think inquiry could work, I will try it (Steve Final Interview, 6/01/06). He commented:

> We as teachers need to be more aware of inquiry. We need to be more willing to let students explore and learn for themselves. When creating a lesson we need to think about one way that students can discover something for themselves. We need to just keep it (inquiry) always in the back of our mind (Steve Final Reflection, 6/05/06).

Recommendations for Increasing the Frequency and
Quality of Science Inquiry in the Classroom

During the third interview and final reflection, participants were asked to provide recommendations for increasing the frequency and quality of science inquiry in the classroom. Participants provided recommendations for district-level curriculum coordinators, professional development facilitators, publishers, and classroom teachers.

Curriculum Coordinators. The recommendations that participants suggested for district-level curriculum coordinators focus on two distinct areas. First, curriculum coordinators should revise learning targets and standards to clearly articulate the essential knowledge and skills that students should exhibit if they meet the target. Curriculum coordinators should focus on fewer topics and specify what core concepts students should get out of each unit. Second, curriculum coordinators should provide ongoing professional development that is part of the goals of the school. This professional development should provide time for teaching cohorts to develop units. Curriculum coordinators should provide resources that incorporate inquiry or at a minimum, identify ideas that can act as a starting point for teacher created units.

Professional Development Facilitators. The recommendations that participants suggested for professional development facilitators involves: strategies for planning; strategies for getting started; and leading by example. Facilitators should help teachers understand exactly what they want their students to learn. They should also help teachers create assessments that identify the gaps between what students know and what the teacher wants them to know.

John states that previous professional development that he has had on science inquiry promoted a binary view of science teaching, "If you are not teaching everything in an inquiry manner, you are not a good teacher (John Final Interview, 6/01/06)." John continues by explaining that the majority of these experiences involved reading and discussing volumes of redundant articles, "They told us how great it was, but all we did was read and talk about it (John Final Interview, 6/01/06)." Steve and John agree that professional development experiences should provide teachers with the opportunity to learn about science inquiry, but also to practice using it. John explains that teachers need to practice science inquiry in their classroom as part of ongoing professional development, "You need to do inquiry on inquiry (John Final Interview, 6/01/06)." Sam adds that facilitators should "provide some structure, like the Inquiry for Conceptual Change model, that will help teachers organize their thoughts (Sam Final Interview, 6/01/06)."

Emma and Jason recommend that facilitators provide opportunities for teachers to learn how to encourage students to generate their own questions. They also recommend

that facilitators introduce inquiry through an abbreviated unit and provide suggestions as to what topics are the most fruitful to be taught using science inquiry.

Publishers. The key recommendation presented by each participant for publishers was to provide teachers either with short or long-term activities that can be integrated with each unit or at a minimum, provides teachers with suggestions for starting points for inquiry. Sam also emphasizes that textbooks should focus on fewer concepts, "deeper, not wider (Sam Final Reflection, 6/05/06)."

Classroom Teachers. Participant recommendations for classroom teachers can be categorized into five themes. The first theme involves making the decision that you are going to try science inquiry. The second theme includes understanding that science inquiry might seem overwhelming at first, but it has many benefits. The third theme describes the mindset that teachers need to have when starting to implement inquiry. The fourth theme includes suggestions for getting started. The final theme provides a recommendation that teachers scaffold inquiry with their students.

John recommends that teachers, "…just get started. They should find out a little about inquiry and then get going (John Final Reflection, 6/05/06)." He stated that it is easy for teachers to say at the beginning that, "Inquiry is impossible, you can't expect us to do this (John Final Interview, 6/01/06)." But, Steve explains, "Don't be afraid of it. Learn a little and then start using it (Steve Final Reflection, 6/05/06)." Jason stated that, "actually using inquiry is probably the only way to really see how it will work in your classroom (Jason Final Interview, 6/01/06)."

Jason says that he would not try to hide the downside of science inquiry if he was working with a teacher, "It is a lot of work, it can get real messy, it takes time, but it is something that really sticks with the kids…and I have data (pre / post test) to prove it (Jason Final Interview, 6/01/06)!" He continues by saying:

> I would list the costs (time) and benefits (results) to any teachers that want to get started using inquiry. Most teachers probably have the same reservations that I did about the time and effort needed to implement an inquiry unit. But, I would extol the values of science inquiry, especially for students in our exceptional education program. Students are highly engaged and there is a huge decrease in management issues. Plus, students really are learning (Jason Final Reflection, 6/05/06).

Emma adds that teachers should not be afraid of how the students will do, "They will have some management issues, but probably less than what they have now (Emma Final Interview, 6/01/06)."

Sam and John emphasize that teachers need to be flexible and be OK about making mistakes as they begin implementing science inquiry. Sam states, "Don't go into it thinking that you need to get it all figured out right away. If the kids don't respond as expected, don't panic. Reflect on what happened and learn from it (Sam Final Interview, 6/01/05)." He adds, "You do not have to be perfect. It is 'OK' to shift in midstream if you need to. You don't have to know how everything is going to turn out and that is 'OK.' You have to be open willing to ask questions and be open minded about how your kids approach a problem (Sam Final Interview, 6/01/06)." Sam provides an example of this from his inquiry unit:

> After we did some things with pollution, I didn't get the feel that kids had connected it to their lives. I did not anticipate this. So, I brought it up explicitly. They had to answer the question, why is it important that you

learn why pollution affects plants?" It wasn't scripted that I would do that, it was a response to what I saw happening in class. It really pushed them to think and increased their engagement in the unit (Sam Final Interview, 6/01/06).

Summary of Post-Implementation Conditions

In this section, participants describe their understanding of science inquiry and how their views have changed over the course of the project. The participants discuss their feelings about the benefits and challenges of using science inquiry in the future. Finally, the participants share their recommendations for increasing the frequency and quality of science inquiry in the classroom. Table 16 provides a matrix that summarizes this section.

Table 16. A summary of Participant Responses to the Final Interview and Final Reflection.

	Sam	Jason	Emma	Steve	John
Understanding Science Inquiry					
Defining Science Inquiry	Students generate questions, find their own way to answer questions, and communicate their findings	Students generate questions, find their own way to answer questions, and communicate their findings	Students generate questions, find their own way to answer questions, and communicate their findings	Students generate questions, find their own way to answer questions, and communicate their findings	Formalized extension of human curiosity
					Student centered, students ask questions, design experiments, answer their questions, open-ended and sometimes unpredictable
	Important to determine what the students already think and to help students to become dissatisfied with their initial knowledge	Important to determine what the students already think and to help students to become dissatisfied with their initial knowledge	Important to determine what the students already think and to help students to become dissatisfied with their initial knowledge	Important to determine what the students already think and to help students to become dissatisfied with their initial knowledge	Important to determine what the students already think and to help students to become dissatisfied with their initial knowledge
	Science inquiry is on a continuum of teacher control. It is often desirable to provide some structure and benchmark activities	Science inquiry is on a continuum of teacher control. It is often desirable to provide some structure and benchmark activities	Science inquiry is on a continuum of teacher control. It is often desirable to provide some structure and benchmark activities	Science inquiry is on a continuum of teacher control. It is often desirable to provide some structure and benchmark activities	Science inquiry is on a continuum of teacher control. It is often desirable to provide some structure and benchmark activities
Benefits of Science Inquiry	Systematic approach to planning the unit was very helpful.	Systematic approach to planning the unit was very helpful.	Systematic approach to planning the unit was very helpful.	Systematic approach to planning the unit was very helpful.	Systematic approach to planning the unit was very helpful.
	High level of student engagement and evidence of good student learning.	All of my students made learning gains, especially special education students	High level of student engagement and evidence of good student learning.	High level of student engagement and evidence of good student learning.	High level of student engagement and evidence of good student learning.

Table 16. Continued.

	Sam	Jason	Emma	Steve	John
Frustrations with science Inquiry	Determining the big ideas is frustrating because the district learning targets are too vague.	Frustrated by not being able to give students as much assistance as he would have liked. Students needed significant guidance to get to the big ideas. Logistics were a nightmare	Logistics were a nightmare Bilingual students had difficulties communicating what they learned. It didn't go smoothly for students, so I would provide more modeling in the future. I'm early enough in my career where I will give things a try, even if they go against what I learned about being a teacher – always model, always structure, always show kids what they are supposed to do before they actually do it.		
Changes in understanding of science inquiry	I had not considered long term investigations before. Now I see the value in them	At the beginning, I had no idea how it was going to play out. It didn't go smoothly, but it was rewarding. Students learned and were engaged.	There are different levels of inquiry	Much more comfortable than at the beginning.	This reaffirmed a lot of things that I already valued.

Table 16. Continued.

	Sam	Jason	Emma	Steve	John
The Science Inquiry Continuum	It depends on my goals. Some things are better with student centered instruction, but other things are more efficiently accomplished with teacher-centered instruction.	More on the teacher – centered side. I am sure my students would learn more if I shifted towards student-centered. I'll get there over time.	Normally I lean towards teacher-centered. I might give students more opportunities to do things on their own, but give them more structure. Kids react better to teacher-centered instruction, probably because they have been conditioned to prefer it throughout their schooling.	Teacher centered, but would like to shift towards student centered.	More towards the student-centered end I noticed that Jason and Emma were very skeptical of science inquiry at the beginning of the unit. Now, they are thinking that inquiry isn't so bad.
Using science inquiry in the future					
Was the project worthwhile?	Enthusiastic and energized by what was accomplished during the unit. It was definitely worth the time.	I felt lost even as we started the unit, once we got started, it was cool. The investment of time was worth it. Even though the logistics were miserable, I will implement more inquiry units because of the success of this one.	Overall the project was worth my time and I will use science inquiry in the future. Frustrated by her students' inability to communicate what they learned.	Anything that is good for kids is harder. This was good for them.	The results made the time investment worth it.

Table 16. Continued.

	Sam	Jason	Emma	Steve	John
Designing full units	Likely to develop multiple units next year I taught a lot of science, but usually only showing teachers inquiry that could be done in a day or two. I want to do more long term inquiry projects with my students.	Likely to develop multiple units next year, however they will probably be on a smaller scale,	Does not see herself developing a complete unit, but feels that she can incorporate elements of science inquiry into existing units.	Likely to develop multiple units next year. It takes time, but it is something that engages kids and you can use it year after year.	Definitely will attempt larger inquiry projects with my students.
Revisiting time constraints	Has a high interest in this type of work, so doesn't feel this time constraint. It is difficult to use science inquiry extensively and still hit all of the learning targets for multiple subjects. NCLB adds to this tension since it seems to focus on facts, not concepts and skills.	Time is a constraint, but I can do it a few times per year. Getting this first unit under my belt will minimize the time constraint. I wasted a lot of time being uncomfortable with how this was going to play out. It is difficult to use science inquiry extensively and still hit all of the learning targets for multiple subjects. NCLB adds to this tension since it seems to focus on facts, not concepts and skills.	Development time is a constraint It is difficult to use science inquiry extensively and still hit all of the learning targets for multiple subjects. NCLB adds to this tension since it seems to focus on facts, not concepts and skills.	Knowing that I will see successful results and that it can continue to be used in the future helps to minimize the time constraint. I don't feel a tension with NCLB. If teachers focus on student learning instead of the tests, NCLB will fall into place.	Development time is a constraint Working with a cohort of teachers should help to minimize development time. It is difficult to use science inquiry extensively and still hit all of the learning targets for multiple subjects. NCLB adds to this tension since it seems to focus on facts, not concepts and skills.

Table 16. Continued.

	Sam	Jason	Emma	Steve	John
Incorporating elements of science inquiry	Short inquiry activities can be based on student questions generated through a KWL activity or other means. It should be realistic to do a guided inquiry activity every other week.	Focused on the "activity before content" strategy. Currently, it is very scripted, I want to move away from that to something that doesn't let students 'cop out' on the thinking.	The way I normally teach does not foster higher level thinking, but it does keep lower level learners on task and give them some successes. She can see using elements of science inquiry to increase higher-level thinking in her classroom. She sees having students determine procedures for experiments as one way to do this.	I have been teaching things the same way for years. That will change. I will look at each topic and see if inquiry might work. If there is a chance that it will, then I plan on using it.	It is important to continually focus on students' initial conceptions.

Recommendations for Increasing the frequency and quality of science inquiry in the classroom

	Sam	Jason	Emma	Steve	John
Professional development facilitators	Facilitators should provide a model, like the Inquiry for Conceptual Change model, to help teachers organize their thoughts.	Help teachers learn how to encourage their students to generate questions. Introduce inquiry through an abbreviated unit and provide suggests as to what topics are the most fruitful for science inquiry	Help teachers learn how to encourage their students to generate questions. Introduce inquiry through an abbreviated unit and provide suggests as to what topics are the most fruitful for science inquiry	Professional development should provide opportunities for teachers to learn about inquiry and to practice using it.	Professional development should provide opportunities for teachers to learn about inquiry and to practice using it. Professional development should be based in practice, you need to do inquiry on inquiry

Table 16. Continued.

	Sam	Jason	Emma	Steve	John
Curriculum Coordinators	Revise learning targets so they clearly articulate what students should be able to do. Provide ongoing professional development that is part of the goals of the school	Provide ongoing professional development	Revise learning targets so they clearly articulate what students should be able to do	Provide time for cohorts to develop and implement units Provide resources and identify starting points.	Provide ongoing professional development that is part of the goals of the school Provide time for cohorts to develop and implement units
Publishers	Focus on fewer concepts	Provide short and long term inquiry activities that can be integrated with each unit	Provide short and long term inquiry activities that can be integrated with each unit Provide teachers with starting points for inquiry	Provide teachers with starting points for inquiry	Provide short and long term inquiry activities that can be integrated with each unit
Classroom teachers	Have the proper mindset – be flexible and be OK about making mistakes. Scaffold inquiry with your students, Do not jump directly into open inquiry, instead provide them with guidance in how to conduct inquiry.	Science inquiry may seem overwhelming, but it has many benefits Scaffold inquiry with your students, Do not jump directly into open inquiry, instead provide them with guidance in how to conduct inquiry.	Scaffold inquiry with your students, Do not jump directly into open inquiry, instead provide them with guidance in how to conduct inquiry.	Science inquiry may seem overwhelming, but it has many benefits Make the decision to learn a little and then get started.	Make the decision to learn a little and then get started.

<u>Focus Question One</u>

At its core, this study is interested in answering two broad questions. The first question is; "What are teachers' perceptions of science inquiry and its implementation in the classroom? In order to answer this question, a series of sub-questions were pursued. These questions focus our attention on how teachers understand the nature of science inquiry and how that understanding changed, how that understanding influences their implementation of inquiry and what challenges teachers face when implementing science inquiry in a diverse classroom.

How Does Teachers' Understanding of Science Inquiry Change as a
<u>Result of Professional Development and Implementation of Inquiry?</u>

In order to understand how the participants understanding of science inquiry changed during this study, we need to begin with what they view as important for good teaching. Jason, Emma and Steve have similar initial views on science inquiry, so we will look at them first. Sam and John have similar views and will be looked at second.

<u>Limited Initial Understanding.</u> Jason, Emma and Steve had a limited understanding of science inquiry at the beginning of this study. These participants taught in a teacher-centered manner and valued structure. Of the three, Emma had the strongest feelings about the importance of providing students with structure. She states, "I have a great group of students, but it has remained that way because I provide a strong structure by giving clear explanations and expectations. I don't know

if you can do that during science inquiry (Emma 2nd Reflection, 3/13/06)." All three participants placed importance on helping students see the relevancy of concepts. They also stated that they used their textbook as the primary source for sequence, content and activities. Jason and Emma valued beginning by assessing their students' initial knowledge. Jason felt that good science teaching should be more student centered, but he felt that his attempts at teaching in that manner had failed. Steve was not satisfied with the way he was teaching science and was looking for a new way.

Before this study, Jason, Emma and Steve had little exposure to science inquiry beyond the school's science fair. They did not feel that students were successful in science fair because the students lacked the knowledge and skills necessary to conduct investigations on their own. Jason, Emma and Steve felt that their students were overwhelmed by the opportunity to investigate any scientific question of their choosing. Before the study began, Jason, Emma and Steve understood that science inquiry was more student led and involved students investigating questions that they generated. Emma states, "science inquiry is different from traditional science teaching because it is more student led (Emma Initial Interview, 2/27/06)." Jason explains, "Science inquiry involves students investigating their own questions, not mine. It is more student led. It needs to stay within the guidelines of the curriculum, but students should be able to steer the learning toward their interests (Jason Initial Interview, 2/27/06)." Steve says, "Science inquiry should have less teacher guidance. Students should look for answers and want to discover on their own (Steve Initial Interview, 2/27/06)."

Jason and Emma were concerned about the impact that shifting responsibility to students would have on classroom management. Jason sees a problem of trying to give each group attention to keep them engaged, "Without engagement, they will be unfocused and off task (Jason Initial Interview, 2/27/06)." Emma stated that providing structure makes it, "easier to control and handle squirmy children. I have had problems when students were given more freedom or choice (Emma 1st Reflection, 2/28/06)." Jason and Steve saw science inquiry as having potential to engage and motivate students. Jason explains, "science inquiry appears to be more engaging because it uses their experiences to help guide their learning. It makes science relevant to them, which should get them excited and increase conceptual understanding (Jason 1st Reflection, 2/28/06)." Steve remembers activities that he has done in the past that allowed students to produce questions, "Those activities were engaging for the students and it was engaging for me because I could see their motivation." Steve believes that, "science inquiry can produce better scientific thinkers (Steve 1st Reflection, 2/28/06). Jason and Emma were very concerned about what science inquiry would look like in their classroom.

After the professional development sessions were completed, Jason, Emma and Steve had a stronger understanding of science inquiry. They explained that science inquiry is student centered, involves students generating questions, conducting experiments and communicating results. Emma explains, "In science inquiry, teachers do not plan a project from beginning to end. Instead, they think about what they want students to discover and plan experiences to help them find

what they already know, generate questions, and determine an experiment to answer those questions (Emma 2nd Interview, 5/01/06)." Jason states, "there needs to be a structure to collect data related to the question. Students also need to be able to communicate their results to other people (Jason 2nd Interview, 5/01/06)." "Without a good, researchable question, you can't do inquiry," states Steve (Steve 2nd Interview, 5/01/06).

They felt that it was important to identify students' prior knowledge and use it as a starting point for generating questions. They also came to the understanding that it was crucial to have a clear idea of what they expected students to learn as a result of the unit. Jason states, that inquiry involves "turning over the reigns to the kids a bit. If they can incorporate their background knowledge to start forming concepts and questions, maybe it will have more meaning for them (Jason 2nd Interview, 5/01/06)."

Jason, Emma and Steve's biggest change in understanding of science inquiry was realizing that there was a continuum of teacher control. Initially, they had the impression that science inquiry was an open process that was almost completely student centered. By this point in the study, they came to the realization that science inquiry can include structure and teacher guidance. "I thought it had to be open discovery, but I discovered that there can be some structure," said Emma (Emma 2nd Interview, 5/01/06). Jason states that he did not understand that there were different levels of science inquiry, "I saw it as binary, either it is open inquiry or it is not inquiry (Jason 2nd Interview, 5/01/06)." Jason describes the level of teacher control as, "is it more in the students' hands or is the teacher a script writer (Jason 2nd

Interview, 5/01/06)?" Steve notes that it is possible for there to be inquiry in a more guided approach. He adds, "What is important is that there is thinking going on all the time. There has to be some guidance going on to make sure that kids are getting what they need to know (Steve 2nd Interview, 5/01/06)."

Before implementing their unit, Jason and Emma were still concerned with the diminished structure of science inquiry and the possibility that it could lead to increased classroom management problems. Jason, Steve and Emma saw the importance of clearly identifying learning outcomes and identifying students' prior knowledge as a planning tool. Jason began to doubt many of the things that he had done in the classroom as a result of his students' poor pre-test results. Jason and Steve were confident that their science inquiry unit would work for their students. Emma thought that it would work, but was more skeptical.

After the implementation of their unit, all three students had a deeper understanding of science inquiry. Emma explains that, "Science inquiry is a student oriented way of learning. Students ask questions about a topic and design experiments to answer those questions. Students create their own procedures, analyze their data and communicate the results. Inquiry is open-ended and sometimes unpredictable (Emma Final Reflection, 6/05/06)." Steve stated, "I feel I understood what inquiry learning was, but I learned that students and teachers need to come up with more questions throughout a unit. There needs to be more investigations going on throughout the unit (Steve Final Reflection, 6/05/06)." Jason commented on his strong change:

My understanding of how science inquiry "looks" changed from the beginning of this project to now because, to be honest, I had no idea how it was going to play out. I was pleasantly surprised by the questions raised by my students, but I was disappointed by their inability to discover the big ideas on their own. This project definitely changed the way I look at students' initial ideas. When I used to do a KWL, the "K" was what I knew, if they said something wrong I didn't put it up. Instead, I should let them confront and explore it. Getting dissatisfied with your ideas is important and I overlooked that. This project didn't go smoothly, but it was just as rewarding as that Subaru pump (mentioned in the Initial Conditions portion). It was a good end result (Jason Final Reflection, 6/05/06).

Jason and Steve were enthusiastic about the student learning that they saw taking place. Emma knew that her students learned, but was frustrated with their inability to communicate what they learned. All three teachers saw that their students were engaged, which resulted in a decrease in classroom management problems. Jason and Steve explained that they felt much more comfortable using science inquiry.

Strong Background. Sam and John both believed that good instruction should be relevant to students and focused on students' initial knowledge. They had extensive knowledge of science inquiry, including leading professional development, before this study began. They understood that science inquiry was student centered, involved students generating questions, designing experiments and communicating their results. They also understood that science inquiry could be implemented with different levels of control.

Since Sam and John already had a good background, their knowledge of science inquiry did not change dramatically as a result of the professional

development. However, they did gain a new appreciation for the importance of determining student outcome goals and the creation of pre-tests as a way to clarify those goals. Sam and John also saw the benefit of the systematic planning process that we used during the development of their unit.

Sam and John both felt that the inquiry units that were developed were effective from a learning standpoint. They found this motivating and felt that it opened them up to conducting more long term investigations with their students in the future.

How Does Teachers' Understanding of Science Inquiry
Influence Their Implementation of Inquiry in the Classroom?

Sam. Initially, Sam had a strong background in science inquiry. However, his experience focused on working with teachers to incorporate short inquiry activities into their teaching. As a result of this, he generally thought of using science inquiry to support other teaching strategies instead of being at the center of his teaching. Additionally, even though he had experience with science inquiry, his current teaching demands caused him to focus much more on mathematics and reading over science. Therefore, he did not incorporate science inquiry into his teaching and generally only did hands-on activities during his assigned laboratory time.

Sam understood that science inquiry could be implemented along a continuum of teacher control. He also saw that his students lacked experience with conducting investigations and had poor science process skills. This strongly affected how he conceptualized his unit for this study. He made extensive use of benchmark activities

to help students gain the background knowledge and skills that they would need to be successful in the unit. Sam provided guidance to help students generate questions, create a procedure and data collection protocol. He placed science inquiry at the center of his unit, instead of in a supporting role as he had done in the past. Sam felt that his unit was very successful. The development and implementation of this unit increased his enthusiasm for teaching science and has motivated him to attempt additional long term investigations in the future.

Jason. Throughout the development process, Jason remained concerned about what science inquiry would look like in his class. He was also concerned about how giving up control in the classroom would affect classroom management. His normal teaching style placed heavy emphasis on reading. As a result of working with John, he had begun trying to start units with an activity. His hope was that this "activity before content" approach would engage students and give them some experiences that they could attach the textbook content to. However, he noted that the activities he used were very scripted.

Jason and Emma collaborated on their unit. They did not initially know that science inquiry could be implemented on a continuum of teacher control, so they conceptualized their unit with an open investigation at its core. The unit began with a short structured inquiry activity at the beginning to help students get a better understanding of the water cycle. This was followed by some benchmark activities that prepared students for a field trip. The field trip gave students the opportunity to see the unit concepts in the real world. After the field trip, the students began their

investigations. As a class, they generated questions. Then, most of the groups used stream tables to try to answer their questions. Some of the groups investigated filter systems for cleaning water. Initially, students were given very little guidance at this stage. However, as students became stuck, Jason provided them with some guidance.

Jason felt that the experience was rewarding and thought that it was effective from a student learning perspective. He was frustrated with the logistics of using stream tables for student-centered investigations. He plans on using inquiry, in the form of full units and smaller activities, in the future.

Emma. Out of all of the participants, Emma was the most concerned about how her students would react to the lack of structure. Her normal teaching style emphasized reading, modeling, and demonstration. She also created very detailed lesson plans. She felt uncomfortable with science inquiry because she was not able to do that. Emma and Jason collaborated on the design of their unit. The two participants implemented their unit in a very similar way.

Emma shared Jason's frustration with the logistics of their unit. She found that her students did learn, however she was frustrated with her students' inability to communicate their results. Her students were not engaged in the final presentation and did not perform well. Emma stated that she is unlikely to develop additional science inquiry units. However, she does expect that she will incorporate smaller inquiry activities into existing units.

Steve. Steve at the beginning of the project, Steve admitted that he had a very basic understanding of science inquiry and a limited background in science. Therefore, he felt that he probably had the longest road to travel before he could implement science inquiry in his classroom. His current science teaching practice emphasized reading and completion of reading packets almost exclusively. Hands-on activities were limited to his sessions in the science laboratory with John. Although he may not have realized it, he had two mindsets that proved to be invaluable during the study. First, he knew that the way he was teaching was not the best approach for his students. He was looking for new ways to teach and therefore was very receptive to the Inquiry for Conceptual Change Model. Second, he was flexible. He was not overly concerned with trying new things and was confident that he could react to situations as they arose. During the project, he realized the importance of using student prior knowledge in the planning process. The learning goals that he chose for his unit came directly from the pre-test results.

Unlike the other units, Steve's unit included a variety of inquiry activities. He began with a very student-centered discovery activity. This was followed by a structured inquiry activity. Two benchmark activities built students capacity to use specific tools to collect data. These tools were then used in two separate guided inquiry activities.

Although he was expecting better post-test results, he was pleased with what his students learned. He says that he plans to develop more inquiry units in the future. He also expects that he will keep inquiry in the back of his mind as a very successful

teaching strategy. As he plans a unit, he will ask himself if inquiry could be successful. If it has a chance, he plans on using it.

John. John is in a unique situation at this school. As the science laboratory instructor, he is not responsible for a specific group of students. Instead, every student in the building sees him occasionally for science instruction. He meets with students in grades 1-5 once every six days. He meets with students in grades 6 – 8 twice every six days. Since these are not "his" students, he does not have complete control over which activities he can use. He does try to incorporate short inquiry activities with these students whenever possible. Although his overall understanding of science inquiry did not change as a result of this study, he does feel that he has a greater appreciation for the balance between teacher guidance and student freedom. Most of the professional development that he has participated in made it seem like an "either-or" proposition. Either you taught with open inquiry or you were not teaching well.

John did not develop a specific unit during this study. However, he actively collaborated with Sam on his plant unit and Jason and Emma on their water unit. John feels that his experience in this study has opened his eyes to the benefit of longer-term investigations. He also has a greater appreciation for how to use pre-assessments and students' prior knowledge to plan units. He expects that he will continue to use short inquiry activities whenever he can and will plan longer term investigations in the future.

What Challenges Do Teachers Face When
Implementing Science Inquiry in a Diverse Classroom?

Teachers face three types of challenges when implementing science inquiry in a diverse classroom. The first type of challenge involves overcoming personal factors. This includes discomfort with shifting away from a structured, teacher-centered approach, lack of ability to 'see' what science inquiry will look like in their classroom, and a lack of confidence in their science content understanding. These challenges can be overcome by committing to trying science inquiry and developing a mindset that allows for flexibility and an acceptance of mistakes.

Another challenge that teachers face when implementing science inquiry is student factors. Many diverse students lack background science knowledge and process skills that are crucial for success in science inquiry. This study found that students did not always have adequate skill, specifically measurement, and had difficulties generating questions. Students in Emma's bilingual class also struggled with communicating their results. These challenges can be overcome with proper scaffolding that introduces skills and provides guidance until students are comfortable working on their own. Students from diverse backgrounds may also have less life experiences. I do not think that it is fair to say that they have less experience than other students. However, they probably have very different experiences from those that their teachers had at their age. This increases the importance of determining students' prior knowledge and building from that knowledge base.

The most difficult challenge to overcome while trying to implement science inquiry in the classroom is overcoming time constraints. The participants in this study felt pressure to meet a laundry list of learning targets in science. Additionally, the participants placed a greater emphasis on math and reading instruction because of district pressure to improve student performance in those areas. Science inquiry takes more time to conduct than traditional lessons. Therefore, implementing science inquiry places even more stress on teachers' schedules. This stress can be minimized by using a mix of short and long-term inquiry activities. Additionally, careful planning of units can help teachers maximize the number of learning targets that are met within one unit.

Teachers also face the challenge of finding time to develop new units. Developing a full science inquiry unit is very time consuming. This makes it more difficult to balance planning for science, other subjects, and maintaining a personal life. One way to overcome this is to develop units with a cohort of teachers.

Focus Question Two

The second focus question for this study is; "How does the use of the Inquiry for Conceptual Change model affect the learning of students in a predominantly Hispanic, urban neighborhood? In order to answer this question, four sub-questions were posed. These questions focus our attention on the level of student engagement during the unit, the types of research questions students pose, differences between the pre- and post- assessment results, and evidence of cognitive engagement. The

students involved in this study were predominantly Hispanic. Of the 97 students in the participants' classes, 80% were Hispanic and 9% were White.

Do Science Teachers Observe any Difference in Student Engagement Between
the Inquiry for Conceptual Change Unit and Their Previous Teaching Methods?

Engagement promotes a higher quality of learning. It promotes creativity and cognitive flexibility instead of just rote learning. Engagement is a prerequisite for the development of understanding (Voke, 2002). All of the participants in this study felt that their students generally had a high level of engagement throughout the unit. This high level of engagement led to an increase in on-task behavior and a decrease in classroom management problems. With one exception, participants felt that their students were more engaged and more interested in this unit than in their other science units.

John witnessed high levels of engagement and low incidences of behavior problems with students who were working on the water and plants units. He did not observe students working on the electricity unit. Sam saw that his students had a high level of ownership of their investigation. Jason also saw that his students were engaged and focused on their questions. He was surprised with how engaged his students were when planning for their final presentations. Jason was very happy with how his exceptional needs students reacted to the unit. Steve enjoyed working with his students and saw that they were highly engaged throughout the unit. He felt that they were very interested in what they were doing and attributed that to the instructional approach and not a native curiosity in electricity. Emma's feelings were

more mixed. She was impressed with how her students were able to collaborate during the investigation. She also found that they were very engaged during the inquiry activities. However, her students were not engaged while preparing for their final presentations and did not perform well.

<u>What Types of Research Questions Do Students Pose?</u>

Students posed and investigated a variety of questions within the three units. The participants provided guidance, usually through class discussions, while students were generating questions. Sam's students investigated how different types of pollution affected plant growth. Students brainstormed list of testable pollutants included road salt, ammonia, gasoline, engine oil, smoke, laundry detergent and anti-freeze. Jason and Emma's students investigated questions such as: can dirty water be cleaned with these materials; how can a dam be built in the middle of a flowing river, how does a dam affect the landscape near it; how does a meander form; and how do rapids form? Steve's students did not formally record questions. However, they did investigate things like: what happens when additional light bulbs are added to the circuit, what happens if wires are added to make a larger circuit; and what happens if we add more batteries. Students also investigated teacher provided questions related to the direction and amount of current flow and solved open-ended tasks that led them to discover series and parallel circuits.

Is there Evidence of a Conceptual Change in
Students Between the Pre- and Post-Assessment?

There were substantial differences between pre- and post- assessment results for all of the units. Sam's students were able to label more parts of a plant, identify more needs for plants to grow and causes for unhealthy plants, and draw more detailed life cycle diagrams when compared to their pre-test responses. Sam's students also showed a dramatic increase in their understanding of the role of insects in the pollination of flowers.

Jason and Emma's students made strong improvements in their post-test results over their pre-test results. Before the unit, students did not have an understanding of condensation and its role in the water cycle. After the unit, many students were able to describe condensation. Students had an increased understanding of their local water supply and sources of pollution. Jason and Emma's students were also able to identify more river features and exhibited an increased understanding of how water shaped the land when compared to their pre-test responses. The post-test revealed that many students held the misconception that rivers flow south. It is very likely that this was caused by the two rivers that did flow towards the south that students visited during their field trip.

Steve's students' post-test results also increased as a result of the unit. Before the unit, less than one-half of students were able to correctly identify the direction of current in a circuit. After the unit, all of the students were able to do this. The vast majority of students showed that they could correctly apply the characteristics of series and parallel circuits to a problem. However, many of them continued to

struggle with correctly drawing these circuits. Most of the students also began using some circuit diagram elements on the post-test. No students incorporated circuit diagram elements on the pre-test.

<u>Is there Evidence of Deep Cognitive Engagement on the Part of the Students?</u>

Multiple observations by participants and the research provides evidence that students had deep cognitive engagement while working on the unit. All of the participants noticed that their students were asking insightful questions and made comments that showed thinking beyond what was found in the textbook. Jason and Emma observed students questioning each other and debating alternative hypotheses. They also observed students making connections between the field trip and their investigations. Emma was impressed by her students' ability to collaborate during their investigations, but was discouraged by their difficulty communicating what they learned.

CHAPTER 5

CONCLUSION

Providing students with a quality science education for "all" Americans has been a National issue for more than 15 years. Unfortunately, large-scale testing of students throughout the nation has shown that "all" Americans are not achieving at the same levels in science. As I illustrated in Chapter One, a significant achievement gap exists between white students and minority students. Since the publication of the National Science Education Standards (NCR, 1996), science inquiry has been the preferred vehicle for science education reform. However, a decade later, the Highlights from the TIMSS 1999 Video Study of Eighth-Grade Science Teaching (2006) shows that science inquiry may not be commonly found in many of our schools. Research suggests that the quality of a teacher's instruction has a significant impact on student achievement (Feldman, 1991; Sanders & Rivers, 1996; Darling-Hammond, 2001; Marzano, 2003). An increase in the use of science inquiry in schools with high populations of minority students may help shrink the achievement gap.

The purpose of this study was to examine how teachers' understanding of science inquiry and its implementation changes as a result of professional development, including the development and enactment of a science inquiry unit. Additionally, the study explored how the Inquiry for Conceptual Change model

affects the student learning in classes serving primarily Hispanic students. This study consists of two focus questions.

1. What are teachers' perceptions of science inquiry and its implementation in the classroom?

2. How does the use of the Inquiry for Conceptual Change model affect the learning of diverse students?

Four classroom teachers and the science laboratory teacher at an urban school participated in this study. The school serves a very high Hispanic population. Sam is a fifth grade teacher. Jason is a sixth grade teacher. Emma teachers a sixth grade bilingual class. John is the school's science laboratory teacher. These teachers collaborated with me over the course of one semester to learn about science inquiry and develop and implement a science inquiry unit using the Inquiry for Conceptual Change model. We met formally for six working sessions and three units were produced. The participants were interviewed at three stages during the study. The first interview took place before the first professional development work session. The second interview took place after the participants had developed their units. The third interview took place after the participants had implemented their units. Participants also completed two reflections early in the study, a journal during the unit implementation, and a final reflection. The participants created and administered a pre- and post- assessment with their students. Additionally, I observed each teacher once during the implementation phase of the study.

This chapter will present conclusions from this study and implications of those conclusions. Additionally, suggestions for further research and recommendations for educators will be presented. The conclusions, implications and research suggestions will be organized in three categories: The Inquiry for Conceptual Change model; teacher understanding and practice; and student learning. The recommendations will be presented at the end of the chapter.

<u>The Inquiry for Conceptual Change Model</u>

Teacher participants in this study developed units based on the Inquiry for Conceptual Change model. I will present a summary of the model in this section. A detailed description was provided in Chapter Three. An illustration of the Inquiry for Conceptual Change Model is shown in figure 30.

Figure 30: The Inquiry for Conceptual Change Model.

In the Preparing stage, the teacher determines her students' initial conceptions regarding the target concept. This involves the teacher developing a clear understanding of her learning expectations. Once the teacher has identified her students' conceptions, she can generate activities for the "Wondering" phase. She can also identify activities and ideas for the "Connecting" phase.

In the Wondering stage students are introduced to the topic of the study. They identify and commit to their initial conceptions. During this step, students should connect their initial conceptions and the topic to situations that affect their lives. Next, students should work to identify disagreements between their initial conceptions, the initial conceptions of their peers, and experiences introduced by their teacher. The teacher's goal at this point is to help students become dissatisfied with their initial knowledge state. Finally, students should generate questions that they can investigate.

During the Investigating phase students work in small groups to refine their questions and develop a procedure for conducting research. Students should be encouraged to use multiple sources of information and should develop investigations that allow them to conduct experiments and collect data.

In the Constructing phase, students should analyze their data and begin to answer their research question. Students should be expected to communicate their results to their classmates and possibly to audiences beyond the classroom. Students should also return to the question of how their knowledge is connected to their lives.

The Connecting component of the Inquiry for Conceptual Change model has two attributes. This component is found visually at the center of the graphic that represents this model in order to emphasize that connections can and should be made in any phase of the model. The first attribute is making sure that the activities and concepts are relevant to the students. Students' initial conceptions, cultural ways of knowing, and interest should act as access points to learning new concepts. The second attribute is between the students' investigations and the curriculum. Curricular demands make it important for students to develop specific concepts. Teachers can use "benchmark activities" to introduce these important concepts and skills.

The Inquiry for Conceptual Change model also includes two aspects of a proper classroom environment. The first aspect is encouraging instructional conversations. These types of conversations differ from usual teacher-centered conversations by emphasizing student "cross-talk" about ideas. The classroom environment should also provide opportunities for students to think about their ideas and how those ideas change. Brief metacognitive instances can be used to do this.

Conclusions Related to the Inquiry for Conceptual Change Model

Participants were introduced to the Inquiry for Conceptual Change model and were asked to use it as a guideline while developing their unit. Strict adherence to the model was not expected, but participants were told to try and keep with the "spirit" of the model. The participants and researcher worked closely during the preparation phase. This section will briefly describe how the participants used the model and benefits and concerns with the model.

Use of the Model. Three units were developed in this study. Jason and Emma collaborated on their unit. John worked closely with Sam, Jason and Emma. Sam developed a unit for his fifth grade students that focused on how pollution affected plants and on the lifecycle of plants. The core of the unit was an investigation, facilitated by Sam, of how specific types of pollutants affect plants. The students identified potential pollutants and procedures for conducting the activity. Sam facilitated this in a whole class discussion. The unit also included many benchmark activities that connected pollution and plants to the students' lives and built specific background knowledge and process skills. Students communicated their results to a visiting class of third grade students. During my observation and through Sam's interviews and reflection, evidence emerged that students were involved in discussing ideas with each other. Sam was able to include all of the components except for metacognition in his unit.

Jason and Emma developed a unit for their sixth grade classes that had the dual purpose of helping their students understand local water issues and how water shaped the surface of the Earth. At the core of the unit was a very student centered investigation where students either explored how water shaped the land or developed water filtration systems. Jason and Emma worked with their students to generate questions for their investigations. The remainder of the investigation proceeded with little guidance from the teachers. The unit was specifically connected to water in their community and included a field trip to two rivers, a water treatment facility and a university hydrology laboratory. The unit also contained benchmark activities that

were used to increase students' background knowledge on the water cycle and a few other important concepts. There was strong evidence that students discussed ideas with each other. Jason and Emma explicitly incorporated all of the components of Inquiry for Conceptual Change in their unit except for metacognition.

Steve developed a unit for his eighth grade students that focused on electric circuits. The goals of the unit were for students to understand how to build a complete circuit, understand the direction of current flow in a circuit, and understand differences between series and parallel circuits. The unit included four inquiry investigations that had a range of structure. Two benchmark activities were also included to build knowledge on specific measurement tools used in the investigations. Steve noticed that his students were highly engaged even though he did not explicitly address relevancy.

Benefits and Concerns of the Model. One of the major benefits of using the Inquiry for Conceptual Change model in this study was in providing a structure for participants to use as they thought about how science inquiry would look in their classroom. Inquiry for Conceptual Change presents a comprehensive, but straightforward model for science inquiry. All of the participants felt that the preparing phase of the model was incredibly important for the success of their students. By developing a pre-test, participants were forced to clearly define what they wanted their students to know as a result of the unit. Additionally, the pre-test allowed participants to find the gaps between their students' initial knowledge and the unit goals. This helped participants focus instruction to meet their students' needs.

Combining the pre-test with the post-test also provided concrete evidence that their students learned as a result of the unit. This realization can prove motivating for teachers to continue exploring new teaching strategies.

Participants had a number of concerns regarding the Inquiry for Conceptual Change model. One concern was the perception that their students lacked the background knowledge and skills necessary to conduct scientific investigations. Since this is a comprehensive model, it may be overwhelming to teachers that do not have previous experience with science inquiry. During the development portion of this study, I quickly realized that I would not be able to ask participants to incorporate the entire model. Therefore, I did not explicitly introduce the concepts of instructional conversations and metacognition. In retrospect, I believe this was the proper decision because the participants' would have struggled with adding specific metacognitive "instances" on top of the new strategies that they were implementing. The act of conducting science inquiry in small groups encouraged a high level of student-centered discussions that had the characteristics of instructional conversations. Jason and Emma indicated that they found the development of a full unit daunting and were concerned throughout most of the study with what inquiry would look like in their class. In the end, both of them found the investment of time and energy worthwhile.

The participants' major concern with the Inquiry for Conceptual Change model was the 'two-headed animal' of time constraints. The participants are expected to cover a broad list of science learning targets throughout the year. Furthermore, the classroom teachers that participated are general education teachers. In addition to

science, these participants are expected to teach all of the other core subjects. Math and reading often took priority over science. Developing full units based on the Inquiry for Conceptual Change model is also time consuming. Participants spent approximately 12 hours in formal work sessions and many hours beyond that to develop their units. Although all of the participants thought it was a worthwhile time investment, it does cause tensions when trying to balance preparation for other subjects and the participants personal lives.

Implications of the Use of the Inquiry for Conceptual Change Model

The Inquiry for Conceptual Change model provides a useful structure for thinking about science inquiry. The preparation stage is very important to unit success. This study showed that using the model to create a full unit helps teachers develop an understanding of the full range of science inquiry possibilities. However, it can be overwhelming for teachers that lack previous experience with science inquiry It may be useful to provide teachers that are new to science inquiry with an incremental approach to the Inquiry for Conceptual Change model. Although all of the components of the model are important, the model will be more approachable for first-time implementers if they are not expected to focus on instructional conversations and metacognitive instances. However, if this approach is taken, it becomes important that a long-term plan that phases in these two components is created.

It is likely that teachers would be less overwhelmed if they were "scaffolded" into using science inquiry instead of being introduced to a comprehensive model.

However, these teachers may not see the broad range of how science inquiry can be used. For example, Sam had extensive experience with using small scale science inquiry. However, he had never thought of using science inquiry for long-term investigations. As a result of this study, he is enthusiastic to find other opportunities for long-term inquiry with his students.

The approach taken in this study of having participants create and implement a unit based on the Inquiry for Conceptual Change model instead of implementing a pre-packaged curriculum unit should be very beneficial for the participants. The exposure to a deliberate planning process that focuses on students' initial knowledge, components of science inquiry, and suggestions for engaging students should allow participants to modify and adapt curriculum to meet the needs of their students.

Suggestions for Research

The participants in this study dove into the deep end by developing a unit with science inquiry at its core. One fruitful area of research would be to compare this approach to one that scaffolds teachers into science inquiry by incorporating inquiry skills slowly and implementing multiple short inquiry activities within the context of existing units. How would changes in participants understanding of, and attitude towards science inquiry compare? Perhaps a continuum of teacher learning will emerge from this type of research that could define starting points for professional development based on individual teacher's experience and understanding of science inquiry.

A second research area that would be very interesting is to investigate how these teachers approach and modify pre-packaged curriculum units as a result of their intensive experience with the Inquiry for Conceptual Change model. A comparison between how these participants and other teachers (without the experiences in this study) approach and implement pre-packaged units could provide significant insight for professional development planners and facilitators.

Teacher Understanding and Practice

One of the two primary purposes of this study was to explore how teachers' understanding of science inquiry related to their practice and how this understanding changed over time. Two specific conclusions can be made in this area. First, an understanding of science inquiry is not enough to change practice. Second, an understanding of science inquiry on a continuum of teacher control and a focus on planning can move teachers from managing activities to managing learning. After discussing these conclusions, implications for professional development and suggestions for further research will be provided.

Conclusions from Teacher Understanding and Practice

Two conclusions related to teacher understanding and practice can be drawn from this study. First, teacher understanding of science inquiry is not enough to ensure that the teacher implements science inquiry in the classroom. Second, increasing a teacher's understanding of science inquiry can help her move from a

teaching practice that focuses on managing activities to a practice that involves managing student learning.

Understanding of Science Inquiry Is not Enough. The four classroom teachers' reactions to this study provide an interesting window through which to view how a teacher's understanding of science inquiry relates to her use of science inquiry in her teaching. Emma, Jason and Steve began this study with little understanding of science inquiry. Their instructional style was teacher-centered and when they used hands-on activities, it was almost always in a very controlled situation. The participants guided their students through the activity step-by-step so that their students would stay on task, complete the activity, and achieve some success by receiving the "correct" answer.

During the study, all of the participants were involved in a similar professional development experience. By the end of the study, Emma, Jason and Steve all had increased their understanding of science inquiry and had implemented a science inquiry unit. All three of the participants had evidence that their students were successful in learning from the unit. However, when asked about how they thought they would use science inquiry in the future, they had very different responses. Steve was very enthusiastic about using science inquiry in the future. He commented about always thinking about science inquiry as he planned science instruction. If he thought that an inquiry approach could be successful, he would use it. Although Jason found the project rewarding, he was less enthusiastic about how much science inquiry he would use in the future. He said that he expected that he would include short inquiry

activities in many of his units. However, he felt that he would only be able to use full inquiry units infrequently. Emma stated that she did not see herself developing new science inquiry units in the future. She did see the value of science inquiry to encourage higher level thinking with her students, so she could envision incorporating elements of science inquiry into existing units.

Sam started with a different knowledge base than his colleague. He had a strong understanding of science inquiry and had led professional development for teachers on how to use science inquiry in the classroom. However, he admitted in his initial interview that his current teaching style was very teacher-centered and did not include science inquiry. By the end of the project, Sam was energized and enthusiastic about using science inquiry more frequently in his teaching. He felt that this experience really opened his eyes to the value of long-term investigations. Sam expected that he would use shorter science inquiry activities on a regular basis and longer-term inquiry a few times per year.

Why are these teachers' responses to implementing science inquiry in the future so different? In Chapter Two, I discussed research conducted by Feldman (2000). Feldman applied Posner et al.'s theory of conceptual change (1982) to explaining how a teacher changed her practical theory of teaching. In order for teachers to change their practical theory, they must become discontented with their initial practical theory by recognizing that it is ineffective or unsuccessful. Then, she must see the new practical theory as sensible. It should be comprehensible and reasonable in particular situations and consonant with the teacher's goals. Feldman

adds that the new practical theory must have beneficialness. This means that the new theory must lead to "better" outcomes than the previous theory. Finally, the new practical theory must be illuminating in order for the teacher to accommodate it. A theory is illuminating if the teacher can see using it in a variety of situations (Feldman, 2000).

We can apply Felman's (2000) conditions for practical theory change to explain why the participants see different futures for their use of science inquiry. The easiest case to begin with is Steve. At the beginning of the study, Steve explained that he did not feel that he was teaching science in a manner that was good for his students. When asked how he would explain to a student teacher how to teach science, he stated that he would ask the student teacher what he thought because he is looking for a new way to teach. Steve was very discontented with his teaching, so he was open to changing his practical theory. Steve had some experience with teaching mathematics in a constructivist manner, so the language of science inquiry was sensible. His students' increased engagement and achievement showed Steve that his approach to science inquiry had beneficialness. Finally, Steve saw multiple ways to implement science inquiry and felt that he could overcome many of the constraints related to implementing science inquiry. Feldman would say that Steve found science inquiry illuminating as a practical theory. All four conditions for practical theory change were strongly met by science inquiry. Therefore, Steve has embraced science inquiry as a fruitful approach to teaching science.

At the beginning of the unit, Jason expressed some concerns about how he was teaching science. After he examined his students' pre-test responses, he began to have some serious doubts as to the effectiveness of his teaching. Jason had become discontented with his initial practical theory of teaching. By the end of the study, Jason also saw that science inquiry was beneficial for similar reasons as Steve. However, throughout the development of the unit, Jason was very apprehensive as to how science inquiry would look in his classroom. Additionally, he saw the time it took to conduct science inquiry as a serious constraint to implementation. In Jason's case, science inquiry as a practical theory may not seem fully sensible or illuminating. Although Jason still has some lingering concerns about science inquiry, he did see the value of using it and planned on using it in the future. Did Jason undergo practical theory change?

Feldman's (2000) description of how practical theory changes may have been overly simplistic. Obviously, Jason did undergo some changes in his beliefs about teaching. However, he has not embraced the new beliefs as fully as Steve. Hewson's expansion of conceptual change (Hennessey, 2003) may shed light on Jason's case. Hewson and Hennessey explain that the degree to which the conditions for conceptual change are met gives a concept a certain status. If conceptual change takes place, the new conception has a higher status than the previous conception. This can be applied to Jason's case by saying that he has given science inquiry enough status that he will continue to consider using it. However, he has not given it enough status to completely embrace the new practical theory.

Emma did not have the same level of discontent with her initial practical theory of teaching. Additionally, she places strong importance on structure, demonstration and guidance to meet her students' learning needs. This view is not unwarranted. Research has shown that Hispanic students often need more structure than other groups of students (Griggs & Dunn, 1995). Therefore, it is likely that Emma did not see inquiry as sensible. Emma saw evidence that her students learned during the unit. However, her students struggled with communicating what they learned and she saw the time that inquiry takes to implement as a constraint to implementation. Emma may view science inquiry as having some beneficial outcomes and limited illumination. Since Emma saw the benefits of inquiry, she will use certain aspects in the future, but she did not assign science inquiry with enough status to develop additional full inquiry units.

Sam already had a strong understanding of science inquiry at the beginning of the study. Therefore, it is not fair to say that he underwent conceptual change to the same extent as Steve and Jason. Instead, Sam underwent conceptual extension (Hennessey, 2003). He added new understanding to his practical theory that was already consistent with his beliefs of science inquiry. If Sam already held science inquiry as his practical theory, why did he not implement it in his teaching practice before this study? This can be answered by looking at status as a dynamic force in decision making. This year, Sam felt strong pressure to emphasize math and reading over science. Therefore, much of his energy and focus was on these subjects. As a result, his view of what was "sensible" for science instruction changed. A more

teacher-centered approach to teaching science takes less instructional time, leaving more for other subjects. Therefore, Sam assigned that practical theory of teaching a greater status than science inquiry.

Moving from Managing Activities to Managing Learning. All of the participants placed importance on understanding that science inquiry can be enacted on a continuum of teacher control. In Chapter Two, I discussed Bonstetter's (1998) description of this continuum. At one extreme lies complete teacher-centered instruction, the teacher controls the topic, question, procedure, analysis, and conclusion. The student is successful if they can replicate the experiment and produce the results that the teacher expects. At the other extreme lies complete student-centered instruction, or student research. The student controls the topic of study, question, procedure, analysis and conclusion. The student's success is measured by the rigor of their investigation and the logic of their conclusion. Bonstetter (1998) explains that as teachers become more comfortable with science inquiry, they may evolve from a teacher-centered approach to student research. He states, "[the continuum] shows how we can use inquiry to move toward more student centered classrooms and create a classroom where the focus is clearly on learning and not on the teacher teaching."

All of the participants in this study have been responsible for coaching their students in the school's science fair. In theory, the science fair is at the student research "extreme" of Bonstetter's continuum. Most of the students at Becker School did not have a high level of success with the science fair because they did not have

the prerequisite skills needed to do inquiry. Additionally, all of the participants have a concern that even if their students had mastery of the skills needed to do independent student research in science, this type of research would make it nearly impossible to reach the wide range of learning targets expected for their grade.

Sam understood that his students did not have mastery of the skills needed to do open inquiry. Therefore, he included many teacher-centered activities and provided significant guidance during his students' investigations. Is it fair to say that, because he used teacher-centered techniques, he was not focused on student learning? The investigation that Jason and Emma used in their unit would be classified as "student directed" on Bonstetter's continuum because the teacher provided the topic and the teacher and students collaborated on the question. Students were responsible for what materials they wanted to use (with some teacher constraints) and the procedure for answering their question. Emma noted that her students struggled with many aspects of this student directed approach. If she uses this unit again, it is very likely that she will incorporate more structure for her students. Would it be fair to say that Emma was taking a "backward step" away from a student-centered approach and a focus on student learning? The answer to the questions posed from Sam and Emma's actions can only logically be seen as no. In both cases, their actions are a result of focusing specifically on student learning. Bonstetter's (1998) science inquiry continuum is useful for conceptualizing what science inquiry could look like in the classroom, but is not an adequate evolutionary model.

All of the participants in this study agree that they lean either towards the teacher-centered or student-centered ends of the science inquiry. However, they emphasize that where specific lessons fit on that continuum is based on a number of factors, including the needs of the curriculum and the needs of the student. Their view of the science inquiry continuum closely echoes Fradd and Lee (1999). Fradd and Lee state that "Teacher-as-knowledge-transmitter" is not positively viewed in the literature and professional development circles, however the transmission of knowledge is essential in ensuring students learn how to participate. "Teacher-as-facilitator" is often positively viewed, but teachers who facilitate without teaching may not provide the knowledge students require to learn and achieve. Fradd and Lee contend that the discussion should not focus on which is better, but on how different approaches can meet students' needs.

If a teacher adopts Fradd and Lee's (1999) view of a science inquiry continuum, she can begin to move from managing activities to managing learning. However, for this to be successful, teachers must carefully plan their teaching by focusing on what students already know about a topic and what they expect students should know at the end of the unit.

Implications for Teacher Understanding and Practice

Having the ability to move along a continuum of teacher control when implementing science inquiry takes a very sophisticated understanding of science inquiry. Teachers need clusters of experiences that show them how science inquiry can be used to meet different classroom needs. This understanding requires ongoing

professional development that includes enactment of new teaching strategies. In Chapter Two, I described a professional development model used by Krajick and his colleagues (Krajick et al, 1994). Ladewski, Krajick and Harvey (1994) examined how one teacher changed her conception of science teaching during their professional development model and conclude that teaching is often a balance between theoretical statements of what teaching should be and practical statements about coping with the demands (e.g. covering the required curriculum, maintaining control of the classroom, etc.). If teachers are to develop complex new conceptions and strategies of teaching, they need professional development that includes repeated cycles of collaboration, adaptation and reflection. By enacting and reflecting on new teaching paradigms in a variety of situations, teachers will increase the status with which they hold these new paradigms.

The success of the professional development approach used in this study reinforces the importance of seeking models of professional development in which facilitators view participants as peers, showing respect for the participants' teaching experience, and being responsive to their needs and concerns.. This requires that the facilitator has a flexile rather than rigid structure in place for the professional development opportunity.

Suggestions for Research

A number of fruitful areas for future research exist in this area. First, a longitudinal study of how teachers' conceptions of science inquiry change as a result of ongoing professional development that focuses on enactment and reflection of

inquiry would be useful. Second, research into how science inquiry can be used in different situations to meet curricular demands and the needs of the student can help professional development facilitators create situations that will improve teachers' abilities to move along the science inquiry continuum. Finally, research that seeks to understand conditions where teacher-centered instruction may be more appropriate than student-centered (or vice-versa) approaches would be useful. This last body of research should move towards the creation of principles for using science inquiry. For example, one principle could be, "The method should meet the goal." Teacher-centered methods may be appropriate where structure does not remove the thinking relative to the learning goal.

Student Learning

The other primary goal in this study was to examine how the Inquiry for Conceptual Change model impacted students' learning in classes that were predominantly Hispanic. Three specific conclusions can be made from this study: first, The Inquiry for Conceptual Change model increases Hispanic students' engagement in science; second, Hispanic students can learn by using science inquiry; and third, some concerns about using science inquiry with Hispanic students have emerged. After discussing these three conclusions I will present implications and suggestions for future research.

<u>Conclusions for Student Learning</u>

This study found that the units designed based on the Inquiry for Conceptual Change model led to increased student engagement. Additionally, the students in this study learned by using science inquiry. However, some concerns also emerged from the use of the Inquiry for Conceptual Change model.

<u>Inquiry for Conceptual Change Increases Student Engagement.</u> The Inquiry for Conceptual Change model emphasizes identifying students' initial knowledge on a subject for use a as starting point for instruction, encouraging relevancy and connection to students' lives, and other aspects of culturally responsive teaching. According to Ginsberg and Wlodkowski (2001), this emphasis addressed the needs of diverse students by improving motivation and engagement. Voke (2002) states that engagement is a prerequisite for the development of understanding.

All of the participants in this study observed that their students were highly engaged in their investigations. The participants saw an increase of on-task behavior and a decrease in classroom management problems when they compared this unit to previous science units. Students consistently asked good questions related to the topic and discussed ideas within their groups. The participants noted that student-centered and initiated discussions related to the topic of study was not something that was often found during other units.

<u>Science Inquiry can Support Hispanic Students' Learning.</u> A comparison of pre- and post- assessments showed that all of the units implemented in this study

increased student understanding of the science content. Students were able to better describe scientific concepts, use more vocabulary, and provide more detail and accuracy in diagrams related to science concepts. There was also a decrease in the prevalence of misconceptions, specifically related to pollination and current flow in a circuit, as a result of the units. It is important to note that the student pre- and post-assessments and the researchers' observations of the students participating in science inquiry were not disaggregated by ethnicity. However, 80% of the students in this study were Hispanic. The conclusions in support of student learning from this study should be viewed as preliminary since the study did not incorporate control groups, there was a small sample size, and the pre- and post- assessments were teacher constructed. Nonetheless, these results are very promising.

Concerns Related to Student Learning. Three specific concerns related to student learning emerged from this study. First, is that many students lack experience using process skills. Students were particularly challenged with generating testable questions. This proves a significant barrier to conducting science inquiry without extensive teacher guidance, Second, bilingual students had difficulty communicating what they learned, at least in the manner that was used in this study. Third, many students had a lack of confidence in their ability to do science inquiry. They expected more teacher structure and guidance and grew frustrated when they did not receive it. This study confirms findings by Seiler (2001) that instruction that is relevant to the contemporary urban youth culture can increase student engagement and thoughtfulness. Additionally, this study confirms findings by Rodriguez and

Berryman (2002) that instruction that focuses on Hispanic youth's contemporary culture and ways of knowing increases student engagement.

Implications Related to Student Learning

The inquiry for Conceptual Change model can provide a useful framework for increasing student engagement and increasing student learning in science. Success in learning requires that students feel confident and competent (Fradd and Lee, 1999). Therefore, it is important for teachers to use extensive scaffolding to increase students' skills and confidence. Sam's unit provides an excellent example of how benchmark activities can be used to increase students' understanding of prerequisite knowledge and ability with process skills.

In this study, the participants developed units that they felt would be relevant to their students' lives. They also focused on their students' initial conceptions related to the topics. Student initial knowledge and interests were used as access points to engage students in the learning process. However, the units did not specifically include elements that were relevant to the students' traditional Hispanic culture and cultural ways of knowing. It is possible that even stronger successes could be realized if these were included.

Suggestions for Research

Research that identifies which process skills are most important for student success in science inquiry is needed. Additionally, research that identifies best practices for developing these skills is crucial. Emma's belief in the importance of

structure for bilingual students is consistent with research presented by Griggs and Dunn (1995). Further research into the type of structure that should be provided is needed. Also, it is important to determine if this need for structure is a conditioned response due to students' lack of confidence with science. A follow-up study will be conducted to determine if the students' learning is durable. Finally, quantitative studies that compare the Inquiry for Conceptual Change model to other teaching methods is needed.

Additional research on the importance and characteristics of culturally responsive inquiry approaches for Hispanic students should be conducted. These studies should look at student engagement and learning when inquiries are explicitly designed to make strong connections to traditional Hispanic culture, contemporary Hispanic youth or community culture, or transitional Hispanic culture.

<u>Recommendations</u>

Recommendations for curriculum coordinators, professional development facilitators, publishers, and classroom teachers have emerged from this study. Following these recommendations may help to increase the frequency and quality of science inquiry in the classroom.

Recommendations for science curriculum coordinators involve two specific aspects of education that are under the control of a school district. First, learning targets should be revised so that they clearly articulate what students should be able to do when they "meet" that standard. Second, curriculum coordinators should adopt a

professional development process that is ongoing and part of the goals of the school. Curriculum coordinators should encourage professional development that is done in cohorts and includes enactment of and reflection on new teaching strategies.

This study provides three recommendations for publishers of textbooks and other curricular resources. First, publishers should integrate both short and long term inquiry activities in each unit. Second, publishers can help teachers develop their own inquiry activities by providing "starting points" for student inquiry. Third, publishers should resist "breadth versus depth" publications. Publishers should focus on fewer topics and clearly present a hierarchy of concepts and "big ideas."

Four recommendations are provided for professional development facilitators. First, facilitators should provide a specific model, such as the Inquiry for Conceptual Change model, during professional development. A model provides participants with help organizing their thoughts and gives participants a common base for discussions. Second, facilitators should help teachers understand how to improve students' mastery of skills needed to conduct science inquiry, specifically techniques to help students generate testable questions. Third, facilitators should introduce participants to inquiry by having them actually participate in an inquiry activity. Fourth, professional development should be based in practice. As John states, "You need to do inquiry on inquiry." Professional development should include a collaboration between facilitators and participants as they enact and reflect on their practice and new strategies for science inquiry. This collaboration should respect and be responsive to the experiences that all of the participants bring to the session.

The recommendations directed at teachers for increasing their use of science inquiry are primarily focused on the mindset of the teacher. First, make a commitment. Learning how to do science inquiry may not be easy, but it is important. A teacher needs to commit to learning how to do science inquiry over time. Second, teachers should not sweat the details. At first, incorporating science inquiry may seem overwhelming. However, science inquiry is rewarding. Teachers need to make the decision to get started, learn a little, and then start practicing and reflecting. Third, be flexible. Teachers need to understand that they will make mistakes as they implement science inquiry in their classroom. They need to treat these mistakes as personal opportunities to learn. Additionally, situations will arise where teachers need to make on the spot decisions. Have the flexibility to move in different directions as necessary to meet your learning goals. Fourth, know your students. Understand your students initial conceptions and their experience with science inquiry. If your students have not done much science inquiry in the past, do not expect them to successfully jump into an open investigation. Provide students with scaffolding so that they can learn background knowledge and skills that are prerequisites for science inquiry. This means that it is important to carefully plan your science inquiry implementations.

Summary

This study showed that the Inquiry for Conceptual Change model can be used by teachers to develop units that are engaging for Hispanic students and help them learn science concepts. Three units based on the Inquiry for Conceptual Change

model were shown to have a positive impact on student engagement and learning. The study also showed that teacher enactment of science inquiry during professional development is essential for teachers to understand how science inquiry can be implemented at the classroom level.

<u>Epilogue</u>

The participants in this study teach in a challenging environment and face a number of challenges while helping their students learn. They often do this in a hostile climate where school systems are blamed for failing students. Under these circumstances, it would be easy for teachers to give up and take the easy road. This study ended shortly before the end of the school year. Instead of asking about my plans for the summer or talking about their plans, they asked me a simple question, "What's next?" All of the participants saw the benefit that our collaboration had on their students and wanted the project to continue. We began talking about questions that were left lingering from the initial project. We agreed that the most pressing of these was determining strategies to scaffold science inquiry skills throughout the year with a tangible goal of increasing the number of students that could participate in the school's science fair without needing extensive guidance. All of us are also interested in the durability of the learning that we have achieved. We have planned to follow-up with this year's fifth and sixth grade students next fall in an attempt to understand how enduring their understanding was.

The participants in this study deserve our respect and commendation for unselfishly giving their time to improve the profession's understanding of how teaching can be improved to better serve these students.

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APPENDICES

APPENDIX A

PARTICIPANT CONSENT FORMS

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Project: Investigating the implementation of the Inquiry for Conceptual Change model.

You are being asked to participate in a research study of the effectiveness of the implementation of a science inquiry model. This study will help educators understand how the Inquiry for Conceptual Change model can be used to help the learning of science by diverse students. You have been chosen because of your assignment to teach science in grades 5-8.

If you agree to participate, I will collect data from you in the following manner:

1. Three interviews will be conducted by this researcher with you. The interviews will be conducted in the spring of 2006. Each interview will last approximately 60 minutes and will be conducted in person at a location of your choice. The interview will be designed to gain insight into your beliefs about teaching, specifically those related to teaching science.

2. You will be expected to keep a reflective journal of your experiences during the creation and implementation of a unit of study based on the Inquiry for Conceptual Change model. This reflective journal will be used to help understand your thinking throughout the study.

3. Products that you create as a result of this study will be examined for understanding of how science inquiry can be used to improve student learning.

4. Observations of your teaching during implementation of the unit of study will be conducted to determine the affect of the professional development related to Inquiry for Conceptual change affects your teaching and the learning of your students.

We want you to know that:
1. Your participation is confidential and voluntary.
2. You may choose not to participate or to withdraw your consent at any time without penalty.
3. You will receive a $750 stipend for your participation. You will be paid in one lump sum no later than June 15, 2006. If you choose to withdraw from the study, you will receive compensation for the time that you have contributed to the project.
4. Participating in this study may also have some general benefits in that you will be contributing to the improvement of teacher education and student learning. Participating in this study may also provide you with new ideas about your teaching and student learning.

5. The risks for participating in this study are minimal. This may include risks such as feeling uncomfortable talking about your teaching beliefs.
6. Your decision to participate/not to participate in this study will have no effect on your professional standing within Milwaukee Public Schools.
7. All data collected from you and personal information will be kept confidential and secured in locked offices or in password protected computers. No one outside the principal investigator and approved research staff will have access to your information. Your privacy will be protected to the maximum extent allowable by law.
8. In research papers or other public presentations resulting from this study, your name will not be used and any identifying characteristics or personal information that could be used to identify you will be deleted or masked. It is highly unlikely that anyone would be able to identify you from any published report, although it is slightly possible that another MPS employee might read a report based on this study and recognize your remarks. Your privacy will be protected to the maximum extent allowable by law.
9. If you have any questions or concerns regarding your participation in this study you can contact me at:
   Eric Brunsell, 401 Brent St. Hatley, WI 54440, 800-215-1511 x 701
10. If you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Institutional Review Board Chair, 960 Technology Blvd., Room 127, Bozeman, MT 59717. For information and assistance, call 406-994-6783.

Your signature below indicates your voluntary agreement to participate in this study.

==

Participant's Signature _____ Date _____

Researcher's Signature _____ Date _____

APPENDIX B

PARENT CONSENT FORMS FOR STUDENT PARTICIPATION IN RESEARCH

Parental Consent Form for Child to Participate in Research Study

Title of Research: *Inquiry for Conceptual Change*

A. PURPOSE AND BACKGROUND
Eric Brunsell, a graduate student at Montana State University, is conducting research on the use of science inquiry instruction with diverse students. The purpose of this research is to determine whether students learn more science when they are given the opportunity design their own exploration of what they are studying. The following teachers at Alexander Mitchell School are participating in this study:
Ms. "Emma"
Mr. "Sam"
Mr. "Jason"
Mr. "Steve"
Mr. "John"

Your child is being invited to participate in this study because he / she is a student in one of these teachers' classes at Alexander Mitchell School.

B. PROCEDURES:
If you agree to allow your child to participate in this research project, the following will occur:

1. Your child's teacher will give tests and other assessments (projects, presentations, worksheets, etc.) during the science unit.
2. The researcher will study the results of these assessments in order to determine how students have learned science during this unit.
3. Students not participating in the research will have the same instruction and take the same assessments as students participating in the research. However, their assessments will not be seen by the researcher.

C. RISKS
There is a risk of a loss of privacy. In order to protect subjects' privacy, the records from this study will be kept confidential. No names or individual identities will be used in the publication of this study. Student work will be coded by their teacher and the researcher will not know the names of individual students.

D. ALTERNATIVES
You are free to choose to not have your child participate in this research project.

E. QUESTIONS
If you have any further questions about this project, you can contact the researcher, Eric Brunsell, by calling him at school at 1-800-215-1511. Additionally, you can contact your child's teacher or the school principal.

F. CONSENT
PARTICIPATION IN THIS RESEARCH PROJECT IS VOLUNTARY. You are free to decline your child's participation in this research project, or may withdraw your child's participation at any point without penalty. Your decision to have or not have your child participate in this research project will have no influence on your child's present or future status or grades as a student at Alexander Mitchell School.

My child _____has my consent to participate in the educational research study.

My child, _____ DOES NOT have my consent to participate in the educational research study.

Parent/Guardian: _____ Date: _____

Researcher: _____ Date: _____

Consentimiento parental para que su estudiante participe en un estudio educacional

Título del estudio: *Investigación para el cambio conceptuall en ciencia*

A. PROPÓSITO DEL ESTUDIO

Eric Brunsell, estudiante graduado de Montana State University, está conduciendo una investigación sobre el uso de la instrucción de la ciencia con estudiantes de diversas culturas. El propósito de esta investigación es determinar si los estudiantes aprenden mejor cuando se les da oportunidad de diseZar su propia exploración de lo que están estudiando. Los siguientes profesores de la escuela Alexander Mitchell participan en esta investigacion:

> Ms. "Emma"
> Mr. "Sam"
> Mr. "Jason"
> Mr. "Steve"
> Mr. "John"

Su hijo esta invitado a participar en esta investigacion porque él/ella es un estudiante de uno de los profesores de la escuela Alexander Mitchell mencionados arriba.

B. PROCEDIMIENTOS:

Si usted permite que su hijo participe en este proyecto de investigación, ocurrir< lo siguiente:

1. El profesor de su hijo dará copias de las pruebas y otros trabajos (proyectos, presentaciones, hojas de trabajo, etc.) de ciencia al investigador.
2. El investigador analizar< estos trabajos para determinar cómo los estudiantes han aprendido ciencia durante estas lecciones.
3. Los estudiantes que no participan en la investigación tendrán la misma instrucción, har<n los mismos trabajos, y tomar<n las mismas pruebas que los estudiantes que participan en la investigación. Sin embargo, sus resultados no serán considerados por el investigador.

C. RIESGOS

Hay un riesgo de una pérdida de privacidad del tranajo de su hijo. Para proteger la privacidad de los estudiantes, los resultados de este estudio serán confidenciales. No se utilizará ningun nombre o identidad de los estudiantes en la publicación de este estudio. El nombre del estudiante en el trabajo será reemplazado por un c∴digo conocido solo por su professor, y el investigador no sabrá los nombres de estudiantes individuales.

D. ALTERNATIVAS

Usted está libre de elegir no permitir que su hijo participe en este proyecto de investigación.

E. PREGUNTAS

Si usted tiene cualquier otra pregunta sobre este proyecto, usted puede entrar en contacto con al investigador, Eric Brunsell, llamándolo en la escuela en 1-800-215-1511. Además, usted puede entrar en contacto con el profesor de su hijo o el director de escuela.

F. CONSENTIMIENTO

LA PARTICIPACIÓN EN ESTE PROYECTO DE INVESTIGACIÓN ES VOLUNTARIA. Usted está libre de declinar la participación de su hijo en este proyecto de investigación, o puede retirar la participación de su hijo en cualquier momento sin penalizaci∴n alguna. Su decisión para permitir o para no permitir que su hijo participe en este proyecto de investigación no tendrá ninguna influencia en las presentes o futuras notas de su hijo, y no lo influenciar< como estudiante en la escuela Alexander Mitchell.

Mi hijo(a) _____tiene mi consentimiento de participar en el estudio educativo de investigación.

Mi hijo(a) _____NO TIENE mi consentimiento de participar en el estudio educativo de investigación.

Padre/guardian: Fecha del _____: _____

Investigador: Fecha del _____: _____

APPENDIX C

INTERVIEW GUIDES

INTERVIEW GUIDES

<u>Framework</u>

Patton (2002) defines six types of questions that elicit different types of responses from participants. Behavior questions focus on what a participant does or has done. These types of questions elicit behaviors, experiences, actions and activities. Opinion questions are aimed at determining interpretive processes, what do people "think" about a concept. Feelings questions aim to reveal emotions related to concepts. Knowledge questions identify the factual information possessed by the respondent. Sensory questions reveal what participants see, hear or smell related to specific concepts or phenomena. Background questions identify characteristics of the participant. Background, behavior, opinion, and knowledge questions are specifically pertinent to this interview.

The interviews conducted in this study will use the interview guide approach described by Patton (2002). In this approach, topics to be covered are determined in advance, but the interviewer decides the sequence and wording of questions in the course of the interview. This approach increases the comprehensiveness of the data and makes the data collection somewhat systematic for each respondent. The interviews remain conversational and situational. However, it is possible that the different wording and sequencing of questions may result in substantially different responses from different respondents that may reduce their comparability.

<u>Guide for the Initial Interview</u>

NOTE: These questions are guidelines to identify specific interview areas.

<u>Background Questions</u>

How many years teaching experience do you have?

   Science or general?

How extensive is your formal coursework in science?

Describe your involvement in professional development related to teaching science.

How do you describe your science content knowledge?

<u>Practice</u>

If I observed your classroom, what would I see?

Describe what a typical science unit looks like in your classroom.

What are the primary resources that you use for science activities?

How do you approach the design of a science unit?

How often do you use "hands-on" activities in your science lessons?

Can you describe what a typical "hands-on" activity looks like in your classroom? (It is

   OK to describe a specific activity that you think is representative of what you do)

Do you determine your students' initial ideas on a topic? When do you do this (before

   planning, before instruction)?

What methods do you use to determine students' initial ideas?

How do you use this information?

During a hands-on activity, how often do you provide them with:

A focus question

A Procedure

Data Tables

--- Follow up (opportunities for students to generate their own questions / procedures / data tables)

When students complete a hands-on activity, how do they share what they have learned (w/ teachers, w/ whole class, worksheet vs. presentation, etc.)

Do your students usually work individually or in groups? How do you determine how they group?

How would you describe the typical conversation / discussion in your classroom?

Teacher question, student response, teacher clarification

Teacher question, multiple student response

Student question, teacher response

Student question, student response

How do you typically assess your students?

How do you think your students are different from those in a suburban class?

How do you adapt your teaching (how is it different) to better work with your students? (OK to discuss specific examples)

What do you do to make science units relevant to your students? (OK to discuss a specific example).

Ideal Teaching Situation

If you had a student teacher, how would you explain to them about how they should

approach teaching a science unit?

What would you tell your student teacher are the most important components or

characteristics of good science teaching?

How would you define science inquiry?

What do you think science inquiry should look like in an ideal classroom?

What are some of the essential features of science inquiry that might separate it from a

typical hands-on activity?

What challenges or obstacles do teachers face when trying to use science inquiry in

classroom situations like yours?

Guide for the Post-Development Interview

General

If you had a student teacher, how would you describe science inquiry?

What do you think are the most important components of science inquiry?

How do you think your understanding of science inquiry has changed during this project?

Do you think this "type" of science inquiry will work with your students (why)?

Science Fair

Can you describe your involvement with science fair?

How successful are your students in the science fair format (concerns)?

How does the type of inquiry involved in the science fair compare to the inquiry used in

the unit?

Can you describe "in general" the types of questions that students chose to research for

their science fair?

Unit Specific

Please describe the unit that you developed.

What did you see as the most valuable portions of the development of this unit?

How did you "react or view" your student's responses to the pre-assessment?

Was the pre-assessment valuable in helping you to plan the unit? How?

What were the most challenging aspects of developing this unit?

What concerns do you have about implementing this unit?

What do you see as obstacles to implementing this unit?

Do you see yourself developing more units based on inquiry?

What do you see as the biggest obstacles to overcome to implement more inquiry based

units?

Guide for the Final Interview

What was your reaction?

Did you think students were engaged? How could you tell?

Do you think students learned? How could you tell?

Could you tell if students were thinking deeply about the content? How?

How did the students' reaction to this unit compare to their reaction to other science

units?

How effective do you think the unit was…from a student learning perspective?

What makes a good student investigation?

In one of his reflections, Jason wrote "It sounds so simple, but so did installing a water

pump on a Subaru – I hope this endeavor goes more smoothly." Did it?

(What frustrations do you have about designing and implementing an inquiry unit?)

If you had to design a professional development workshop on science inquiry for teachers

in your building, what would be the "big ideas" that you would want to convey?

One tension in implementing more inquiry is the time demands – from both a curriculum

and development perspective. How realistic is it to develop more inquiry based units?

What do you think you could do to make teaching in an inquiry manner more realistic?

What elements of inquiry methods of teaching can you see implementing on a regular

basis?

A few of you mentioned the "Activity Before Content" method of teaching – how could

you tweak that to be inquiry based?

A few of you mentioned that you were concerned about what inquiry would look like in
your classroom…and I never really answered those concerns. Now that you are done
with the unit, how did inquiry look in your classroom?

What recommendations would you give to teachers that want to get started using science
inquiry in their teaching?

Teaching philosophy can be described on a continuum between two paradigms. One of
these is the paradigm of direct instruction (where the teacher is the center of
classroom activity) the other is the paradigm of student open inquiry (where the
student is at the center of classroom activity). Where do you see your self as a
teacher?

How does this compare to where you were before this project?

APPENDIX D

FINAL REFLECTION GUIDELINES

FINAL REFLECTION

Thinking about Student Learning

1. Briefly describe how your unit looked as implemented.

2. What were the specific learning goals or targets that you wanted your students to have at the end of the unit (outcomes).

3. How engaged were your students in the unit? How did this compare to their engagement in previous science units? (please include specific examples if possible)

4. What do you think could be changed in the unit to increase student engagement?

5. What types of research questions did students pose during the unit? How did they modify their questions during the course of the unit? (please include specific examples if possible)

6. Was there evidence that students were really thinking about the content of the unit? How did this compare to other science units? (please include specific examples if possible)

7. Did student learning meet your expectations (based on your initial targets or goals)? (please include specific examples if possible)

Thinking about Teaching

1. How would you define science inquiry

2. What did you find beneficial (or the opposite) about designing and implementing an inquiry unit?

3. How do you think your understanding of science inquiry has changed from the beginning of this project?

Thinking about the future

1. Many of you commented on a tension between designing inquiry units and having the time within your curriculum to devote to inquiry. Do you feel that your inquiry unit was "worth" the instructional time devoted to it?

2. Many of you commented on a tension between designing inquiry units and having the personal time available to devote to development. Do you have any ideas on how to minimize this tension?

3. Do you see yourself developing one (or more) additional inquiry unit(s) next year?

4. Since the investment of instructional and development time is significant for implementing full science inquiry units, how might you incorporate the "core characteristics" or specific elements of science inquiry into your everyday teaching?

5. Do you see a tension between using science inquiry and No Child Left Behind? Why / Why Not? If so, how can it be minimized?

Recommendations

1. What recommendations would you give district curriculum coordinators for helping classroom teachers implement more science inquiry in their teaching?
2. What recommendations would you give professional development facilitators for helping classroom teachers implement more science inquiry in their teaching?
3. What recommendations would you give curriculum developers (ie: publisher) for helping classroom teachers implement more science inquiry in their teaching?
4. What recommendations would you give to teachers that want to get started using science inquiry in their teaching?