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## **An Exploration Of Middle School Science Teachers' Understandings And Teaching Practice Of Science As Inquiry**

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**AN EXPLORATION OF MIDDLE SCHOOL SCIENCE TEACHERS'  
UNDERSTANDINGS AND TEACHING PRACTICE OF SCIENCE AS INQUIRY**

by

**MARGARET ANN CASTLE**

**DISSERTATION**

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

in partial fulfillment of the requirements

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**DOCTOR OF PHILOSOPHY**

2014

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(Science Education)

Approved by:

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Advisor

Date

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## DEDICATION

This research project is dedicated to my parents who were excellent role models. My parents provided the impetus for learning and instilled the value and desire for continued life-long education. They taught me to set attainable goals and to achieve them. Their hard work and support provided the resources, confidence, and perseverance necessary to complete this project.

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## CHAPTER 1

### INTRODUCTION

#### Background

In 1989 the American Association for the Advancement of Science (AAAS) published *Project 2061: Science for All Americans All Americans*, denoting long-standing competencies for science education reform in K-12 schools. In addition to competencies related to what students should understand and be able to do at the cessation of K-12 education, this document also delineates conceptual structures and goals related to the benchmarks for the teaching of scientific inquiry (SI) (Barrow, 2006; Rutherford & Ahlgren, 1989). In 2001 AAAS added three strand maps detailing benchmarks that serve as the vehicle for interpretation of important philosophies that underpin the teaching of scientific inquiry. The first benchmark, evidence and reasoning, essential to performing inquiry includes dual categories: lines of reasoning and evidence based on observations. The second benchmark includes four categories of scientific investigation: control and condition, reliability of results, record keeping, and kinds of investigations. The third benchmark consists of six categories: (1) making sense of evidence, (2) stating alternative explanations, (3) forming theory modifications, (4) ensuring reliability of results, (5) using safeguards, and (6) crafting explanations that resemble scientific argumentation. These categories provide a framework of how scientific inquiry should be implemented when teaching science.

The message in these documents conveyed to school administrators, science education coordinators and science teachers, is that scientific inquiry must be considered as a science content topic. When science is taught using inquiry, scientific knowledge is linked with science

processes. The process begins with students developing scientific questions about phenomena in nature based on conceptual principles and knowledge and use the information to guide scientific inquiries. Using a team approach, students are actively involved with key concepts within the content subject matter and collect and use evidence that justifies answers to the questions. Students must also obtain and provide both historical and current perspectives of content knowledge and be able to provide clear interpretations of the data that they have collected. Clearly, this means deemphasizing the memorization of technical vocabulary which we now know to be a thing of the past.

The National Science Education Standards (NSES) (NRC, 1996, 2000, & 2012) published essential features of inquiry to ensure that teachers practice scientific inquiry as a content topic. In 2012, NRC added dimensions of learning to the science educational framework. Dimension 1 describes scientific and engineering practices; Dimension 2 covers crosscutting concepts of applicability across science disciplines; and Dimension 3 addresses core ideas in the science disciplines and the relationships among science, engineering, and technology.

In order to fulfill the NRC (2012) mandates, the K-12 science curriculum needs to include the following set of five scientific practices across grade levels: First, students need to immerse themselves in scientific practices by asking empirically, answerable, scientific questions for investigation about natural phenomena. After developing an answerable scientific question, students construct models and simulations that help them develop explanations about natural phenomena that they are investigating. Next, students prepare and carry out systematic investigations to study the phenomenon in question. Consequently, students collect, analyze and interpret data produced in the investigations from which they derive meaning. Subsequently,

students employ mathematical and computational approaches in the collection, analysis, and interpretation of data seeking out significant patterns and correlations from findings. Of great consequence, students use reasoning and argumentation skills essential to determining strengths and weaknesses in explanations for the natural phenomena they have investigated. Furthermore, students must practice persuasive communication of ideas and results of inquiries through scientific oral discourse, writing, use of tables, graphs, and equations.

Students are natural born investigators, they have the potential for sophisticated thinking about the world, and educators should build on their prior experiences. When given the opportunity to discern phenomena for themselves, they are capable of engaging in rather complex reasoning. Although students will not reach the same level of proficiency that scientists do, they need opportunities to practice all of the aforementioned skills in order to become scientifically literate (NRC, 2012).

A key factor in the use of scientific inquiry in k-12 settings is that educators must avoid excessive coverage of material with many disconnected, decontextualized topics, which produce limited student understanding of science. A better choice is to study in depth and breadth, a limited set of core ideas in a rich contextualized setting. Students need to learn science concepts over time or a period of years because it allows students to make interconnections at each grade level; to build on prior understandings; and to assimilate new knowledge. Students need to deconstruct concepts in order to develop a greater personalized meaning of core ideas and practice self-reflection in order to gain a broader understanding of their investigations. All in all, students benefit most when given the opportunity to practice science and engineering skills associated with the investigation of scientific phenomena. Students then begin to act more like experts in the field, and develop a more coherent understanding of science. These practices are

used by scientists to establish, extend, and refine knowledge and are essential skills of the contemporary scientific enterprise that we need to extend to science classrooms (NRC, 2012).

Inquiry as content is disproportionate among grade levels when examining science classrooms. Even though prominence has been bestowed to scientific inquiry through systemic reforms in K-12 science education, Banilower, Smith, Pasley, and Weiss (2006) found that, the percentage of lessons illustrating scientific inquiry varies from 2% in grades 9-12 to 15% of lessons in elementary schools. One could conclude that the downward trend of teaching scientific inquiry from elementary to high school is due to high school science teachers' focus on the teaching of scientific knowledge as fact. Often, high school teachers neglect the epistemic elements that create the facts and the social aspects that validate these facts. Windschilt (2009) concurs that science teachers do not seem to consider scientific inquiry as content and therefore, it is difficult for them to integrate it into their repertoire of teaching practices.

Science teachers often employ science activities in their classrooms and engage students in laboratory learning, but these practices are usually used to prove existing principles of science. For example, when a science class is studying physics they learn Newton's three laws of motion: "an object at rest tends to stay at rest, an object in motions tends to stay in motion in a straight line at a constant speed, or  $F=ma$ " (Kuhn, 1996; pp. 13-14). Rather than having students memorize the concepts, they need opportunities to explore conceptual principles and knowledge that will guide scientific inquiries. NRC (2006) emphasized that student investigations should allow students to develop meaning about science in the context of how scientists actually work. Students should be taught that scientists conduct studies for a host of reasons. For example, students, just as scientists, should conduct studies using conceptual principles and knowledge to:

- (1) discover new aspects of phenomena
- (2) explain new phenomena,
- (3) test conclusions of

previous investigations, or (4) test predictions of theories (Barrow, 2006). Students also need to use technology to analyze data. Technology applications provide students with mathematical tools and models for improving questions, testing theories, gathering data, constructing explanations, and communicating results based on explorations and experimentation. Furthermore, students must learn to defend their results by employing logical arguments that identify connections between phenomena and former investigations, and use both historical and current science knowledge to do so. The environment in which these scientific practices are employed will result in epistemic student learning through consensus building activities involving public communication among others in the science classroom environment (Barrow, 2006).

Scientific inquiry refers to the various ways in which scientists study the natural world. Scientists' work is clearly evidence-based and as they study the natural world they propose explanations based on massive collections of data. Scientific inquiry in the middle school classroom must emulate the work of scientists, and their practices should encompass a wide range of activities such as the ones mentioned above. SI practices, such as these, are crucial to learning science and the trajectory teachers follow to practice scientific inquiry with students may be diverse as they learn to adopt them into routine pedagogical practices. The process of scientific inquiry is messy, nonlinear, chaotic and creative therefore it is impossible to teach it as a step-by-step process. Most certainly, however, there is an expectation that middle school teachers explore opportunities for learning science ideas through inquiry and put into practice some of the elements of full or partial inquiries.

One of the aims of this study is to explore how middle school science teachers and the district science coordinator interpret the new dimensions of the science standards; how they

impact the design of science curriculum, influence professional development training; and how teachers translate these dimensions into science classroom practice.

### **Problem Statement**

A number of reports have raised a concern that the U.S. is not meeting the demands of 21<sup>st</sup> century skill preparation of students, teachers, and practitioners in the areas of science, technology, engineering, and mathematics (STEM). In 2005 and 2006 five reports were released indicating a need for improvement in science and mathematics education in the U.S. The reports were: *Keeping America Competitive: Five Strategies To Improve Mathematics and Science Education* (Coble & Allen, 2005); *National Defense Education and Innovation Initiative: Meeting America's Economic and Security Challenges in the 21<sup>st</sup> Century* (The Association of American Universities, 2006); *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academies Press, 2007); *Tapping America's Potential: The Education for Innovation Initiative* (Business Roundtable Taskforce , 2005); and *Waiting for Sputnik: Basic Research and Strategic Competition* (Lewis, 2005). Consensus of data in these reports indicates that the U.S., as compared to other industrialized nations, does not fare very well in science achievement and STEM degree attainment. For example, on the 2003 Program for International Assessment (PISA), 15-year-old students in the U.S. ranked 28<sup>th</sup> in math and 24<sup>th</sup> in science literacy (Kuenzi, Matthews, & Mangon, 2006). Furthermore, the U.S. ranked 20<sup>th</sup> among all nations in the proportion of 24-year-olds who earned degrees in natural sciences or engineering (Kuenzi, 2008). As a result, if the U.S. is to remain scientifically and technologically competitive in the world, it is necessary to increase our efforts to incorporate scientific practices associated with science, technology, engineering, and mathematics into the science classroom. This means teaching in a reform

oriented manner by implementing the elements of scientific inquiry that form the basis for the enactment of the contemporary science curriculum stated in reform documents previously discussed. When science teachers employ methods of a contemporary science curriculum, they are teaching and fulfilling the demands of practicing science as enterprise. This in turn should increase students' scientific knowledge and raise the U.S. scores to the levels of attainment so desired.

The term inquiry is prominent in science education and it refers to a least three distinct categories of activities. Inquiry refers to that which scientists do such as conducting investigations and using scientific methods. Inquiry also refers to how students learn by actively inquiring through thinking, about a scientific phenomenon or problem, and doing something by mirroring the processes used by scientists. Moreover, inquiry is a pedagogical approach that teachers employ as they design curriculum and use curriculum that provides opportunities for students to perform extended investigations (Minner, Levy & Century, 2010).

Teachers may use varying degrees of direction and decision-making with their students during the teaching of scientific inquiry, resulting in a distinction between open and guided inquiry. Open inquiry is analogous to doing science, as students formulate their own problem to investigate and select materials to use, while in guided inquiry, the teacher provides the necessary materials and a problem to investigate, allowing students in turn to devise their own procedure to solve the problem (Bianchini & Colburn, 2000).

Minner et al. (2010) characterize contemporary science instruction as: 1) the presence of science content, 2) student engagement with science content, and 3) student responsibility for learning science content. Science as content includes implementation of scientific inquiry practices to study the Life Sciences, Physical Science, and Earth and Space Science. Student

engagement includes a host of practices such as manipulation of materials, observing scientific phenomena, watching a demonstration of phenomena, and use of a range of secondary sources such as reading material, the Internet, discussion, and lecture. Student responsibility means that students decide which questions to investigate and they design studies that include variables and procedures: students decide how to collect and interpret data, and communicate the results. There is a need for greater emphasis on students' investigations of everyday phenomena by employing either open or guided inquiry approaches that result in deeper understandings of scientific principles.

Enactment of reform-oriented teaching practices of scientific inquiry while essential pose problems for today's middle school science teachers. Anderson (2002) contended that many teachers have false conceptions of inquiry and that the research literature on inquiry lacks a precise definition. Windschitl (2003) also found that one reason for the lack of proper understanding of scientific inquiry may be the term "inquiry" itself. Interpretations of the meaning of inquiry include: inquiry oriented curriculum projects, project-based science instruction, inquiry-discovery, student-centered and less step-by-step teacher directed learning (Anderson, 2002). Thus, the problem of coining a precise definition of inquiry teaching perpetuates and continues to plague teachers today.

Windschitl (2009) expounds a sequence of challenging events that determine the need for science teachers' acquisition of 21<sup>st</sup> century reform-based teaching skills. First, teachers must have deep interconnected understanding of conceptual principles and knowledge associated with various science disciplines as well as a solid foundation of factual and theoretical knowledge that guide student inquiries. Understandings of science content directly influence science teaching and the strategies that science teachers employ in the classroom. Hypothetically, a teacher must



have strong content knowledge as a basis for teaching science subject matter that consists of accurate information. Otherwise, teachers are unable to help students obtain the proper knowledge, connect knowledge to various scenarios, or pose appropriate questions to fit a study of phenomena (Roehrig & Luft, 2004). Second, teachers must have the ability to engage students in science discourse, which Windschitl (2009) refers to as sense-making discourse, which provides students opportunities to build the links between theory and observation that lead to conceptual understanding. Students must develop skill in formulating logical, consistent explanations, and follow rules of evidence. Explanations must be open to question modification and students must be involved in the process of checking their own understandings with others in the science classroom. When students check their own understandings, they are also more inclined to actively solve problems and make connections between phenomena and with previous and historical investigations (Scott, Mortimer, & Aguiar, 2006). Third, teachers must come to better understand an assortment of assessment strategies, purposes and contexts and be able to determine which to employ under different circumstances (Darling-Hammond & Richardson, 2009). Students need to play an active role in determining what they understand and how they came to understand it (NRC, 2000). Some suggestions for assessments include peer and self assessments and those that use writing and discussions. Fourth, Fullan (1993) stated that teachers are change agents or career-long learners. Teachers learn by reading, reflecting and collaborating just as students do. Inquiry into teaching is necessary for forming and reforming personal purpose and to advance knowledge of science and science teaching practices. When teachers enter the classroom, the preparation and initial training they bring with them is only the beginning of an articulation of knowledge that they will acquire during their teaching career. Teachers must continually learn from their own practice, upgrade skills, develop greater

understanding of how to teach science, and develop career-long aspirations for improved science teaching. Just as scientists, teachers need to learn from systematic cycles of inquiry related to their teaching practices to reshape future science instruction (Grossman & McDonald, 2008).

Teachers' lack of prior inquiry learning experiences and knowledge in inquiry based curriculum and pedagogy, has an impact on how and what students learn in the science classroom. Trumbull and Kerr (1993), found that much of what went on in typical biology classes was highly automated and tightly controlled as students were given questions to answer and the methods to answer them. This resulted in the students' lacking of knowledge and skills necessary to carry out the inquiry or even to understand the reasons for collecting data. Bowen, Roth and McGinn (1999) found lack of competencies in students with B.S. science degrees, both individual and in groups, to understand, interpret, and elaborate on data produced by graphs during undergraduate studies. Students appeared to be concerned with the form of the graphs rather than with the natural phenomena to which the graphs referred. Students also seemed incapable of using outside resources such as references to natural populations or mathematical tools in their interpretations of a population graph. Furthermore, students were unable to advance interpretations appropriate to the field of biology and were unable to use the data to make verbal distinctions, increase their knowledge of specific biological populations, and develop general skills in taking factual material and combining it with the power of explanatory information. Students had learned to apply explanation of specific graphs as provided in lectures and seminars, but students' use of tables, graphs, and equations to develop persuasive arguments was definitely non-existent.

According to Staer, Goodrum, and Hackling (1998) inquiry approaches are not understood by teachers of science in the junior high grades because time and material demands

are significant barriers to open-ended inquiry. Curriculum materials such as laboratory manuals and textbooks that are not inquiry-based strongly influence classroom transactions (Roehrig & Luft, 2004). Some science textbooks are devoid of constructivist theory thinking and contain limited opportunities for students to develop scientific inquiry skills.

Anderson (2001) pointed out that textbooks are written by textbook company authors that read summaries of scientific studies and devote explanations to the use of models from which they draw conclusions. Displays that summarize patterns in data—graphs, charts, and maps accompany such explanations. However, the original data from the study is absent. Undoubtedly, something will be lost in the translation and coherence of the science studies due to the fact that textbook authors do not have first-hand knowledge of what has taken place in the studies. Only scientists who have conducted the research, used a specific research design, employed specific data collection methods, provided analysis of the data, recorded details, and communicated results of the study in research journals can portray scientific principles and phenomena accurately, scientifically and with authenticity. The representations of scientific knowledge and practice, in textbooks, are divorced from scientists' personal experiences and ignore the details and nuances of the research that support data and arguments posed by the researchers.

Beck, Czerniak, and Lumpe (2000) maintained that it takes time and classroom knowledge to re-design curriculum materials that focus on inquiry. As we now know, scientists support rigorous model-based reasoning and apply practices associated with it. They have developed an assortment of specialized intellectual and technological tools to use in their studies. Teachers have the daunting task of translating scientists' science into school classroom science by learning to use the same set of advanced tools. It takes time to learn and master the use of

laboratory equipment and measuring tools. For example, telescopes in conjunction with advanced computer systems may be used to study distant objects in space or laser devices may be used to measure distances. Seismographs may be used to measure shock waves and centrifuges may be used to separate materials. Furthermore, mathematical tools for measurement have infinite power that allows predictions to be made and they take time to learn. Moreover, technical vocabulary, such as force, energy, plate, cell, photosynthesis, and ecosystems, used for making precise descriptions and explanations must also be learned. In addition, much time in science classes must be designated to helping students master the use of these tools (Anderson, 2001). When teachers begin to feel time constraints and pressure to complete units, they may resort to the lecture method rather than exploring science concepts through inquiries. Teachers report that inquiry teaching is too time consuming, causing a slower instructional pace which in turn results in concern over having an adequate amount of time for coverage of science content (Roehrig & Luft, 2004). However, Duschl and Grandy (2008) argued that if we want to promote student engagement in scientific inquiry, then we must immerse students and teachers in long-term problem-based, full-inquiry units with greater depth and less content that aligns more closely with scientists' research projects.

If we want students prepared for the future, so that they can make informed decisions as citizens of a competitive global society, then we must demonstrate concern and take responsibility to ensure that problem-solving measures are being taken to improve the manner in which science is being taught to middle school students. This is a problem of magnitude for science education researchers, science teacher practitioners, and policy makers alike as seen in the results of standardized tests in science and mathematics. Reports such as the National Assessment of Educational Progress (NAEP) (Perie, Grigg, & Dion, 2005), Program for

International Student Assessment (PISA) (NCES, 2006) and Trends in International Mathematics and Science Study (TIMSS) (NCES, 2007) indicate that students are not performing to the level they are expected.

### **Purpose of the Study**

The purpose of this study is to examine middle school science teachers' understandings and skills related to scientific inquiry; how those understandings and skills are translated into classroom practice, and the role the school district plays in the development of such understandings and skills.

### **Research Questions**

#### Research Question 1

What experiences have contributed to middle school science teachers' understandings of the practices related to teaching science as inquiry?

#### Research Question 2

In what ways are teachers' understandings and skills, related to teaching science as inquiry, reflected in their practice?

#### Research Question 3

What role has the school district played in the development of teachers' understandings and skills related to teaching science as inquiry?

## Significance of the Study

Middle school is a critical point in students' science education and it is in middle school that they begin to dislike science. Research indicates that when students learn science through inquiry their interest in and understanding of science increases (Akkus, Gunel & Hand, 2007; Gibson, 2002; Liu, Lee & Linn, 2010). As a result, it is important to explore middle school science teachers' definition of science as inquiry because of its importance in how their understandings are reflected in their practice. Researchers must witness, first-hand, what is taking place in middle school science classrooms with respect to the teaching of scientific inquiry before recommendations for improvements can be made. We must also allow opportunities for middle school science teachers to broach, examine, explore, interpret and report implementation strategies when practicing the elements of scientific inquiry as a science content area. It then stands to reason that more research needs to be done to: (1) assess teachers' knowledge related to reform-based teaching, (2) investigate teachers' views about the goals and purposes of inquiry, and (3) investigate the processes by which teachers carry out SI and motivation for undertaking such a complex and difficult to manage form of instruction.

According to Keys and Bryan (2001), "more research is needed in teachers' knowledge bases for implementing inquiry, teacher inquiry practices, and students' science learning from teacher inquiry-based instruction" (p. 632). Lawsen (2002) examined the hypothesis-testing performance of 22 biology teachers and found that teachers could construct arguments to test hypotheses when the hypotheses involved observable entities (eg. pendulums), but not when they involved unobservable phenomena (eg. animal systems). Windschitl (2003) investigated six teachers' conceptions of inquiry and found that some had a reasonably realistic view of inquiry while others viewed inquiry as a linear or sequential process. Shapiro (1996) found that a science

teacher chosen as representative of 21 science teachers in a larger study had difficulty asking appropriate scientific questions. Researchers believe that teachers have not acquired skills in these areas and these skills are not in their repertoire of pedagogical practices. In general, studies such as these illustrate that many teachers have unsophisticated understandings of scientific inquiry and related skills. Thus, this study will explore the meanings that middle school science teachers attach to skill implementation with scientific inquiry practices.

The exploratory classroom-based research approach, such as that used in this study adds new information on how teachers implement the elements of scientific inquiry and sheds light on the realities of student experiences in the contemporary science classroom. Working with teachers in their own classrooms and exploring the skills and procedures used in teaching scientific inquiry, provides evidence for the need of professional development that matches teachers' needs. This study also helps inform policy makers of the trials and tribulations associated with the implementation of scientific inquiry in the science classroom and reveals the realities of what is actually doable from a science classroom perspective.

## CHAPTER 2

### THEORETICAL FRAMEWORK

This chapter discusses logical frameworks pertaining to curriculum that embrace scientific inquiry. The enactment of middle school science curriculum, in the classroom, will be viewed through Doll's ideals of post-modern curriculum (Doll, 1993) and the theoretical underpinnings that underscore the works of Duschl and Grandy (2008).

#### **Complex Adaptive Systems Theory**

Doll (1993) characterized curriculum as a Complex Adaptive System (CAS). CAS is a metaphor for the science classroom and forms a theoretical umbrella that encompasses several smaller theoretical spokes, all pointing to a comprehensive way of thinking about science curriculum. The theoretical spokes of CAS are as follows: a) the theory of a driving force of development—the cultivation of perturbations, b) the theory of firm formlessness—a curriculum that emerges continually and often out of antagonistic parts; and c) the theory of chaos—dynamism of action, reaction and interaction (Doll, 1993).

Briefly stated, the driving force development theory, firm formlessness theory, and chaos theory combined not only produce a comprehensive picture of the science classroom as a CAS, but also complement each other to create an “organocentric” (Doll, 1993, p. 160) approach to curriculum. Organocentric means that living organisms, in this case students manifest certain qualities of ideas that are unpredictable, irreducible, irreversible and emergent. An organocentric approach to curriculum is intimately tied to the experiences of students, and the idea that an emergence of knowledge is produced from individual students' self-reflections and their interactions with other students. Additionally, an organocentric approach to learning embodies a synthesis of both the psychological, individual and social aspects of students during the learning



process. The self and others are secured in such a way that together they comprise an individual student's learning experience. This stems from Dewey's opinion that the learner is a social individual and society is an organic union of individual learners. Individuals within a classroom provide meaning to the science curriculum by understanding and building relationships with each other creating a social environment (Doll, 1993). The social aspect of knowledge construction will be discussed after a thorough discussion of the psychology of the learner.

According to Doll (1993), the driving force of development constitutes three major ideas: (1) Curriculum thought is described by a biological metaphor, characterizing "complexity, hierarchy, and network relations" (p. 67). (2) The generative curriculum thought, using a biology metaphor, can be adopted only by moving from a closed (modernist system) to an open (post-modernist) one. (3) Development means a move from "mere accumulation of facts to a transformation in thinking," (p. 67) while working through taxing problems and challenging or confronting both "problems and perturbations" (p. 67).

Doll borrows the expression "polyfocal conspectus" from Schwab (1978) to define transformative development in science education. This means that the science teacher takes up, compares and contrasts related, yet differing theories or multiple perspectives from students, about an object or phenomenon in science, by putting all coherent ideas on the table. By working in this manner, the science teacher is able to obtain what Doll (1993) refers to as richness in the curriculum. Richness refers to curriculum depth or layers of meaning and to its multiple possibilities or interpretations. The science teacher must delve deeply into the subject matter at hand forcing students to delve deeper into science concepts that broaden their understandings of the subject matter at hand. Probing topics, the examination, acceptance, and or rejection of former and acceptance of new ideas are the basis for transformative development. The key to

transformative development lies in the interaction between many levels of student conceptualizations within a hierarchical system, rather than an alternation between any two levels. Moreover, a transformative development curriculum supports students' multi-perspectives, reflects complexity of students' interactions, is based on students' past experiences that give rise to the present, and brings the present to the future by developing into a set of interconnected experiences. For example, curriculum with a biology orientation should be more interactive, transformative and bring to the fore self-organization with a purpose. Purpose is not defined here as moving to a pre-determined end, but rather to self-organization, and to open-ended, divergent learning. The open-endedness means the end of one learning experience is the beginning of the next. It is the dialogue between self and the construct or problem offered by the environment that determines unpredictable learning.

Generative learning that propagates new information, underpins a transformative curriculum. The result of generative learning is the result of an active process of individual articulation, reflection, and reflective action on what we know and takes place within a context that promotes discovery. Bruner (1990) states "learners need to discover and to describe formally the meanings that human beings create out of their encounters with the world, and then propose hypotheses about what meaning-making processes were implicated" (p. 2). The knowledge that is generated is a product of the mind and requires the learner to examine thinking and learning processes. Additionally, learners reflect on previous understandings and experiences encountered in learning environments, as well as in the real world, and construct their own meaning that results in interpretations of the context (Jonassen, 1991).

Doll (1990) expounds on the process of self-organization in humans. Self-organization in human development involves both points of equilibrium and disequilibrium. Disequilibrium

and perturbations equate with the driving force of development and generative learning that leads to transformation in thinking. To overcome perturbations, caused by the pattern of equilibrium and disequilibrium, students are constantly conceptualizing and restructuring thoughts. Piaget (1977) addresses the idea of equilibrium and disequilibrium similarly, and refers to this process as assimilation and accommodation. Students perform tasks that cause tension between assimilation which is the integration of knowledge and accommodation which is modification in thinking. Restructuring is a result of this tension or disequilibrium and it leads to more advanced insights. Disequilibrium or perturbations are at the root of all learning and must be deeply felt by the learner for re-organization and restructuring of thought to occur. Human beings are naturally active therefore, learning automatically takes place. To address this human need, learners should be provided with more than hands-on activities, but rather with actions that involve “intellectual restructuring” that align with Piaget’s adaptation model of equilibrium and disequilibrium. The learner ought to move from the physical plane (hands-on and activity) to the intellectual plane (minds-on). For Piaget (1977) the purpose of education and development is one of re-structuring thought which leads to transformational learning. This symbolizes Dewey’s ideas on the reconstruction of experience. Dewey (1910) believes in the principle of continuity of experience. Every experience takes up something from those that have taken place before and modifies in some way the quality of those that come after. Piaget (1977), Dewey (1910), and Doll (1990) recognize the value of student experiences to the learning process and reiterate that a transformative curriculum is underpinned by the concepts of disequilibrium and internal minds-on restructuring of thought processes.

The theory of firm formlessness signifies a curriculum that emerges continually, often out of antagonistic parts, and causes development in the system (the system of ideas, thoughts,

concepts and theories). This information will not be predetermined because it emerges from the intersection of ideas, linked in the formation of a multi-branched, non-linear trajectory. Messages or ideas will travel around in a cyclical path, collecting and generating new knowledge along the path, and at times students may experience disequilibrium or creative tension. A loss of ideas may occur so that the system can reorganize to better fit the needs of the problem. With loss, new knowledge is gained and it will come back to a point of origin with a clearer interpretation of meaning (Doll & Gough, 2002).

Chaos theory is a means of describing unpredictable behavior and it recognizes that order reveals itself. Order evolves or emerges and it cannot be pre-programmed or planned (Doll & Gough, 2002). In chaos theory, “attractors” arise from and within the process of interaction among students and eventually the system will settle into a more organized state. There is a dynamism of action, reaction, and interaction which has a sense of direction.

After reading Doll (1993), my interpretation of complex or chaotic order is that, with the passage of time, change occurs and the system in question may perpetuate without loss of control. Two examples come to mind when I think of changes in a system, emergence and feedback loops. One is the Sierpinski triangle in geometry which is a fractaled pattern. The Sierpinski triangle uses an equilateral triangle with a base parallel to the horizontal axis. Then one shrinks the triangle to  $\frac{1}{2}$  its height and  $\frac{1}{2}$  width, makes three copies of it, and positions the three down-sized triangles so that each triangle touches the two other triangles at a corner. Step two is repeated with each of the smaller triangles. The point is that the largest equilateral triangle represents the system of the entire classroom of students’ conceptualizations but within a set of boundaries just as the equilateral triangle has the boundaries of equal side and equal angles. The smaller triangles represent students’ conceptualizations or groups of students’

conceptualizations that are also bounded, all working together to create the big picture or the overarching science principle being taught. A second example is a snowball chaotically rolling down a hill, gaining more snow that it did the previous roll and it will soon become a giant snowball when it stops rolling. Each snowflake is a fractaled pattern, which is a smaller copy of the whole and together all flakes generate a bigger pattern in the form of the snowball. Each snowflake is like a student conception, which then becomes a system of students' conceptions expanding the conceptualizations to overarching scientific principle yet ideas have been bound just as the snowflakes are bound by a geometric pattern. This is analogous to students' conceptualizations being smaller copies of the complete pattern or theoretical picture for the discipline they are studying. Finally scientists' work involves the search for patterns because this unusual or chaotic sense of patterning seems to permeate the systems of the universe in which we live and students must follow this platform.

The butterfly effect may also illustrate the underlying idea of iteration in complex systems. Small changes in the initial condition of a system, after passing through a state of emergence, can have a significant effect on the system. For instance, just as the butterfly effect is dependent on initial conditions in the nonlinear atmospheric system, and experiences a small change at one place, it can result in large differences in a later state. In other words, a butterfly's wings might create tiny changes in the atmosphere. As a result, this may alter, delay, accelerate or even prevent the path of a tornado. The analogy of the classroom is that small intellectual changes in theoretical positions within the system of the science classroom may significantly alter classroom conceptualizations creating a more grandiose and accurate understanding of the scientific principles being studied

The purpose of science is for students to examine first-hand experiences and to extend them as new lines of reasoning come into play. Through conversations, intellectual discourse, sharing of ideas, experimentation, and argumentation students expand the base of their knowledge and the knowledge of others. This process, as stated, is somewhat disorganized, but eventually reasoning comes to order as ideas begin to connect in a cogent manner. Experience is the necessary element that affords us the opportunity to develop a comprehensive view of science phenomena. Furthermore, as acquisition of knowledge assumes greater breadth and depth, it is only logical that we may have to alter our points of view to create harmony in our experiences. It is this alteration in knowledge, a more accurate view that is the essence of transformation of knowledge that takes place in the minds of students of science.

Doll and Gough (2002) state that the production of scientific principles is chaotic. A chaotic process of learning, that takes place in the science classroom, may be described as unpredictable when there is randomization of ideas, excessive flow of information, numerous exchanges of thought, and intersection of many ideas. There is a circular self-organizing network in progress and boundaries are naturally created. A science teacher will soon sense the development of recognizable patterning and this will reduce tensions resulting in a sense of order. CAS underpinned by chaos theory, are bounded as they do not expand out to infinity but remain confined to the close neighborhood of some attractor. The attractor cannot be predicted or explained in terms of causal relationships, but it can be described. The attractor identifies the unique character of the system and reduces it to order. There is a developmental organization with a hierarchical frame in the system. There is a part-whole relationship that is nested and each whole is a collection of interactive parts; being itself part of a more inclusive whole. For example, each student contributes scientific ideas, each being an individual part in and of itself,

part of various collective student contributions (e.g. thoughts aligning with a specific group of students), and still yet, part of the whole collective mass produced picture or understanding. This whole depends on the parts, parts depend upon the whole, and that creates an interrelation between them. Additionally, the big picture outcome or end result would not be the same if only a few parts were contributing, so it is true that all parts generated individually and parts generated by dependency upon each other, generate or form more parts and the eventual outcome or the big picture is comprised of all the parts, nested, creating a much different picture than what would be understood by many unconnected individual parts. Chaos theory underpins the model for understanding contradictory influences produced by students, is observed by and dealt with by students and the teacher, during the study of scientific phenomena.

The subject matters of a science middle school curriculum may also be translated as many CAS, and students' conceptualizations acting as external agents, represent the self-organizing network mentioned earlier. If we know that the brain is self-organizing, a characteristic of a non-linear systems, then we know that many brains operating in a classroom are also non-linear. CAS is complex, just like the human brain, and exhibits networked rather than hierarchical structures of scientific information flow. Rather than vertical, linear lines of control, there are multiple branches of scientific information or feedback loops, connecting concepts and extending in many directions. Organization, order and direction, that create a coherent big picture, do not emanate from a single point or location—single student's view—, but from many points or locations—many students' views. There is multiple branching of ideas and feedback loops, information can be communicated quickly, and the possibility exists for learning multiple things without a single master plan, directed by the teacher that represents when and how something is learned.

Global warming, for example, is a subject matter that may be used as a model for explanation of a biological CAS and it demonstrates how feedback loops occur within a system of the classroom. For example, if a teacher asks the question, “How does global warming impact the environment?” Feedback loops of ideas can go in many directions, opening up a world of possibilities for extended learning of many integrated science concepts. For example, there is an increase in the earth’s temperature. Why? Increase in temperature is due to formation of a collection of greenhouse gases such as carbon dioxide, water vapor, nitrous oxide and methane. Why is greenhouse gases a concern? Gases trap excess heat and light, acting just like a wall rather than allowing gases to travel back into space. Why is excess heat and light a problem? The gases do not allow heat to escape from the atmosphere. The rapid rise in greenhouse gases is a quandary because scientists believe that it is changing the climate in various ways. Animals become affected by global warming due to changes in their habitats caused by changes in climate. Why is this quandary? Fast climate change may not allow some living things to be able to adapt, posing unpredictable and unique challenges to all life. The effects of global warming could annihilate the habitats of and threaten extinction of over one million species of plants and animals. Some ideas that may crop up from students are that melting ice will cause the loss of habitat for species such as the polar bear or warmer water will cause the population of fish such as salmon to decline. Coral bleaching will occur on coral reefs and this is also due to rise in water temperature. The ecosystems of many marine creatures will be disrupted. Changes in temperature will cause many species to become extinct as they cannot adapt quickly enough to rises in temperature. Who is responsible for the problems and what can we do to correct the situation? The point here is that, from this subject matter emanates numerous subject matters



that promote or propagate ions of scientific conceptualizations that overlap, are embedded within each other, or create a map of information to be sifted through by students and their teachers.

Doll (1993) refers to this as “*rigor*.” Rigor is the complexity of uncertainty that requires students’ to examine a host of conceptualizations and then form critical interpretations from them. Tension exists between two interacting forces; the unpredictable and the understanding, explanation and analysis of the situation. The science classroom as a CAS has the capacity to self-organize or self-regulate under the direction of a skillful science teacher using the principles of scientific inquiry. When science is learned as inquiry, the science classroom, representative of a CAS, may at times appear as in a state of disequilibrium because students present related, unrelated, divergent and opposing conceptualizations. Disequilibrium causes misconceptualizations to scatter, vanish or dissipate just as clouds dissipate, and then the system can reorganize with more accurate conceptualizations into a structure that is better suited to the problem at hand. Disequilibrium is a positive force or a creative tension and it has the capacity for students to generate, produce, and reproduce original information. Temporary disequilibrium, born from perturbations in the system of classroom transactions, is eventually replaced by organization, and influence changes in patterns of thinking that yield a more sophisticated end result. It is important to note, that this does run counter to past traditional didactic forms of teaching and learning, where the teacher lectures and students regurgitate desired responses, but the contemporary classroom, as a CAS, with disequilibrium and tension associated with it, provide the powerful mechanism needed for advanced, higher learning to take place.

According to Doll and Gough (2002) Complex Adaptive Systems (CAS) often develop into nested layers of information. Using the global warming example, earth and its atmosphere,

with the balance of gases, make up the earth's weather. Weather consists of weather elements such as atmospheric pressure, temperature, wind, precipitation, cloudiness, and humidity. Extended over time, long term weather patterns combine to create the climate. Climate underlies the distribution of the Earth's biomes. Climate determines the nature of plant and animal life at particular locations. Simply put, nesting of biological concepts would be the earth's atmospheric gases, are nested in weather concepts, weather concepts are nested in concepts of climate, and climate concepts are nested in global warming concepts. All of these impact and have an influence on each other. At the core of this point, is that students as agents interact together powerfully, in such a way those new, emergent, organism-wide qualities, namely ideas, develop. New qualities of ideas interact and this produces another level of complexity that has grown from the previous layer of thinking. Each new layer of conceptualizations emerges and it is nested or resides in, the previous layer. The individual qualities in the system are able to work autonomously and yet, different parts work together to form multi-layered sets of concepts.

CAS is a metaphor for the science classroom because students and the teacher may each be considered as smaller systems that have intricate conceptual ideas in them and they contribute to the composition or formation of a larger/complex system called the science classroom. Each small system comprised of individual students' conceptions, are interacting with other small systems—a varying assortment of all classmates' conceptions and the teacher's conceptions. Many interactions, conversations, reflections, and dialogues are taking place and may be doing so in some chaotic fashion. Each of these smaller systems contributes to the development of the larger picture or conceptualization of the science subject matter that is being learned. Putting all small systems together creating one complex-super system maximizes the scientific knowledge produced and learned in the science classroom. By working in this mode, intense interactions of

students will contribute to transformations in acquired knowledge and most importantly, the emergence of yet another level of complexity in conceptualization of the details of the science subject matter at hand. Each new layer of facts emerges and is nested in the previous layer of facts resulting in further, greater knowledge production.

As a whole, the characteristics of the described complex phenomena above include networks or webs of student and teacher science conceptualizations, feedback loops whereby, the teacher, or students, ask questions and re-craft questions and responses to solve a scientific problem. When students are solving their own problems using inquiry, this procedure repeats itself until a suitable answer is achieved that makes it possible to develop a plan to solve the problem. Iterations are repeating or executing the loop of questioning techniques and responses until the scientific problem is resolved or expands to open the door for future scientific problems to be studied. CAS systems experience a temporary disruption to balance, but self-organization, natural regulation, or coming together of ideas eventually play out. Teachers must be cautious and allow for a sufficient number of interactions to take place, over an extended period of time and a natural occurring order or organization will frequently emerge from within the system, as students become more fluent using the processes of scientific inquiry.

Doll (1993) provides a three-part view of the science curriculum as: a) science—the discovery and prediction, b) story—the narration, culture, personality, metaphor, interpretation, and the subjective that complement the scientific and c) spirit—mystery, complexity and the aliveness of the curriculum. This 3-S view of Doll's (1993) curricular frame may be placed in the context of the Life Sciences (e.g. Biology) for a point of illustration. In biology, through a) the science—the discovery and prediction, b) the story—the narration, culture, personality, metaphor, interpretation, and the subjective that complement the scientific and c) the spirit—

mystery, complexity and the aliveness of the curriculum, students will discover over time, that there is a set of characteristics common to all living things. For example, all living things take energy from the environment and convert it to other forms of energy for their own use. Animals eat and convert the energy they get from food, to chemical energy which they store in their bodies. The chemical energy is converted into kinetic and potential energy that allows them to move and grow. It is predictable, that living things develop and grow such as the baby bird that is born with skin and grows to develop feathers and the ability to fly. Living things maintain themselves by generating structures such as skin and bone and they have the ability to repair damage done to those structures. Living things, with systems of extreme complexity, have the capacity to reproduce and make offspring that are exact or inexact copies of themselves. Lastly, living things, through the story of evolution, are parts of populations that change over time, across generations.

The magnificent natural world is like a colossal puzzle. This puzzle, much like a kaleidoscope, with a complex set of events and circumstances surrounding it, provides scientists such as Darwin an avenue of wondrous exploration. In order to understand it, Darwin (1859) demanded reasons for answers to complex scientific questions about the biological world such as “Why are different organisms so similar?” Or “Why has there been a succession of different kinds of species throughout geologic time?” (as cited in Levine, 2004, p. 384). Several laws of evolution, broadly stated, such as growth and reproduction, inheritance, variability, and natural selection are ways of informing explanations about the biological world. Darwin developed his knowledge of inheritance, variability, and natural selection when he studied fossil evidence in South America. Evidence was obtained for the prior existence of ancient species that had many of the unique features of living armadillos, yet they were clearly different. Such fossils were

found nowhere else in the world. Darwin then posed the scientific question: why are both living and ancient armadillo-like species confined to the same geographical region?

According to Darwin (1859):

There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or onto one; and that whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved (as cited in Levine, 2004, p. 384)

Through his work, Darwin used his intuitions, imaginative and interpretative skills in explaining his views and narrating about them so eloquently. If it not for scientists such as Darwin, where might we be today? Darwin's work is a spiritual journey and a remarkable story that demonstrates natural selection in evolution and illustrates one of Doll's 3-S frames (Spirit). His story disproves that existing animals and plants appeared separately, but indicates that they must have gradually transformed from ancestral creatures. His work is also a perfect example of using other modes of thought: the intuitive, imaginative, and interpretative that is needed in viewing the world and is influenced by literary, philosophical and religious thinkers as well.

According to Bruner (1977) these other modes of thought are storied and spirit-full. The story is filled with narration, culture, personality, metaphor, interpretation, and the subjective. The story is a fine curricular complement to the scientific, analytic, rational, and logical that needs to be recognized and used by science teachers and students. These modes are of equal importance and they complement each other in building a rich science curriculum. Science educators must draw on and combine several traditions when teaching science. These traditions, illustrated in Doll's 3-s curriculum frame, include science (logic and reason), story (culture and

narrative) and spirit (vitality, and wonder). Science curriculum that includes these characteristics provides students with powerful and stimulating learning experiences that will motivate and inspire them.

According to Doll (1993) *relations* are the making of conceptual connections in science, and the understanding that our immediate perceptions integrate into a larger, global science matrix. In the case of biology (Life Science), there is an intense scientific integrated matrix of science subject matters when studying living organisms. Over time, as students study animal systems they will soon make connections in the relationships or integrations of biology—the study of living organisms, to chemistry—the study of cell types (prokaryotic and eukaryotic) or cellular respiration, and to physics—the use of the microscope to study cellular structure and function. Furthermore, there is a huge matrix or set of ecological webs that explain the relationships of particular ecosystems and their living organisms, to each other. Moreover, in the case of the units on Discipline 3: Life Sciences, one would expect students to integrate the knowledge learned during animal systems studies into further knowledge development when learning about evolution and natural selection, through the development of ideas and relationships between them. Natural selection describes evolution as the impetus behind the reasons for diversity of organisms on earth. Scientific history of life, depicted in fossil records is evidence of similarities and differences within the diversity of existing organisms. The theoretical processes of evolution indicate that species develop from earlier forms of life. Students must be cognizant that evolution does not dictate a long term progress in some set direction because it is a process of adapting to the environment. According to Darwin (1859) organisms that are best suited to survival in their physical and biological environment achieve greater reproductive success as (cited in Levine, 2004). In turn, these organisms are able to pass

advantageous genetic characteristics on to future generations. For millions of years, the continuing operation of natural selection on new characteristics, in changing environments, has produced a progression of diverse new species. Since environments change over time, different organisms may be well suited at different times. In learning goals such as these, each contributes to an understanding of another, thus illustrating the meaning of relationships in the ideas being learned in this subject matter (National Academy of Sciences, 1998, p. 64).

There is a call for *collaboration and conversation* in the field of science curriculum (Doll, 1993). In this conversation, we need to consider the accumulation of knowledge that students have gained from their life experiences rather than base the conversation on specialized curricularized methods or procedures used by the teacher. When we converse with each other, a process of coming to an understanding takes place and each person opens him/herself to the other. Educators must be encouraged to respect and appreciate the otherness of their students (no matter the age, gender, race, religion) and they must also encourage students to respect the otherness of their classmates and incorporate this value into instruction. This type of conversation during scientific inquiry allows students to discuss their ideas with others, discover the differences between their thinking and others', and gain practice in defending their position, or possibly changing their own thought processes as the group works toward consensus.

According to Doll (1993), *community* is reconceptualizing humanity as we re-generate understandings of human experiences. Doll states that community is the most important C of all. Community has a high degree of care and critique and emphasizes a high degree of trust. The social-cultural aspect of learning, in the science classroom community, cannot be ignored because of its value for great potential in learning. What students learn on their own must be shared with others in order that information may be validated for its truthfulness. The processes

of student interaction, cooperation, and collaboration are powerful, essential tools for the process of learning in science.

Classrooms are highly specialized communities, and classroom interactions of the community form the process of curriculum. Experience is not a private affair but needs to be reconstructed or transformed via public interaction. The integrity of a theoretical position comes from having a dialogue with others to find out whether or not there is consensus of opinion or to find out if one is correct in one's thinking. Knowledge begins with the thinking of the individual, but one must present ideas to others, through dialogue, to find out whether one is right (Holton, 2005). This is the idea of transformative experience where interaction helps us transform our thoughts into disciplined inquiry and intellect.

Based on the three sub-theories of CAS, Doll frames the post-modern science curriculum as one of complexity. According to Doll (1993) complexity involves the embodiment of simplicity within complexity, and complexity within simplicity, and *recursively* the two repeat themselves when studying science subject matters. Complexity is characterized by self-organization and emergence of knowledge as learners strive to move from a simple order, toward an ever evolving more complex order. The key idea of complexity is that nature, life, and organization all occur when there are sufficient, but simple levels of complex interactions among science students. Complex simple interactions, combined, compound the information and create new and more complex levels of understanding of nature, life and organization. This yields greater conceptualization of both science content and use of contemporary methods used in the production of scientific knowledge.

The challenge for classroom teachers is the opportunity for them to take advantage of the reservoir of experiential and creative knowledge that resides in students. Doing science involves



creativity, imagination, and logical thinking to generate and test the validity of ideas. Even though scientific practices is the major thrust of this research proposal because I am focusing on middle school teachers' understanding of the tenets of teaching scientific inquiry and how such understanding is translated into practice. Doll's (1993) forum elements will be considered as juxtaposed to all events taking place in the science classroom. For example, does the teacher allow students to express their personal reflections and what does the teacher do with the information? Does the teacher create learning opportunities for students to experience disequilibrium? —a creative tension that exists between multiple thoughts and reasoning as they grapple with ideas and conceptualize and reconceptualize them. Additionally, students need to examine their own articulations and I would like to see how the teacher provides opportunities for students to do so and the approaches they use to lead students toward a direction of transformation in their reasoning. Inquiry is a transactional art, not only involving empirical standards, logical arguments, and skepticism, making predictions, using rules of evidence, scientific methods and procedures, but also the spirit of one who creates. Student ingenuity drives the processes used during scientific inquiry. Indeed, SI is a set of abilities and understandings, but they are linked to and can only be reached through some of the elements of Doll's (1993) theories.

### **Integration of Science Domains—Conceptual, Epistemic and Social Domains**

The learning sciences research, and incorporation and assessment of scientific inquiry may be synthesized into three integrated domains. First, both scientists and science students, when reasoning scientifically, need to use conceptual structures and cognitive processes that serve to support or expand existing theories. Next, science students must develop and evaluate scientific knowledge based on an epistemic framework that includes the foundation, scope and

validity of the scientific knowledge. Last, students of science must embed themselves in the social processes that shape how knowledge is communicated, represented, argued and debated (Duschl & Grandy, 2008).

Conceptual understandings in science include: a) the abilities to perform scientific inquiry and b) the understandings about scientific inquiry (NRC, 2000). According to NRC, “teachers can support learning by promoting the communication of scientific ideas, developing scientific reasoning, and developing the ability to assess the epistemic status that can be attached to scientific claims (p. 3). These articulations are consistent with a general move in current science education reform that emphasizes the inter-subjective processes of representation, communication, and evaluation of the evidentiary bases of knowledge claims (Sandoval & Reiser, 2004).

Science learning should be designed to meet epistemological goals with students and to provide a science classroom environment that permits students’ scientific work to demonstrate evidence supporting their inquiries. This begins by implementing aspects of inquiry such as knowledge of the kinds of questions that can be studied through inquiry. Additionally, an understanding of methods that are accepted within the science discipline must be applied. The methods include legitimate forms of data collection, data interpretation, scientific explanations, and use of models in performing all of these. It also includes formulation of and revision of theories associated with science concepts. It is incumbent that we focus students’ inquiries on the kinds of products that the processes are intended to create. The science educator’s goal is to design science curriculum and endorse effective science learning environments that promote think tank research classrooms similar to the authentic scientific community.

The characteristics of scientific explanations are unique to the science community and meet a specified set of empirical standards, logical arguments and cynicism. Scientists' explanations come from a combination of what they observe and what they think. First and foremost, explanations from experimental and observational evidence, about nature, must produce accurate predictions of the system being studied. Explanations or arguments must be logical and adhere to the rules of evidence, in other words, claims must be backed up by evidence and scientific principles. Students, just as scientists, must test scientific claims by using observations, experiments, theoretical, and mathematical models. Moreover, arguments based on evidence must be open to criticism or debate and scientists/students must include a report of methods and procedures when making knowledge public. The nature of science means that scientific ideas must be substantiated by experimental and observational data. The nature of science also means that all scientific knowledge is subject to change as new evidence becomes available.

According to Duschl and Grandy (2008) scientific inquiry involves (a) conceptual change, (b) experiments, (c) theory development and (d) model building. Conceptual change is pictured as a change in the philosophy of scientific inquiry or a paradigm shift that views the growth of scientific knowledge as a problem solving activity rather than reasoning that is accepted from a higher authority. Conceptual change uses diverse approaches in scientific inquiry rather than adhering to a positivistic view that incorporates strict rules and explicit methods. The growth of scientific knowledge is conceptualized as a problem-solving activity that takes place in a scientific community/classroom.

A case in point is that evolution by natural selection is the central theory of biology. Scientific discourse with conceptual understanding of natural selection involves knowledge of

heritable, advantageous traits and that organisms having these will produce more offspring than organisms with other traits. This will cause advantageous traits to become more common in populations over time. It is critical that students comprehend the theory in order to appreciate the scientific debate that surrounds it because early formed student misconceptions could follow students into higher grades. It is common for students to struggle with understanding the mechanism behind natural selection. Teachers must ensure that students experience conceptual change and take note of the fact that natural selection is caused by chance genetic mutations.

For example, a student investigation that provides opportunity for scientific inquiry related to natural selection and adaptation might be for students to take a hike, or walk in their neighborhoods or schoolyards to examine some of the insects, birds, or plants and other organisms they find. For each of the organisms, they could note one or two traits that make the organism adapted to its environment. It would be advantageous for teachers to prompt students with a set of investigative questions such as did you notice any adaptations that keep organisms from being eaten by potential predators? Or what types of adaptations did you see that allowed them to escape or to be camouflaged? And what adaptations did you find that might relate to raising offspring?

Scientists still engage in conducting experiments however the role of experiments is situated in theory development. Theory development involves three processes--cognitive, the ability to reason; epistemic, the ability to construct, evaluate and revise scientific arguments; and social, the ability, through a collective effort within a community of science to construct argument through a dialogic process in the form of conversation that shape evidence and the explanatory frameworks (Duschl, Schweingruber, & Shouse, 2007). Using the previous student walk example, students will begin to theorize, according to Darwin's theory of survival of the

fittest, that individuals with the best combinations of inherited traits are the most likely to survive. If they are the most likely to survive, then they are most likely to reproduce. Natural selection means that over time, populations of these animals are more numerous than populations without special adaptations. Living organisms are often adapted in several different ways to the environment in which they live. Students will then begin to extend their knowledge as they contemplate the species' ability to coexist with humans in a human-created environment.

The most authentic form of thinking, essential to the scientific community is model-based reasoning because it deepens understanding of any scientific subject matter (Duschl & Grandy, 2008). Students need to use scientific models as a means of a complete theoretical representation of a system that is not well defined. A theoretical representation includes important parts of the system, rules and relationships of parts, and it must break parts down into simpler units. This type of reasoning requires an empirical investigation and the collection of evidence in order to check, test, or develop a model or theory. The nature of the explanation about the model is like a storyline, illustrated by experience and theoretical conjectures. Models are connected to experiences through the practices of inquiry and application. If there is discontinuity between observations and theoretical perspectives, then multiple possible models with varying points of view need consideration. According to Duschl et al. (2007), when using model-based reasoning, arguments include inquiry by use of data, analysis, and questioning aspects of the model. This includes claims made about the model, challenges about the coherence of model, and acceptance of alternative explanations. Discourse about the inquiry is framed by the theorized entities and properties and relationships posited in the model.

What matters most, is that K-12 classroom practices for scientific inquiry include opportunities for students to ask questions about phenomena such as what causes rainbows?

Students need opportunities to develop theories that provide answers to these types of questions because it will give them practice and skill development in determining what questions have already been answered and what questions remain to be answered. Students will need to practice using a wide variety of models and simulations as mechanisms to develop explanations. By using models, students will be able to make predictions and then test their hypothetical explanations by engaging in systematic investigations, that involve recording data, and constructing explanations of theories by using evidence (NRC, 2012).

According to Duschl and Grandy (2008), contemporary science instruction needs to be an integration of the cognitive, epistemic, and social domains because student will form incoherent understandings of science concepts if science is taught any other way. To avoid fragmentation of science knowledge, teachers must develop an understanding of the interrelationships of the domains and develop strategies that reflect each. Teachers must devise ways to implement practices that involve students in theory building through the power of reasoning and understanding of science concepts. Students need to have opportunities to create and use theory-laden experiments as explanation, and use models and argumentation to support or refute claims (Duschl & Grandy, 2008).

Duschl and Grandy (2008) stress that science teaching can no longer focus on the management of learners' behaviors and hands-on-materials. The new paradigm of science teaching must focus on the management of learners' ideas, access to information, and interactions between learners. Traditionally, we engaged students with phenomena by manipulation of objects and materials and ignored the core of science, the dialogic knowledge-building processes or those written in the form of conversation. It is imperative that students obtain and use principles and evidence to develop cogent explanations and formulate predictions

that represent logic and reasoning about the natural world. Past thinking was telling what we see which equates with memorization of facts and conversely, new thinking is telling what we see because we know something about it and how it really works. Scientific theories are complex and woven into the design of experimental methods that help in the development of interpretations in meanings associated with the phenomena being studied.

The contemporary view or approach, in the practice of scientific inquiry, is to embrace a model of science instruction by situating learning within a context to facilitate design, problem, and investigation. By situating science instruction and learning within a design based, or project-based context, the teacher creates an environment where members of the class have both individual and group responsibilities. Duschl and Grandy (2008) recommend that a science classroom environment use total immersion units, consisting of 4-6 week long intense lesson sequences, in a compelling project-based context. Total immersion units promote meaningful learning of difficult scientific concepts. Additionally, they promote the development of scientific thinking and reasoning and promote the development of epistemological criteria that is essential for evaluating the status of scientific claims. Immersion units also encourage the development of social skills as students communicate and represent a wealth of scientific ideas and information together. Compelling units may consist of probing questions such as why do objects fall toward the earth? Or how is sound produced? Or why do humans have chambered hearts? And how does sunlight help plants grow? When these types of questions are presented students learn that many things happen without our knowledge, yet they are essential to life. Duschl et al. (2007) emphasize that the depiction of a developmental landscape in science, does not take the liberty of making an assumption that it follows a single developmental route or path but that it does require

a clear understanding of the conceptual, epistemic, and social developmental goals within a unit of science instruction.

Prudence in the scientific enterprise is collecting data from observations and the ability to construct cogent arguments that relate personal explanatory theories to observational data. The art of practicing science requires that students consider differing theoretical explanations from classmates for a given phenomena, as well as deliberating about methods for conducting experiments. Evaluation of interpretations of data is essential to the practices of scientific inquiry. Argumentation is a form of discourse in which individuals take a position, justify that position with claims and evidence, and address possible counter arguments. For example, argumentation in a science classroom setting may involve students contrasting alternative hypotheses, questioning the sources used to construct hypotheses, discussion about a collection of data, or revising a final analysis to include more textual support. In these examples, students engage in dialogue with a peer, an author, or themselves to evaluate claims and evidence.

Exploration of the scientific world-view must take place in the science classroom in order that student may grasp the validity and rationality of the processes associated with it. In short, teachers and students cannot make logical claims about knowing science or what a phenomenon is, without knowing how it relates or connects to other events. They need to investigate why the phenomenon is important and how this particular view of the world came into existence. All of these combined—knowing science, what a phenomenon is, and how it connects to other events is critical for grasping the methods involved in developing a scientific world view.

According to Sandoval and Reiser (2004), final form science is the type of science instruction where theoretical ideas are presented as facts. There is little or no discussion of the history, epistemic value, of the development of these theories. Teaching science in this manner



ignores the fact that students need to be producers of scientific knowledge rather than simply relying on the authorities within various content areas derived from textbooks. What occurs in this situation is that students accumulate numerous facts that describe the world only to forget much of the information because it is not retained. From past experience, I have learned that teaching students with memorization and rote application of procedures and formulas does not promote deep learning or a means of applying that which has been learned. Teaching final form science, in the classroom, does not promote science as a set of scientific practices that include building and revising models and developing scientific theories about the world. Sandoval and Reiser (2004) confirm that inquiry-oriented approaches to science instruction pose a challenge since these involve students explicitly in theory and model building as well as revision.

Students experience difficulties in conducting scientific inquiries in the science classroom for a host of reasons. For instance, question development is dependent upon the different levels of cognitive processes that students must have in order to craft a scientific, researchable question. When questions demonstrate different levels of cognitive complexity, those at higher levels of thinking cause students to restructure ideas that advance conceptualizations. This process is challenging because students' ability to craft questions of higher levels is dependent upon contextual factors such as prior knowledge. Students may lack conceptual knowledge about particular domains thereby making it difficult to craft questions that are appropriate for practical investigations (Chin & Osborne, 2008). However, Olsher and Dreyfus (1999) found that if teachers scaffolded students through questions, students then began to pose improved questions. Interpretation of results may also be problematic, in that, students' designs and models of interpretation may be oversimplified. Sophistication in design requires a model of how components of the design work, including tasks, inscriptions, material means and forms of

arguments. Schauble (1995) found that sixth-grade students could not comprehend experiments designed as an effort to isolate causal variables. However, after instruction on the purpose of experimentation, these students were able to design better experiments. Similarly, Dunbar (1993) found that undergraduate students studying genetic function were more effective in their explorations after being instructed on how to explain data. When students have taken time to develop deeper conceptual knowledge in a particular domain, they tend to investigate it more scientifically because conceptual principles and knowledge will have depth and breadth necessary to guide substantial scientific inquiries.

### **The Importance of Professional Development in Science Teachers' Pedagogical Practices**

Theoretical and practical shifts in teacher thinking are needed for the assessment of scientific inquiry, as proposed by Duschl and Grandy (2008). Reform documents such as Project 2061 provide the benchmarks that are the roadmap of teacher practices to be employed when teaching scientific inquiry. The science learning goal domains are congruent with the paradigm shift in science teaching and promote the communication of scientific ideas (social), developing scientific reasoning (conceptual/cognitive), and developing the ability to assess the epistemic status that can be attached to scientific claims (epistemic). Science educators must adopt the paradigm shifts in the conceptualization of reformed science teaching and incorporate these elements into contemporary science classrooms.

Policy reports such as *Before It's Too Late* in 2000 and *Rising Above the Gathering Storm* in 2005 emphasized the critical need for a mathematically, technologically and scientifically literate work force. These reports exemplify the crucial role that high quality mathematics and science education plays in preparing citizens for an increasingly competitive

global society. The most significant method for increasing America's talent pool is to improve K-12 mathematics and science education.

Professional Development (PD) is an essential tool designed to address the needs of teachers by providing opportunities for them to build their knowledge of science practices. Like students, teachers need to view learning as a lifelong process because ongoing scientific research leads to continuing changes in our understanding of the world. An understanding of inquiry is vital for and understanding of how science is done and what conclusions can be drawn from scientific studies. Effective PD programs that positively assist teachers in improving their use of inquiry in the classroom are the instrument of training.

Loucks-Horsley, Stiles, Mundry, Love and Hewson (2010) found a set of common characteristics among effective PD programs: (1) learning is retained when it is spread out over time; (2) effective professional development programs must allow and encourage collaboration between educational professionals that includes both teachers and scientists; (3) programs must be dedicated to giving teachers the necessary knowledge and abilities needed to enhance the science literacy needs of their students; and (4) professional development must take into account the learning of scientific inquiry skills as a set of abilities and understandings that teachers themselves must acquire first, in order to learn subject content in science. Knowledge that informs teachers' practices and understandings in becoming effective science teachers is a continual process starting with preservice experiences and spanning throughout a teaching career. As teachers learn, they can translate personal experiences with inquiry into better learning experiences for their students.

Professional development is the best way to advance the aims of national, state and local policies that profoundly impact teacher learning, thereby profoundly impacting student

instruction and learning. The National Staff Development Council (2001b) has acknowledged the strong link between effective policy and effective practice therefore; they have set a goal to advance effective policies at the national, state, and local level. Each school district has the duty of translating policies to support professional development that have the greatest benefit, and are grounded in the knowledge of core values of teaching. School districts must focus on developing teachers' content knowledge and pedagogical content knowledge. There is an understanding that one of the most significant influences on student achievement is teacher quality. Furthermore, professional development improves teacher quality and student achievement. Additionally, high-quality professional development needs to be sustained over time, include collaboration, must be linked to student learning goals, and tied to the daily practices of teachers (Loucks-Horsley et al., 2010).

Research indicates that professional development policies impact teaching and learning. For example, Cohen and Hill (2001) found in a 10 year study of mathematics reform in California that state standards and accountability systems positively impacted student learning when teachers had new curriculum, assignments, and good professional development in how to use them. Darling-Hammond (2000) found that states experiencing progress in increasing student learning took two clear policy steps. First, they identified teaching standards for what teachers should know and be able to do at different points in their careers. Second, they used these standards to update certification and licensing systems, align standards to more productive teacher education and induction programs, and create more effective professional development programs. These policies provided the basis for professional development to be interpreted and implemented at the local level.

Research has shown that teachers are central to the success of educational reform efforts (Fullan, 2001). Although there are encouraging examples from research and practice such as those mentioned earlier, there are three specific dimensions of barriers that teachers face when implementing reform efforts: technical, political and cultural.

The technical aspect is the teacher's ability to teach in a constructive manner, thereby, implementing reform. Supovitz and Turner (2000) found that an individual teacher's content knowledge is a powerful influence on teaching practice and classroom culture. Keys and Bryan (2000) established that inquiry-based instruction demands a high level of pedagogical content knowledge.

The political dimension that poses a barrier to teachers is the lack of school or district level leadership and support. Anderson and Helms (2001) found that in order for teachers to implement reform-based practices, they must have district support and resources such as equipment, consumable supplies, and curriculum materials. However, Berns and Swanson (2000) point out that external supports for teachers such as resources and preparation time are rare and that principals must support reform efforts and value science as a core subject. Blumenfeld, Krajcik, Marx, and Soloway (1994) also found potential problems for teachers implementing new instructional methods, such as lack of resources and district curricular policy.

Anderson (2002) claims that the cultural dimension is one of the most difficult barriers for teachers to overcome, and it is critical in implementing change. The cultural dimension is difficult to change and control. The dimension of culture looks at existing beliefs and values regarding teaching. Findings from studies of teacher learning and change identify teacher beliefs as a key factor in whether or not instructional practices will be changed and how they will be implemented and sustained (Anderson, 2002; Blumenfeld, Krajcik, Marx, & Soloway, 1994;

Keys & Bryan, 2000). Also included in the dimension of culture are the pressures that teachers feel related to content coverage in order to prepare students for the next grade level and state and national tests. Due to the aforementioned barriers, federal mandates and accountability requirements have had a mixed impact on teaching and learning. Although good policies may promote good practice, they may also pose challenges to professional learning in science education.

Teachers must be reflective practitioners and have the ability to be professional connoisseurs. This requires opportunity for teachers of science to develop detailed plans, techniques and principles for the teaching of science subject matters. In order for professional development to be effective, teachers need sufficient time for in-depth investigation, reflection, and continuous learning. This is what we require of contemporary scientists therefore, we must allow the same for classroom teachers. It only makes sense that we must make adequate quality time available for science teachers to successfully carry out professional development. This is a challenge faced by all districts and in fact, time has emerged as one of the key issues in virtually every analysis of school change.

According to the National Partnership for Excellence and Accountability in Teaching (2000), the one major reason for failure of school-wide change models is the lack of teacher time focused on the right things during professional development. There is increasing evidence and available research supporting educators in their efforts to find time for teacher learning through professional development. Research documents a positive relationship between time for teachers to engage in professional learning and quality instruction and student learning. Yoon, Duncan, Lee, Scarlos, and Shapley (2007) found positive outcomes related to sustained professional development programs that included 30 to 100 contact hours, over a time period ranging from 6

to 12 months and student learning. These findings substantiate the importance of making time for sustained professional development opportunities.

Districts may actually provide adequate time and support for professional development, but the results are less than desirable because the time is not used well. Additional time for professional development can generate significant improvements in learning if the time is used wisely, efficiently, and effectively. In order for professional development to have long lasting, positive results, there must be deep and profound changes in the organizational culture of many schools.

Reform documents have outlined a change of vision for quality science education that affirms the need for teachers to acquire different types of knowledge and skills. *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989), the *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (National Research Council [NRC], 1996) all describe a vision that emphasizes building on two key points: (1) inclusion of students' prior conceptions in teaching for understanding, and (2) helping students understand the central role of inquiry in science disciplines. The challenge for teachers is that they must be able to select and implement teaching and assessment strategies that support the development of student learning. Teachers must also use the strategy of modeling the skills of scientific inquiry and nurture a community of science learners which includes orchestrating discourse about scientific ideas (NRC, 1996). Research shows that teachers are in dire need of professional development to develop these skills as reflected in the results of a study by Weiss, Banilower, McMahon, and Smith (2001):

Nearly two-thirds of elementary and middle school teachers reported at least a moderate need for professional development in how to use inquiry–investigation-oriented teaching

strategies. Sixty-seven percent of middle school science teachers, and 71% of those at the elementary level, reported a need to deepen their own science content knowledge, and nearly that many cited needs in understanding student thinking in science and how to assess students' science learning. (as cited in Banilower, Heck & Weiss, 2007, p. 376).

Furthermore, according to Banilower, Smith, Pasley, and Weiss (2006) a national observation study of a representative sample of classes found that only 14% of science lessons were of high quality. When lessons are not of high quality, they do not provide students opportunities to learn important science concepts. The science lessons appeared to be developmentally appropriate and did not show significant problems with accuracy, but demonstrate problems with the quality of teacher questioning. Without appropriate questioning techniques, it is difficult to monitor students' understanding of science material. Moreover, teachers' lack of questioning techniques impacts students' abilities to make sense of science content and to develop conceptual understanding. With the need for upgrading teacher knowledge and skills to meet the demands of contemporary science education reform it is critical that professional development be designed to accomplish these goals?

Professional development experiences need to have students and their learning at the core (Loucks-Horsley et al., 2010). If teachers are to deliver science instruction using best possible methods, then pedagogical content knowledge needs to be addressed during professional development activities. Acquisition of pedagogical content knowledge is the unique province of teachers therefore it must be the focus of a set of unique professional development experiences. Principles that guide the reform efforts related to student learning should also guide professional learning for educators. Teachers teach as they are taught, so engaging in active learning, focusing



on fewer ideas in more depth, and learning collaboratively are the characterization of professional learning opportunities that foster professional growth in teachers.

There is a set of specific elements of reform in the teaching of science that need to be addressed in professional development training. According to Windschitl (2009) these elements require that teachers have a specialized set of skills and understandings in order to enact instruction in the classroom (Windschitl, 2009). First, the teacher must identify, in the curriculum, the most fundamental scientific ideas and treat them as the basis of instruction. For example, the human body is comprised of many bones. Second, it is imperative that teachers understand the core concepts they are teaching in science such as that bones make up the skeletal system. Third, teachers must understand the theories that explain the core concepts. For example, the skeletal system of bones support and protect the body. Fourth, teachers must show a connection or relationship between the core concepts and the explanatory theories accompanying them such as there are ten different but connected systems in the body. Fifth, teachers must be able to show how theories apply to a range of phenomena. For example, there are a large number of systems in the body and they work together to produce a complex system or machine called the human being. These elements are the basis of instruction when teaching scientific inquiry that promotes further discoveries or an expansion of knowledge related to the topic of the human body.

Just because students read about science, it does not mean that they have fully comprehended or adopted the concepts associated with the phenomena at hand. Teachers must know how to elicit students' initial conceptions of focal phenomena, guide students to represent what they know, and adapt further instruction based on these understandings or lack of understandings. Digging deeper, students' ideas have to be uncovered or unpacked. The nucleus

of uncoverage is a deliberate interrogation of the content to be learned and this is in opposition to didactic teaching and regurgitation of science material. Key to this approach is that students and teachers alike will struggle with ideas and then construct their own meanings. Doll and Gough (2002) affirms this when stating that learning requires perturbations or disturbances in the process of making meaning. Additionally, teachers must have the ability to craft questions or tasks that have the potential of revealing multiple layers of student thinking on the core ideas. Student responses must be compared to core understandings in order to evaluate cohesiveness in students' conceptualizations and to design future instruction (Windschitl, 2009).

Science policy makers and educators must embrace a paradigm shift that adopts reformed and/or contemporary science teaching practices to be implemented in the classroom. As reported by policy agencies, the time to act is now, as we face an increasingly competitive global economy. The only way to prepare students for this situation is through solid K-12 science mathematics and science education programs. It is critical that professional development policies will be designed to impact both teaching practices and student learning. Delivery of science instruction requires preparation of skillful, highly qualified science classroom teachers and this needs to be done as districts use and apply the set of common characteristics for effective PD programs addressed earlier in this proposal.

Scientific thinking is a complex interconnection of knowledge of the natural world, general reasoning processes, and an understanding of how scientific knowledge is generated and evaluated. Because this form of thinking is prized by the scientific community, the expectation is that students will experience the scientific enterprise in the same manner. The core curriculum designed by the National Academy of Sciences (2012) provides the salient conceptual features of science content knowledge through a framework of K-12 science practices, concepts and core

ideas known as standards that are vital to the understandings of students in science education. In such curriculum framework students are expected to engage in science and engineering practices and apply concepts that will deepen their understanding of the core ideas in the various domains of science. Deeper understanding of core concepts in science provides students with a forum that allows them to engage in life-long everyday decision making exercises that impact their lives. The core curriculum also provides uniformity in content being taught and learned in science across all districts. This ensures that there will be equity in what all students must learn in science and know at the end of their educational careers.

Additionally, in this curriculum experts have delineated a plan for the delivery of science instruction that involves introducing students to the practices of scientific inquiry that scientists routinely engage in. Students, as scientists, will study the natural world and propose explanations based on the evidence obtained from their work. Experts indicate that scientific inquiry is a multi-faceted activity that consists of making observations; posing questions; examining resources to find out what is already known; planning investigations; reviewing what is already known and comparing it to new experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results.

In consideration of the relevance of a K-12 framework as well as the plan for the delineation of it, three theoretical perspectives, each with a set of underlying principles of several authors guide this study. The first one includes Doll's (1993) complex adaptive systems theory (CAS), which in a metaphorical scenario, depicts the science curriculum as one manifesting complexity, develops organically through the action, reaction and interaction of students in the science classroom, and presents itself in a chaotic fashion. Second, Duschl and Grandy (2008) postulate that scientific inquiry is the integration of three science domains: 1) conceptual—

consisting of logical reasoning, 2) epistemic—making use of evidence to build inquiries and eliciting the grounds for doing so, and 3) social—allowing scientific arguments that are open to debate with others. Additionally, Duschl and Grandy (2008) state that scientific inquiry involves (a) conceptual change—taking a misconception and transforming it into the correct conception, (b) experimentation—a procedure designed to test a hypothesis, (c) theory development—development of a hypothetical set of facts and (d) model building—a complete theoretical representation of the facts and principles. Third, Loucks-Horsley, Stiles, Mundry, Love, & Hewson (2010) postulate that teachers are the gatekeepers of science instruction in the science classroom. Teachers must have the ability to use reformed SI pedagogical practices as illustrated by the tenets of contemporary science.

The major premises and underlying operational functions mentioned within each piece of literature are juxtaposed, running side by side therefore the elements of each work in tandem with one another in the science classroom during science instructional teaching and learning. In this study, as I observe classroom science instruction, various observable elements may or may not present themselves. When they do present themselves I anticipate elements to be taking place, simultaneously, and will be recognized as elements coming from each of the three literature areas: Complex Adaptive Systems Theory, Integration of Science Domains—Conceptual, Epistemic and Social Domains, and Professional Development as a Vehicle to Promote (SI) Reform in Science Teachers' Pedagogical Practices, as scientific inquiry elements do not present themselves in isolation or segmentation. The expectation is that the elements described in each literature piece are highly integrated into science classroom lessons and are done so in a natural concurrence.

In drawing parallels between the works of these authors, one could conclude from Doll (1993) that a science curriculum evolves from science inquiry—the natural process scientist use to study nature through discovery and prediction. Clearly, in the model of scientific inquiry presented by Duschl and Grandy (2008) scientific questions are used to creatively explore scientific phenomena, and through the element of discovery follows a theory-laden experimental undertaking, from which predictions are used to form testable hypotheses. Doll (1993) also states that part of the scientific story is interpretation and Duschl and Grandy (2008) espouse the use of scientific models to demonstrate scientific reasoning and to help students develop theoretical representations of science systems. One could also argue that Doll's (1993) elucidation of spirit, mystery, and aliveness in the science curriculum is more than evident when students undertake the scientific enterprise by practicing a multitude of SI skill sets such as: performing a multifaceted activity that involves actively making observations, posing a scientific question, examining resources to find out what is already known, devising an investigation, working with scientific tools, interpreting data, posing explanations, answers, and predictions and communicating results. Undoubtedly, when students are engaged in scientific inquiry practices, they are working in a nonlinear manner. Problems will occur forcing a change in plans. Students will regroup, just as scientists do, reinvent and recreate the situation, making it fit to the question being studied. I cannot see anything inert with these functions and students will be “living” the curriculum if allowed to practice SI as judiciously as real scientists do.

Doll (1993) believes that relations are the making of conceptual connections in science. Making conceptual connections is essential to the understanding that an idea we have at present can probably be integrated into a larger matrix of another set of concepts in science. This means it is necessary to explore the various disciplines in science but to also explore how these overlap.

Doll (1993) iterates that students of science will have collaboration and conversations about science discoveries. This is so that we may consider the accumulated knowledge of each student based on their life experiences. Using students' ideas is a source of inspiration for them and it will fuel innovation and imagination so desperately needed in science education. Bruner (1977) referenced the subjective storyline of students and surmised, as Doll (1993), that these are elements of scientific inquiry that must be included as part of the process of scientific practice. It is necessary to examine the original and inventive thought processes of all students, and this can be done through conversations. As students develop, becoming more sophisticated and ingenious in thinking, they will use conceptual structures and cognitive processes that support or expand theories. Student productive interpretations will be viewed as a form of argumentation discourse as they take a position supported by claims and evidence for the justification of a theoretical position.

The elements of complex adaptive systems theory are juxtaposed to the delineation of core concepts within the science disciplines: science processes; physical science; life science; and earth science. The entire time that students are learning core science concepts and performing multi-faceted activities associated with the practices of scientific inquiry, a chaotic mechanism is at work in the science classroom. Let us remember that CAS has a character of its own: there is a cultivation of perturbations—students will experience a little agitation as they deal with numerous ideas and conceptual understandings that are at work; a dynamism of action—students will grapple somewhat as they decide what do I do with the information; reaction—what is my next plan to gain greater understanding of the concepts?; and interaction—the human connection resulting in the intersection of many student ideas that builds the greater picture. As Dewey (1910) pointed out science concepts should be viewed as know points of

reference by which to get our bearings when we are plunged into the strange unknown. In other words, concepts do not just sit in our minds. Knowing something does not constitute understanding. Instead, students come to understand ideas as they are turned over in their minds and they have opportunities to reflect on their experiences. Students use ideas to interpret and deal with new situations which will then help them refine their conceptual understandings. Students are constantly refining and revisiting ideas as they add new understandings to their repertoire of thoughts. However, getting at this information takes a bit of digging and probing and a teacher has to learn how to manage all of this information coming at him/her from the students in a science class. The teacher becomes a mediator in helping student's bridge gaps between different points of view.

Teachers are the gatekeepers of the delivery of science instruction to students. Teachers' pedagogical practices are a particular form of content knowledge that embodies the aspects of content most germane to its teachability. This includes the most useful forms of representation of ideas, the most powerful analogies, illustrations, examples, and demonstrations to represent and formulate the subject matter in a comprehensible matter. It also includes understanding what makes the learning of certain topics easy or difficult. As shown by the literature review, scientific inquiry (SI) is the preferred method of choice for the construction of knowledge in science instruction. To sever the authentic practices of performing scientific inquiry from other aspects of learning science is to dismantle the entire process of inquiry. For example, to have limited foundational or theoretical content knowledge of subject matter a teacher would have difficulty designing disciplinary activities that are meaningful or relevant. To have limited understanding of scientific practices due to past limited laboratory experiences, would strip the teacher's instruction from authentic scientific inquiry practices. Teachers must have the

professional training and knowledge and it must be ongoing throughout their teaching careers. For science to be taught as inquiry it requires intense training through extended learning opportunities over time and much practice in learning to implement the tenets of scientific inquiry as intended by the powers that be.

My intent in this research study of middle school science teachers was to explore the connections among the theoretical propositions put forth by Loucks-Horsley (2010) and colleagues , Doll (1993 and Duschl and Grandy (2008) and how they play out in the science classroom.



## CHAPTER 3

### METHODOLOGY

#### **Research Design**

This study used an exploratory case study design, involving a mixed-method approach, to explore in depth the science education program in the Caseland School District. There are several justifiable reasons for choosing this design. First, NSF explicitly argues for approaches to critical research issues that incorporate mixed-methods designs to explore contemporary phenomenon, in a real-life context, such as teaching and learning through scientific inquiry (SI) (Green, Camilli, Elmore & Grace, 2006). Second, mixed-methods designs may include a variety of approaches to collect data and this study includes surveys, interviews, classroom observations, detailed fieldnotes, a journal, and various artifacts (Creswell, 2003). Third, Yinn (2003) states that mixed methods are an excellent way to explore phenomena particularly when the boundaries between phenomena such as in this study (the exploration of SI practices deployed by K-8 science teachers), and context (the science classroom), are not clearly evident. Fourth, Creswell (2003) acknowledges that all methods may have limitations, and for that reason, it is possible that biases present in a single method could counteract the biases of other methods. Moreover, the use of multiple forms of data allows for triangulation of the results, thereby adding robustness to the study's results (Greene, Caracelli, & Graham, 1989 as cited in Creswell, 2003).

#### **Setting and Participants**

The research setting for the study was Caseland Community Schools, a large suburb of a county in the state of Michigan. The district served 5, 543 students in grades Kindergarten through 12<sup>th</sup> grade. There were a total of nine schools in the district: 5 elementary schools (one kindergarten building and four buildings housing grades 1-4). Additionally, there was one

alternative education school, one intermediate school (grades 5-6), one middle school (grades 7-8), and one high school. The district employed 259 classroom teachers: two Prekindergarten, nine Kindergarten, 98 Elementary, 45 middle school and 105 high school teachers. There were four science teachers at the Middle School level, two in 7<sup>th</sup> grade and two in 8<sup>th</sup> grade, on who was the focus of this study. The student teacher ratio was 22:1.

The federal No Child Left Behind (NCLB) law had increased a school district's accountability for student learning. It also had increased the requirements for teacher certification beyond the present State of Michigan requirements. Michigan teachers are currently qualified to teach in their major area of study as well as in their minor area. According to the federal government, a "highly qualified" teacher is one who is certified by the state and teaching only in his/her major area or equivalent. All Caseland School District teachers — 100 percent — were highly qualified and 94 of them (36.3%) had provisional teaching certificates.

The total education staff in Caseland including Instructional Aides, Instructional Coordinators and Supervisors, Guidance Counselors, Librarians, Media Specialists, District Administrators, and other Student Support Services was 314. The per student revenue was \$8,568.00. Of the 5,543 students in the district, 94% were European American, 2% Hispanic, 2% American Indian, and 2% African American. In addition, 327 students qualified for free lunch and 68 qualify for reduced lunch. The median household income from 2007-2011 was \$38,000 as compared to the median household income in Michigan which was \$48,000. The percentage of persons below poverty level in Caseland from 2007-2011 was 19% as compared to Michigan which was 16%. The home ownership rate from 2007-2011 in Caseland was 56% as compared to 74% in Michigan. Caseland's population for multi-unit rental housing, from 2007-

2011, was 39% as compared to the state at 18%. Major employers in the near vicinity of Caseland (20 mi.) were automotive manufacturing, retail, health care, and government services.

This study was conducted at Landston Middle School which made Adequate Yearly Progress (AYP) in the 2011-12 academic year in the tested subjects of mathematics, reading and science. As of 2011-12, the percentage of students tested on Michigan Educational Assessment Program and Michigan Merit Exam at Landston Middle School was: 99.9% in English Language Arts (ELA) and 100% in Math. The percentage of students, in the Economically Disadvantaged group, tested in both English and Language Arts (ELA) was 99.75% and in math 100%. For students with disabilities, 100% of them tested in ELA and math. In 2010/11 the data trend in student achievement for all students reaching proficiency levels 1 and 2 on the MEAP exams, at the 5<sup>th</sup> grade level was 88.8% for the district as compared to the state at 78.1%. In 2011/12 the data trend in student achievement for all students reaching proficiency levels 1 and 2 on the MEAP exams, at the 5<sup>th</sup> grade level was 16.3% for the district as compared to the state at 15.3%. In 2010/11 the data trend in student achievement for all students reaching proficiency levels 1 and 2 on the MEAP exams, at the 8<sup>th</sup> grade level was 86.6% for the district as compared to the state at 78.1%. In 2011/12 the data trend in student achievement for all students reaching proficiency levels 1 and 2 on the MEAP exams, at the 8<sup>th</sup> grade level was 16.8% for the district as compared to the state at 16.5%.

Adequate Yearly Progress (AYP) defined by the No Child Left Behind Act (NCLB) is a measure of how public schools and school districts perform academically every year as well as their student attendance rates. The average daily attendance at Landston Middle School during the 2011-12 academic year was 96.5% and Parent Teacher Conference attendance was 70% in the Fall and 17% in the Spring.

In 2012 Caseland School District's proficiency rates, measured on percentages for the MEAP and MME state exams were 77.8% for English/Language Arts and 39.4% for Math. The

percentage of students in the district who scored proficient in eighth grade science was 16.8% compared to the state at 16.5%. For the Economically Disadvantaged Subgroup, 11.3% received a proficiency score, in 8<sup>th</sup> grade science.

In 2012 Landston Middle School met AYP and received a state report card grade of C based on 7<sup>th</sup> and 8<sup>th</sup> grade student performance on the state's standardized tests (MEAP). The average daily attendance at Landston Middle School during the 2011-12 academic year was 96.5%, Parent Teacher Conference attendance was 70% in the fall and 17% in the Spring.

Report cards are based on standardized testing and performance indicators. All elementary schools in Caseland School District met AYP and received a grade of A for 2011 and a grade of B for 2012. In 2012, Rockmore Intermediate received a grade of A and in 2012 a grade of C. In 2011 Landston Middle School received a grade of A and in 2012 a grade of C. According to the district the drop in grade was due to a change in the state's scoring procedures.

In May 2009, a Quality Assurance Review (QAR) Team visited the district and recommended AdvancED Accreditation. AdvancED is the parent organization for the North Central Association Commission on Accreditation and School Improvement (NCA CASI). The district and its schools were granted a 5-year term accreditation, which indicates the district has demonstrated the ability to use a set of strategies intended to improve instruction and student success.

### **Ethics and Protection of Participants**

This study conforms to standard educational research ethics. The research proposal was approved by Wayne State's Institutional Review Board (IRB), prior to the inception of the research, complying with institutional policies. HIC forms were complete and filed prior to data collection.

Permission for all facets of this study was obtained from the superintendent and the building principal and all teachers invited to participate in the study reserved the right to refuse their participation so that the data collection sessions involved only those who were genuinely interested in taking part in the study. Pseudo names were used for every piece of documentation. Codes were used for all forms of data collection. All survey results, interview transcripts, debriefing notes, and all other documents related to data collection were made available to the participants. All audio-tapes and artifacts will be destroyed at the end of the study. Participants may read the final research report.

### **Data Collection**

This study used four approaches to data collection: a) Caseland District-wide *Science Teacher Survey*, given to science teachers teaching grades 5, 6, 7, and 8 during the first 2 weeks of visitations, b) an interview with Caseland District's Science Curriculum Coordinator conducted during the 3<sup>rd</sup> or 4<sup>th</sup> week of visitations, c) a focus group interview with science teachers teaching grades 5, 6, 7, and 8 conducted during the 4<sup>th</sup> or 5<sup>th</sup> week of visitations, and d) classroom observations in the science classroom of one science teacher, teaching eighth grade, for 4 weeks of science instruction (total of 20 lessons each being 45 minutes = total = 900 minutes). All interviews were audio-taped and transcribed.

The *Science Teacher Survey* (grades 5, 6, 7 & 8), *Focus Group Interviews and Science Teacher Interviews* provided data to answer Research Question 1: "What experiences have contributed to middle school science teachers' understandings of the practices related to teaching science as inquiry?" The *Science Teacher Survey*, *classroom observations of science lessons and debriefings*, helped answer Research Question 2: "In what ways are teachers' understandings and skills, related to teaching science as inquiry, reflected in their practice?" The *Science Teacher*

*Survey, the District Science Coordinator Interview, and Focus Group interviews* helped answer Research Question 3: “What role has the school district played in the development of their understandings and skills?”

Spradley (1980) affirmed that a researcher comes to a social situation, such as a science classroom, with the purpose of making detailed classroom observations. In this study, observations of an eighth grade, middle school classroom were conducted in the context of a unit in the discipline of Earth Science, consisting of one subject matter, Fluid Earth. The activities related to the science lessons for the subject matter “Earth Science” were viewed through the lens of Duschl and Grandy (2008) and Doll (1993). The lessons were audio-taped and detailed field notes were recorded. For student-led activities only field notes were recorded of script conversations and interactions among students whenever possible.

Efforts were made to observe the planning and delivery of a full unit of instruction from beginning to end in order to gain an understanding of the teacher’s thinking related to the planning of all the activities and assessments related to the unit. A debriefing session was conducted at the end of the unit to gain additional insights and clarifications related to the observations. During these sessions extensive field notes were recorded.

A wide-angle lens or a wide observational focus was used in in the classroom observations in an attempt to take in the broadest spectrum of information possible (Spradley, 1980). This included teachers’ actions and comments and students actions and comments in their response to the teacher. A research journal was used to illustrate or diagram important features of the science classroom and my personal reflections on events taking place. The journal allowed me to further evaluate or analyze the findings related to the field notes and

allowed me to look for corroborations or discrepancies in the information from the teacher audio-taped science instructional lessons and my field notes.

### **Data Analysis**

Descriptive statistics were used to analyze the data from the survey and to identify patterns that were further explored during the interviews. A semantic structural analysis was performed on the qualitative data from interviews and field notes and patterns in the data were identified within and across domains. A domain analysis was used to visualize the structure of each domain that included a cover term, included terms, and a semantic relationship (Spradley, 1980). Repeated searches for domains were used to obtain different semantic relationships. This analysis lead to more observations that were added to the fieldwork activities. Based on a single semantic relationship, a taxonomic analysis was performed that shows relationships among cultural knowledge themes inside the science cultural domain. A componential analysis was performed to search for contrasts in data. These analyses were also used on all audio-taped and transcribed science lessons and on all audio-taped and transcribed interviews of the science coordinator and science teachers in grades 7-8. Please refer to the Appendix for the data analysis tools that were used with all the qualitative data (field notes and interview transcripts): Semantic Domain Analysis, Taxonomic Analysis across all domains and Componential analysis done across all domains.

A critical issue in qualitative research is the development of a shared understanding for the use of appropriate procedures that contribute to credibility and trustworthiness assessment during the course of the study. Credibility and trustworthiness help establish validity in the study. Prolonged engagement, also critical to credibility of the study, provided opportunity to gain

familiarity with the research site and persistent observations were used to identify characteristics and elements relevant to the research (Lincoln and Guba, 1985).

According to Guba (1981a) trustworthiness in naturalistic investigations such as this one, may be addressed with four criteria. This research conformed to the standards of credibility or internal validity that demonstrates truthfulness in the findings, transferability that allows for generalizability to another setting in future studies, dependability to ensure that findings are consistent and reproducible, and confirmability that ensures objectivity over biases. This set of criteria form an approach to investigation that is equitable to the reliability and validity used in quantitative studies and was used to ensure the trustworthiness of this study.

In this study trustworthiness was established through the triangulation of data from multiple sources (observations, interviews and surveys) to support claims related to the results of the study as well as through the use of counter examples to the assertions made (Mathison, 1988). The characteristics of similarity, dissimilarity, redundancy and variety were used in order to gain greater knowledge of a wider group of teachers.

According to Merriam (1988) member checks are the gold standard to ensure sustainability of a study's credibility. Member checks relating to the accuracy of the data may take place on the spot and at the end of the data collection dialogues. Science teachers of grades 7 and 8 and the science coordinator were allowed to read the transcripts of dialogues in which they have participated. The emphasis was on whether the informants considered their words match what they actually intended to convey and whether or not my interpretations of their words are plausible. Where appropriate, participants were asked if they could offer reasons for particular patterns observed during data collection.



### **Sequence of Events in the Study**

As soon as approval to conduct the study was obtained, all parties were contacted; superintendent, building principals, and teachers via email to set up times to discuss the study. At the meeting, the study was explained and all documents such as the survey, interview questions for teachers and coordinator discussed. A meeting with the teachers teaching grades 7-8 was used to explain my role in conducting a survey, performing classroom participant observations, taking field-notes, journaling, and audio-taping and transcribing interviews. The classroom teacher and I did a short presentation to the students explaining what would take place during classroom observations and what the research was about prior to the onset of my field observations. Students were informed that I may need to take pictures of activities associated with scientific inquiry.

I was at the research site daily for four weeks during a 45 minute science class, from the beginning of October to mid-November. I recorded field-notes and journal entries based on daily events in the science class. I debriefed with the teacher at the end of the day's lesson. At weeks 3-4, I interviewed the science coordinator about professional development and training provided to science teachers in the district. At week 5, I interviewed a focus group of science teachers teaching grades 5, 6, 7 and 8. Each day fieldnotes were typed for easy referencing and a separate file kept for each teacher. I began analysis of the survey as soon as it was administered, which allowed adequate time to adjust interview questions as needed. Interviews were fully transcribed as soon as they were completed, so the analysis could begin.

## CHAPTER 4

### RESULTS

This chapter provides the results related to the data collected through the survey questionnaire, given to 12 middle school science teachers; a focus group interview with eight of those teachers; the interview with the district's math and science coordinator; and classroom observations and interviews with an eighth grade science teacher. The results are organized around the study's research questions, using data from the various sources that support each of the research questions.

Table 1 (below) provides the demographics of the participants in this study. The demographics are based on questions 1-7 of the survey.

Table 1

#### *Demographics of Teacher Participants*

		Cert.	Cert.	Years	Grade	Subject	Favorite
	<b>Gender</b>	Level	Area	Teaching	Teaching	Teaching	Subject
Male	9						
Female	3						
K-8		8					
6-12		4					
All subj.			8				

Sci (6-8)	9	12	5
Math (6-8)	3		4
LA (6-8)	10		5
Sc. St (6-8)	6		4
			3
0-5		2	
6-10		3	
10+		7	

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As indicated on Table 1, nine of the participants were males and had (K-8) Elementary certifications, which included certification in science (grades 6-8). The majority of the participants had been teaching for more than 10 years and all 12 teachers were teaching either 7<sup>th</sup> or 8<sup>th</sup> grade science. In addition to science, four of the twelve teachers also taught math, 5 taught language arts, and four taught social studies. Five of the teachers reported that science was their favorite subject to teach, three reported social studies, and two reported math.

### **Teachers' Understanding of Scientific Inquiry**

Question 8, on the survey included an open-ended question asking teachers to explain their understanding of scientific inquiry. Teachers' answers revealed three themes: 1) scientific inquiry as "Scientific Method" 2) scientific inquiry as a "Non-linear Set of Procedures" and 3) scientific inquiry expressed as The 5E Learning Cycle Model.

**Scientific Inquiry as "Scientific Method."** Many of the teachers framed their understanding of scientific inquiry in terms of an investigation process that followed a specific set of procedures, starting with a problem or question, making observations, generating a

hypothesis, creating the study design, gathering materials to conduct an experiment, collecting the data, and organizing the data in a graph. They added that data needs to be interpreted, analyzed and conclusions must be drawn from the evidence. As stated by one of the teachers, “It is STEPS! State the problem, state a hypothesis, conduct an experiment, collect data, summarize the experiment, and write a conclusion. We do many labs and always follow the scientific inquiry method!”

This process was also clearly illustrated in Mary’s Power Point Slide Presentation entitled “Scientific Inquiry” that was used by all middle school science teachers. During a debriefing, Mary explained the meaning of the presentation as it related to her understanding of the practices related to science as inquiry:

This Power Point slide presentation includes the following practices that we all try to use in class: (1) Define the problem or question. This is what you are trying to answer. (2) Information and Background—It is important that information on the area to be studied is obtained, so that a logical hypothesis can be formed. (3) Hypothesis—Make an educated guess as to what will happen in the experiment. (4) Experiment—Conduct the experiment to test the hypothesis. (5) Observations—make observations during the experiment. Always include numerical data. (6) Conclusion—State the research question, summarize the experiment, restate the hypothesis, tell if is correct or incorrect, add what you learned from the evidence, and make suggestions for other studies.

**Scientific Inquiry as a “A Non-linear Set of Procedures”.** However, during the debriefing after one of Mary’s classes, Mary stated that all the practices of inquiry are not necessarily a standardized set of procedures and that each practice may not be followed every

single time a lab is done. One of the other teacher's also comments also illustrated an understanding that inquiry is complex versus a simple set of linear procedures. She implied that scientific inquiry can be inconsistent and somewhat chaotic because things might have to be adjusted or revised in a study. These statements indicate some level of understanding that science as inquiry is not necessarily performed in steps following a linear progression. The teacher's statements below reflect some understanding of scientific inquiry as articulated by Doll's (1993) chaos theory.

SI is the process used to study a question or problem. It usually follows a certain progression from question, to hypothesis, materials, procedures, observation, recording of data, studying the data recorded and drawing some sort of conclusion. Depending on the inquiry, *these steps may vary in order* and repeat numerous times. The Process is: Question, Hypothesis, Experiment, Observations, Analyze, Results, Share, and Repeat. I included repeat, because based on the results, you might have to repeat a step, change a hypothesis, or go back and do some things over again.

These explanations show some level of understanding that scientific inquiry is evidence based and that such evidence influences one's decision making process on how to move forward with a study. If the results do not support the hypothesis, then decisions change which means that there is a conceptual change taking place. The design of the study would be altered in some way bearing out the changes. The hypothesis would be revised, causing revisions in the experiment setup, data that gets collected, and the results of the study. All of these steps would produce a change in the conclusions that would be drawn as well as a change in the proposed theories about the problem or scientific question being studied.

**Scientific Inquiry as “The 5E Learning Cycle Model.”** Some of the teachers used the 5E Learning Cycle, which is an inquiry lesson planning model, when expressing their understanding of scientific inquiry. According to one of the teachers, “The Model is: Engage, Explore—not being told, Explain, Elaborate—not being told, and Evaluate—not being told! That is what students must do!” One could argue that the 5E learning cycle model also aligns with Doll’s (1993) theoretical perspective in some ways. For example, when students experience science lessons that follow this model, they might experience doubt or disequilibrium that comes from freedom of expression or a plethora of student ideas during the various phases of the model. The ideas are indeterminate because they evolve spontaneously from students. This results in “chaos” or temporary disequilibrium.

### **Pedagogical Content Knowledge: Sources Of Teacher’s Knowledge about Teaching**

#### **Science as Inquiry**

Table 2 (below) provides teacher responses (in the form of level of agreement) to survey items 9a-11c, which explored the sources of teachers’ knowledge and skills related to teaching science as inquiry.

Table 2

#### *Sources of Knowledge and Skills for Teaching Science as Inquiry*

	Low % (1,2)	Neutral (3)	High % (4,5)
9a. Science Content Courses	8.3	16.7	75.0
9b. Science Methods Courses	33.3	16.7	50.0
9c. Experimenting on my own	8.3	16.7	75.0
11a. Working with Univ.	50.0	8.3	8.3

Researchers			
11b. Attending Workshops	16.7	8.3	75.0
11c. Inservice Training	25.0	41.7	33.3

The results on Table 2 indicate that 75% of the teachers considered science content courses and experimenting on their own, as the two leading sources of personal knowledge and skills for teaching science as inquiry, whereas, 50% percent of the them attributed knowledge and skill acquisition to science method courses.

During the focus group interview, the teachers also stressed that their content knowledge had been obtained from the courses that they have taken and that the evidence of such understanding was demonstrated by the subject matter tests that they passed to get their degrees. Teachers also mentioned science methods courses, which according to the teachers gave them some ideas associated with the teaching of science in labs, but not necessarily teaching science as inquiry. The third source of knowledge mentioned, during the focus group interview was student teaching. Indeed, there was strong consensus echoed by all the teachers, that student teaching was the major contributor to their development of skills and practices associated with the teaching of science. As indicated by Josi, “My personal experience as a science teacher has led me to understand that you can learn philosophy all you want, but you have got to be in there, practicing in the classroom to know what you are doing!”

Question 11 in the survey also asked teachers to rate (from least to most) other areas of knowledge and skills for teaching science, specifically, working with university researchers, attending workshops, and inservice training provided by the school district. The great majority of the teachers (75%) felt that “attending workshops” helped further their skills for teaching

science, whereas only 33.3% of them rated “inservice training by my school district” at the same level. This indicates that workshops are a key component to teachers’ professional development after certification. Only 8.3% of the teachers rated “working with university researchers” as a key contributor to their development of new knowledge and skills for teaching science.

During the focus group interview the teachers were asked about the low score; (33.3%) that inservice training had received in the survey. Their responses indicated that the district did not have a lot of resources for science training, including funds for substitute teachers during inservice days. Paying for substitute teachers and an instructional leader to conduct the inservice can be expensive for school districts.

Teachers also reported that the types of training that they needed to enhance their abilities to teach science had not been offered for more than three years. They mentioned examples of useful activities the district had offered in the past when there was money for training, such as Fieldtrips, Outdoor Training or Summer Science Programs, as well as funds available to attend the annual conference of the Metropolitan Detroit Science Teachers Association (MSDTA).

**Teachers’ approaches to teaching science.** Another question in the survey asked teachers to rate four approaches (from least to most beneficial) for teaching science: lecture, cooperative learning, teacher demonstrations, and student labs-inquiry. Teacher responses show that 83% of them felt that cooperative learning and student labs were most beneficial for teaching science. Fewer teachers (58.3%) rated demonstrations at the same level, whereas 50% of them rated lecture as being the most beneficial approach to teaching science. (See Table 3 below).



Table 3

*Teaching Methodology for Science Instruction*

	Strongly Disagree % (1,2)	Neutral % (3)	Strongly Agree % (4,5)
10a. Lecture	25.0	25.0	50.0
10b. Cooperative Learning		16.7	83.3
10c. Teacher Demonstration		41.7	58.3
10d. Student labs-Inquiry	8.3	8.4	83.3

During the focus group interview teachers were asked about the ways in which they used these various approaches to teaching science.

**Cooperative learning.** Mary commented during the focus group interview on the benefits of using cooperative learning for science instruction:

Students are put in groups so they are able to discuss their findings with each other about science subject matters. Students who are not quite sure of their understanding may get information from those that have a little bit more prior knowledge on the subject. Students can discuss topics with each other and discussion helps the student that has less understanding, “get there”. I think that's very beneficial to those students who have no

prior knowledge in a particular area of science. I use student conversations, talking, turn and tell as methods in science class just like another teacher may use in Language Arts.

Josi added, “ I think we use cooperative learning strategies, because we all know from the learning pyramid, that students learn most effectively by teaching someone else and being involved in that process.” Josi also clarified the notion of the learning pyramid when she said, “The learning pyramid teaches that the average retention rates for remembering are the highest when students have discussions with each other about what they are learning.”

**Student labs with inquiry.** During the focus group interview teachers indicated that student labs with inquiry facilitate students’ learning of science concepts. The teachers discussed the benefits of this type of teaching approach in terms of student control and ownership for their own learning:

I think science inquiry labs put the students in control of their own learning. Students take ownership! Science inquiry raises students’ interest levels because they are more involved with the science concepts and they are having fun with science concepts. It is a multi-sensory approach to learning and students will remember more from inquiry labs than reading from a textbook. There is a Chinese proverb that says, "Tell me, I'll forget. Show me, I'll remember. Involve me, I'll understand". It is probably true.

Another teacher added:

I think it puts the students in control of the learning. I think when students are more involved, they're having more fun. There's less opportunities for distractions. It raises their interest. They take more ownership. I just think that with hands on activities, you

remember more. I think students benefit from a multi-sensory approach. I mean you hit more learning modalities that way. There are some consequences with this. With labs you end up giving up some curriculum, but I do think that the tradeoffs are there. You're better off with labs, and I still remember labs from high school to this day that helped me learn concepts. But, I don't remember ideas that I read from a book!

**Teacher demonstrations.** Teachers' demonstrations were rated not as highly as student labs and cooperative learning. However, during the focus group interview teachers did discuss ways in which teacher demonstrations can be a viable approach to facilitate student understanding of science concepts. According to one of the participants:

Teacher demonstrations may be used because you don't have all the time needed, in the schedule, to get everybody to the lab so that students can work individually on a project. As an alternative, teachers demonstrate the lab and students get a better understanding of the science concept rather than just reading about it in the book. Teachers don't want students doing a science lab every day. Teachers want to mix up the instruction a little bit and they want to use a variety of approaches in learning. Sometimes it is not feasible to do a lab because of the lack of equipment. Another part of the equation is how the teacher does the demonstration. Does the teacher give the students an opportunity to make a prediction or use some of the other science process skills? Then the teacher can have the students follow up with the concept, and give the students some way of figuring out if they've learned it.

Mary elaborated further on how a teacher demonstration may be more effective than a lab. To illustrate this point she described an example of a teacher demonstration that she had done on dispersement of freshwater throughout Fluid Earth:

For example, I did a water dispersement demo lab of freshwater throughout Fluid Earth. I used an aquarium and several beakers. I talked about the percentage of global water distribution; the ocean is 97%, and freshwater is 3% which make up the total of the Earth's water. The breakdown on fresh water is: glaciers 68.7%, groundwater 30.1%, surface water 0.3%, and other 0.9%. Surface water includes lakes 87%, swamps, 11% and rivers 2%. Many liquid measurements were taken to illustrate the levels of water. My expertise told me that students would be confused when measuring the water, the sequencing of the steps involved, and they would have difficulty getting the measurements correct. I think the visual of the demo was most telling for students.

**Types of inquiry methods used in the science classroom.** Statements 12-14 on the survey asked teachers for their level of agreement related to their use of inquiry (structured, guided, and open) in their teaching practice. As results in Table 4 indicate, of the three types of inquiry, guided inquiry received the greatest rating with 100% of the teachers agreeing that they enjoyed doing guided inquiry in their science classes. Open-ended inquiry received the lowest level of agreement (66.7%), whereas 83.3% of the teachers agreed that they enjoyed doing structured-inquiry.

Table 4

*Types of Inquiry Methods Used in the Science Classroom*

	Strongly Disagree % (1,2)	Neutral % (3)	Strongly Agree % (4,5)
12. I enjoy doing structured-inquiry learning with my students in the science classroom.	8.3	8.3	83.3
13. I enjoy doing guided-inquiry experiments in my science classes.			100
14. I enjoy doing open-ended experiments in my science classroom.	8.3	25.0	66.7

During the focus group interview, teachers were asked to clarify the differences between the three methods of science inquiry instruction: structured inquiry, guided inquiry, and open-inquiry.

**Guided inquiry.** One of the teachers defined guided inquiry as:

Guided inquiry is if students are involved in a lab activity, and the teacher has generated questions to study. Students are responding to teacher generated questions, and from those responses, the teacher is guiding the direction that the study takes. The teacher is asking thought provoking questions, and from those thought provoking questions, new questions are coming up. The teacher guides the experiment and is sure of the intended outcome.

**Structured inquiry.** Teachers explained structured inquiry in terms of the teacher's level of control of the activity or as one teacher put it, "a cookie cutter or cookbook lab." They elaborated on this topic further by stating that:

Students are walking through preset steps with answers to the questions, already there. With structured inquiry, it is more of a procedure of asking a question and getting a desired response rather than guided inquiry where you ask a question and then following up with more questions from students. I think guided inquiry is definitely higher level thinking, and structured inquiry is lower level thinking.

**Open-ended inquiry.** Teachers' understanding of open-ended inquiry illustrated two perspectives: (1) that it is a more authentic approach to teaching science as inquiry, and (2) that open-ended inquiry can only be done with students in advanced courses. The two quotes below illustrate both perspectives:

For four years, I've done water testing with students. Water testing was done through Project Green or Flint Green. I do that with the honors students. We had one year that we tried to do that with all the 7th graders but it was difficult. That was too many students to manage. In the end, it's a core group who has a strong interest in science and can meet after school, because of the time it takes for all of that activity. We have to get to the other parts of the curriculum during the day, so it has to be after school. It's a handful, maybe four to eight students after school and then we present all of our data and our findings to a group panel. They have to collect and analyze the data, put it all together and present it back in a Power Point presentation. Last year the panel was at Kettering, in Flint.

One thing that students participate in, that is the honors classes, is a Science Fair Project. It's an honors level requirement to do a project. The project is very much scientific inquiry. Students have to come up with something, an idea; they develop a question, form a hypothesis, and then actually design their own experiment, develop a model, collect data, and draw conclusions. So it's a pretty high level thinking.

During the focus group interview, Chris shared an opportunity that his students had to conduct a full-fledged, open-ended inquiry. Chris worked on the Quakeville project with students and the scientific practices that students used to complete the project align well with the theoretical frame of (Duschl and Grandy, 2008). Chris elaborated on implementation of the project:

Quakeville is part of an earthquake unit and students actually build a prototype. Students start with a question such as: "How does the earthquake shake the table?" Students actually conduct an experiment based on what they build and watch the quake in action. The usage of models is important so that is why students build something in class during this project. Students develop their own model. They use balsa wood and other materials around their house. Then they have to include three earthquake-proof features in the design. They are research based features. For this example, students build something and then they actually test it by running an experiment to see how it withstands the earthquake. Students actually have an opportunity to go through all those steps; question, hypothesis, design, experiment, data collection, results and argumentation and they must use model for explanation. They are using analysis. They draw conclusions. They

theorize. What we teach in science is that your conclusion is not powerful unless it has collected data to support it!

Duschl and Grandy (2008) emphasized the importance of models and that models are indispensable as a scientific practice used for inquiry. The model is a complete theoretical representation of a problem or question that is being studied. Chris referred to the Quakeville project model as a prototype, which students used for explanation when drawing conclusions. He also described the elements of scientific inquiry as proposed by Duschl and Grandy (2008): Students formed a question, hypothesis, design, experiment, collected data, and obtained results.

During a debriefing session with Mary, she also described her vision of what a true open-ended science inquiry project looks like by using a study that she would like to use with her students in the future:

The research would be about pesticides and fertilizers and the impact they have on the environment. The research question is: Does the Introduction of Pesticides and Fertilizers Alter an Aquatic Ecosystem? My objectives would be: (1) Students will be able to: determine if the introduction of pesticides and fertilizers can change the water quality of an ecosystem and (2) Students will evaluate how the introduction of pesticides and fertilizers can change an aquatic ecosystem in a simulated system. Students would obtain a water sample from a local stream or pond. They would identify macroinvertebrates from an online dichotomous key. They would use beakers to set up miniature water ecosystems. Students would use microscopes and hand lenses. Once the pH has been determined, students would separate the 1000 ml. sample into five 200 ml. samples in separate containers. They would label each container in the following manner



and add the listed amounts of fertilizer and pesticide solution to the properly labeled container. Container 1- 5 drops of 5% fertilizer solution ,Container 2- 20 drops of 5% fertilizer solution, Container 3- 5 drops of 5% pesticide solution, Container 4- 20 drops of 5% pesticide solution, and Container 5- is the control. Students would hypothesize about how the contents of each container would change after the 24 hour period. Observations would be recorded in a data table. Some of the questions related to the study would be:

1) Does the data collected support your hypothesis? Explain. 2) Based on your observations, in which container was the survival rate of macroinvertebrates the highest? Why? And 3) Based on your observations does the addition of pesticides and fertilizers to an ecosystem cause a disruption in the ecosystem?

**Supporting areas for teaching science as inquiry.** Because teaching science as inquiry requires extensive teacher planning, seven of the items in the survey (statements 16-22) tried to assess the level of teacher preparation and planning related to their science inquiry lessons.

Table 5

*Teacher Preparation for Teaching Science Inquiry Lessons*

	Strongly Disagree % (1,2)	Neutral % (3)	Strongly Agree % (4,5)
16. Lesson planning for scientific inquiry takes a lot of time.		33.3	66.7
17. Organization of materials is very important when teaching science using scientific inquiry.		8.3	91.7
18. I have few materials & support	50.0	25.0	25.0

for teaching scientific inquiry lessons.

19. Lack of time to plan with colleagues is a problem when preparing scientific inquiry lessons.	16.7	8.3	75.0
20. Before I teach a scientific inquiry lesson I practice it to ensure everything will go as intended.	25.0	16.7	58.3
21. I test scientific inquiry activities before class.	8.3	25.0	66.7
22. Classroom management skills are very important when doing scientific inquiry lessons.		8.3	91.7

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**Time constraints.** Results on Table 5 show that 66.7% of the teachers felt that lesson planning for scientific inquiry takes a lot of time whereas, 75% indicated lack of time to plan with colleagues when preparing scientific inquiry lessons. Over half (58.3%) of the teachers responded that before they teach a scientific inquiry lesson, they take time to practice it to ensure that everything goes as intended and 66.7% of the teachers responded that they test scientific inquiry activities before class.

**Science material needs.** In addition to time, teaching science as inquiry also requires a significant amount of materials and support. Teacher responses indicated that 91.7% of them felt that organization of materials is very important when teaching science as inquiry, yet, 25% felt they had few materials and support for teaching science inquiry lessons.

**Classroom management.** Almost all the teachers (91.7%) felt that classroom management skills and organization of materials were very important when teaching science inquiry.

**Teacher knowledge related to the teaching of science as inquiry.** Two items on the survey asked teachers to rate the level of importance of knowledge of subject matter and knowledge of scientific inquiry content standards for teaching science as inquiry.

As indicated on Table 6 (below), the majority of teachers (91.7%) responded that knowledge of scientific inquiry Content Standards, Benchmarks, and Glicks is important when teaching science as inquiry and 83.4% felt that knowledge of subject matter or content is essential when teaching science as inquiry.

Table 6

*Knowledge That Contributes to the Teaching of Science as Inquiry*

	Least Important % (1,2)	Neutral % (3)	Most Important % (4,5)
31. My knowledge of subject matter or content is essential when teaching science as inquiry.	8.3	8.3	83.4
32. My knowledge of scientific inquiry Content Standards, Benchmarks and Glicks is important when teaching science as inquiry.		8.3	91.7

Science subject matter and inquiry are essential components of teachers' knowledge for teaching science as inquiry. If teaching involves helping students learn, then understanding what is being taught is a critical requirement of teaching. The following comments from the focus

group interview support the critical need for teachers' skills, understanding, and interpretation of the MI Core Curriculum Standards for the delivery of science instruction:

I think we're expected to follow the MI State Core Curriculum Standards or guidelines for 7<sup>th</sup> and 8<sup>th</sup> grade, and that includes the Grade Level Content Expectations for science. I think the state tells us what to teach and we can go from there with translation. I think it is necessary for us, as teachers, to develop our own conceptual knowledge of the subject matters and construct our instructional plans on how to carry out the standards or deliver the instruction. The School Improvement process and professional learning communities are supposed to provide the time for us to collaborate about how we can carry out the core and content expectations. Professional learning communities are particularly designed for teachers to figure out how they will deliver the instruction to meet those standards.

During the focus group interview, teachers confirmed their commitment to what they should be teaching from the MI core curriculum. Specifically, the subject matters related to 8<sup>th</sup> grade Earth Science which includes Fluid Earth, Solid Earth, and Astronomy. They also mentioned the Sun, and Space and Time and obviously Science Inquiry. For the 7<sup>th</sup> grade subject matters include Water, Heredity, Photosynthesis, Waves and Energy, Earth Science: Fluid Earth, Weather and Watersheds, and Chemical and Physical Properties.

**Teachers' actions in the science classroom.** Twelve of the statements in the survey, asked teachers to state whether or not the actions listed in Table 7 below, applied to them as science teachers. Three statements were related to teaching science as inquiry and received 100% agreement: "I provide experiences;" "my students reflect on ideas from the lessons;" and

“students need to explore their thinking.” Another statement, “they watch the lesson unfold” received 91.7% agreement. The three statements with the lowest level of agreement included: “I provide information;” “I seek to control the lesson;” and “students need to explore my thinking,” which received between 0 and 8.3% agreement (see Table 7 below).

Table 7

*Teachers' Actions in The Science Classroom*

Circled Responses	Yes	%
A1. I <i>teach science</i> to students	3	25.0
B1. I <i>do science</i> with students.	9	75.0
A2. I <i>provide information</i> .	0	0
B2. I <i>provide experiences</i> .	12	100
A3. I seek to <i>control the lesson</i> .	1	8.3
B3. I watch the <i>lesson unfold</i> .	11	91.7
A4. Students need to <i>explore my thinking</i> .	0	0
B4. Students need to <i>explore their thinking</i> .	12	100
A5. Students must ask <i>what to observe</i> .	2	16.7
B5. Students trust their <i>own observations</i> .	10	83.3
A6. My students <i>memorize facts</i> .	3	25.0
B6. My students <i>reflect on ideas</i> from lessons.	12	100

In a follow up interview with Mary, she explained the ways in which she uses inquiry in her lessons:

I believe I have had a few lessons or labs that relate to science inquiry or “doing science” with my students. I believe that one of the brief vocabulary activities also related to

inquiry. Students were to use the *Freyer Vocabulary Model* to "gather knowledge" about mechanical and chemical weathering. Part of the model requires students to generate examples and non examples of both. For example students found evidence of mechanical weathering such as animal burrows dug into rocks, repeated freezing and thawing of water that creates cracks, formation of potholes in the road, raised sections of the sidewalk and things like that. Students also found evidence of chemical weathering such as oxidation of minerals that contain iron, action of water, salt, and air on car fenders, or school lawn furniture rusting. This information gathering process allows students to make a good hypothesis on the examples. I know that this activity did not involve the full set of research practices, but it did involve data collection and the formation of hypotheses.

She added:

The *Shake It Up Lab* was also on weathering. Students completed all steps of the inquiry process. They began with a problem, made a hypothesis, followed a procedure for experimentation, and made personal observation that analyzed results of erosion on the sugar cubes. The observations were noted in word and drawing form. Students wrote full conclusions stating the problem, restating the hypothesis, summarizing the experiment, noted their evidence, and discussed possible errors.

### **Scientific Inquiry Practices in The Science Classroom: Doll's (1993) Three C's.**

Doll's (1993) theoretical frame provides a three-part view of the science curriculum. The three C's are the theoretical constructs of collaboration, conversation, and community that framed this study. Doll (1993) deems that there is a call for *conversation, collaboration, and*

*community* in the field of science curriculum. Collaboration and conversation about science conceptual structures form the substance of student interactions during science instruction (Doll, 1993). Conversation and collaboration represent students' accumulation of knowledge gained from past experiences and it is used to fuel learning in addition to the teacher's specialized curricularized methods that are implemented during scientific inquiries. During scientific inquiry, conversation allows students to have knowledgeable interactions with each other. Interaction in the form of conversation allows students to discuss and share their science conceptual ideas with each other. As students engage in collaboration, they soon come to the realization that what they know must be shared with others in order for that information to be validated for its truthfulness. Conversation gives students practice in defending their position. Students will also discover the differences between their thinking and others' thinking and the power that comes from the merging of ideas. Collaboration allows students to reflect and change their own conceptual structures if necessary as the group works toward consensus. Community is reconceptualizing humanity as students re-generate understandings of human experiences through conversations, interactions and collaboration with others (Doll, 1993). The processes of student interaction, cooperation, and collaboration, and community are powerful, essential tools for learning science as inquiry. Doll's (1993) theoretical framework provides meaning for the constructs that frame this study.

Through collaboration, conversation, and interaction in a community of science learners students produce more complex ideas. When the teacher shows restraint from giving all the answers, he or she can guide students along during the science lessons being "a guide on the side." Doll's (1993) expectation is that science conceptual structures unfold naturally, implying

that conceptual structures are of an “organic nature.” This results in a higher yield of complexity that hovers over the regular standardized curriculum.

The 3 C’s, conversation, collaboration, and community in Doll’s (1993) theoretical framework were used to development three statements in the survey listed in Table 8 (below). These statements represent the constructs of student interaction that take place through conversation, collaboration, and community.

Table 8

*Student Collaboration and Interaction*

	Disagree % (1,2)	Neutral % (3)	Agree % (4, 5)
23. Student interaction is to be expected when students do scientific inquiry.	8.3		91.7
24. I am a “guide on the side” when teaching science as inquiry.	8.3		91.7
34. Teaching science as inquiry promotes collaboration and interaction.		33.3	66.7

As results in Table 8 show, the vast majority of the teachers (91.7%) agreed that “student interaction is to be expected when students do scientific inquiry experiments” and “that they are a guide on the side when teaching science as inquiry.” Additionally, 66.7% of the teachers agreed that teaching science as inquiry promotes collaboration and interaction.

The results were also reflected in Mary’s classroom, where students had opportunities to interact and share their experiences with each other. Based on classroom observations, students worked with “table partners” (4 person groups) and had conversations conducive to further



development or extended thinking related science conceptual structures. For example, in the case of mechanical and chemical weathering, students worked in 4 person groups and used a *Frayer Model Guide* in learning about these concepts. The guide included definitions, characteristics, examples and non-examples of chemical and mechanical weathering. Below is one of Mary's directives that encouraged conversation, collaboration, and community during this lesson:

As you are going over this, I encourage you, if you have disagreement, to try to prove your point. I'll eventually reveal the correct answers. We do not want to be obnoxious when trying to prove our point, but I want you to *reason out and give backup statements*, as to why you think your choices are chemical and why other students feel it's mechanical. Again, we are going to use 4 person groups. Turn to your four-person groups and have some discussion.

From a previous collection of Internet researched reading material and after 4 person table partner conversations, Kayla's group confirmed that:

Weathering includes mechanical weathering and chemical weathering. Mechanical weathering occurs when rocks are broken apart by physical processes but the chemical makeup of the rock stays the same. Chemical weathering occurs when chemical reactions dissolve the minerals in rocks or change them into different minerals.

After collaboration, Matthew's four person group confirmed consensus on examples for mechanical (physical) weathering. Matthew read from the Frayer Model Guide what the group had written:

We have learned that mechanical weathering is caused by temperature, frost action, gravity and organic activity. We believe that ice wedging caused by freezing and

thawing ice, burrowing animals that dig holes in the dirt, plant growth that pushes roots through the dirt, and salt wedging where salt crystals begin to grow and the crystals wedge and crack the rocks are examples of mechanical weathering.

Sarah's group collaborated on chemical weathering and they presented the following group ideas:

We think that chemical weathering involves chemistry because it affects molecules and atoms. Chemical weathering is caused by plant acids, sulfuric acid, carbonation, oxidation, and water. Some types of chemical weathering or chemical reactions are: oxidation and acidification. Oxidation causes farm equipment and cars to rust.

There are chemicals or acids in certain plants and they can deteriorate the rock that it surrounds.

In another lesson students were asked to explain in their own words the difference between an *Alluvial Fan* and a *Delta*. Only five out of twenty four students understood the concepts and could distinguish the difference between the two. Mary then referred students back to an ICANN statement in the unit packets: "I can distinguish between a Delta and an Alluvial Fan". Because the students faltered here, they were told to get back into groups, read page 248 in the text, refer to split page notes, discuss the elements of each, and figure out the correct explanations to support the ICANN statements. These were more difficult concepts for the students and I heard comments such as, "These both come from water that flows and they both drop dirt in places!"

Mary reminded the students that an Alluvial Fan and a Delta have something in common and something that is different about them. She asked students to collaborate about what model they could use to display the likes and differences. Eventually, after discourse, Dan's group

suggested a Venn diagram. The groups came to consensus that the Venn diagram would help them present the information. Each four person group developed a Venn diagram to show what is common and what is different about the two concepts:

Samantha's group presented their ideas from the Venn diagram after some debate:

We found out that an Alluvial Fan forms from water moving over the land. Water moves from mountains and deposits sediment over land. We remembered the teacher saying, "Sand over land!" We labeled that circle as Alluvial Fan. The Delta forms from water moving over land to a larger body of water. A delta is over a larger body of water. We labeled that circle Delta. That's what is different! In the middle of our Venn diagram we wrote *both deposit sediments* when moving water slows down and that is what makes them the same type of feature.

Mary then concluded the lesson by an example of a fan and a delta in the Amazon River:

You can see the white and bluish tributaries. All of these are tributaries that feed the Amazon. Here's the fan and this is the Delta. All of the sediments are deposited into the Atlantic Ocean. Gravity causes this. Due to elevation all water runs downhill. The Atlantic Ocean is at a lower point at sea level than compared to the source of the river.

From the classroom example of confusion regarding the likeness and difference between an Alluvial Fan and a Delta, a conclusion may be drawn that in a complex adaptive system students will have a great deal of conversation and collaboration as they grapple with science conceptual information. Interaction in the system may become somewhat chaotic or confusing as students' ideas emerge. Students' ideas will be based on self-reflections, experiences, as well as unpredictable and predictable responses. Responses that develop from interactions,

collaboration and conversations will be structured and restructured many times over as students work through taxing problems and gain clarity in thinking. In this example, students had to restructure their thoughts after further research on the concepts being presented.

Mary presented several lessons on erosion. In one of them, students were required to use self-reflection and personal experience to develop a KWL Chart (Ogle, 1986), in which K represents what the student knows about the concept of erosion, W represents what the student wants to know about it, and L represents what the student has learned about erosion. The KWL Chart is a motivating tool designed for students to explore their personal knowledge of subject matter and in this case erosion. Mary referred to a photograph on the overhead and stated:

Please look at the picture up on the overhead. Answer these questions. 1) K: What do I know about erosion? And give examples of types of erosion you have seen in your personal experience. 2) The W stands for: What do I want to know about erosion? Please remember that you must write a question about this photograph that indicates: What do I want to know about this problem?

The photo represented movement of a very, very big rock that is actually exposed and the students were told that it was about one third of the size in the classroom. There was a riverlet in the picture that was about 6 inches wide and it had merged off of a larger stream bed. It was about 3 to 4 inches deep. Ice and snow appeared around both sides of the riverlet.

Mary first asked students to share their questions in the four person groups. Then she asked to hear some of them aloud:

Emma: "How did the rocks get there?"

James: "Is this oxidation?"

John: "Where did the water go?"

Thomas: "Did the rocks change from the original rock?"

Mary explained that the photograph was a dry streambed and the water dried up. Mary commented:

This streambed was only really very active in the spring and in the summer. This would occur during the rainy season or when there is snow melt occurring. Then, when the rains began in the fall it filled up again. Clearly, there is a change in the rock and it is due to minerals that are found in the water.

Mary then presented a second photograph to the class:

Now let's look at this picture class. You can see the embankment and you can see this very large boulder. This boulder has been undercut and dropped into the stream. You can see where the waterline is here. That boulder is included in the waterline.

Students were told to ask a question about it. Mary said, "This is a "what do you want to know?" question. Tell your partner what you want to know."

Mary presented a third picture. She elaborated, "The rock in my left hand is exactly the same as the rock in my right hand. What kind of rock, do you think this is?"

Tristan responded with a question: "Is it granite?"

Mary confirmed Tristan's answer and indicated that it was a type of granite. She then went on to ask what type of rock granite is. Alleija remarked, "Igneous rock." Mary confirmed the answer and explained that the rock formed beneath the earth in the crust. She stated, "It is a rock that is formed inside the interior of the earth. It is formed from magma."

Mary continued and asked the students, "What were your two questions about these handfuls of rock?"

Alleija: "Are they like the same rock or did something happen to one of them?"

Mary responded, "They are the same rock? The black and white ones are the granite that has not been exposed to the water. The ones with the color have had some chemical reaction because of water exposure."

Mary asked for student generated questions again.

Nathan: "What kind of weathering made this happen?"

Samantha: "Did this tumble?"

Alleija: "Did someone step on it? What happened? What caused it to crack?"

Collaboration, conversation, and communication took place between the teacher and the students. Also, Mary had students share conversation by using the "Turn and Tell" method to examine their questions with table partners before they wrote them down. They collaborated as to whether or not the questions were researchable.

One of the strategies Mary used in the science classroom that gave students an opportunity to "self-reflect" was demonstrated in the "*Buffering Against Erosion*" lesson. The students read the article and applied a formula to it, and demonstrated background knowledge on the topic of Erosion. The formula was: a) text to self b) text to the world and c) text to text. Of particular interest was the text to self. When Mary was asked, during a debriefing about the intent of text to self she reported:

Students need to connect to their prior knowledge to activate schema while reading. Building background knowledge and making connections is a well-known reading strategy, developed by Chris Tovani and it may be used across content areas. This strategy when used before, during and after reading science material increases reading comprehension.

Mary continued:

The connection can be to self, world or text. The reader uses something from their personal experience or memory to help them understand what is happening in the reading. By having students slow down and consciously think about the connections being made to themselves, the content is retained and much more personal. This strategy improves memory and the web of connections and relationships between personal experiences and concepts becomes clearer.

The reflections were written in the unit packets and shared among students in the four person groups, yet creating another opportunity for students to share, communicate, and collaborate about science material.

**Classroom (SI) practices connected to Doll's (1993) 3 R's.** Doll's (1993) theoretical framework for curriculum development includes three more constructs; Relations, Recursion and Rigor. According to Doll *relations* are the making of conceptual connections in science. Teaching the subject matters related to Earth Science, illustrates great overlap of science concepts and that often basic concepts are embedded into the larger matrix of the science systems being studied. Mary was asked during debriefing which of her lessons she enjoyed most. Not only did she describe a series of lessons that students liked as they had the opportunity to work together, but she also drew the connections or relations between the concepts about Fluid Earth:

The lab I enjoyed the most is a combination of items and not really a lab at all. It is however, a series of hands on activities that demonstrated point and nonpoint pollution. The students completed the Algae Addition to understand what caused algae blooms; they completed the crumpled paper lab to show how a watershed is impacted by runoff which ultimately can be a pollutant; then they completed the Great Lakes Toxins poster

which really shows how runoff leads to contamination of the Great Lakes. Finally, students used the Great Lakes profile to understand the impact of a grand drainage basin that can cover 2,200 miles. I think meshing all of these things together really drives home the point that the water cycle and human impact is global.

Doll (1993) further indicates that *recursion* or looping back to previous concepts as they are used to teach new concepts is also significant to the development of understanding in science. These two constructs, relations and recursion were explored during an interview with Mary. According to Mary teachers “cycle and cycle back again” to concepts previously covered in their lessons. She used the concept of density to illustrate her point:

The one concept I can think of in Earth science is density. Everything we've done from metrics, to fresh water, to oceans, and to plate tectonics is a process of relationships among concepts and concepts being embedded in different contexts. Density is a concept that is woven throughout the whole year.

She added:

I complete a metric measurement lab on density. The students measure the volume of 4 cubes. The problem is to see if the gold cube is really gold. The answer is in the density of the cubes measured and the true density of gold being 19.32 g/ml<sup>3</sup>. Density is used over and over again.

Mary went on to discuss four areas of the curriculum in which the concept of density is applied:

For example, freshwater that exists on the land surface is part of the water cycle. Freshwater is essential to all life on the earth. Surface water includes the streams (of all sizes, from large rivers to small creeks), ponds, lakes, reservoirs and canals (man-made lakes and streams), and freshwater wetlands. As a part of the water cycle, Earth's surface-



water bodies are generally thought of as renewable resources, although they are very dependent on other parts of the water cycle. The amount of water in rivers and lakes is always changing due to inflows and outflows. Inflows to these water bodies will be from precipitation, runoff, seepage, and tributary inflows. Outflows from lakes and rivers include evaporation, movement of water into groundwater, and withdrawals by people.

Density relates to fresh water when pollutants float in lakes, rivers, and streams. Density relates to stream load. Density relates to the water cycle because density makes the water cycle work like this: Water is denser than air in its liquid form so it collects together via gravity into bodies of water such as the oceans and lakes. Then as it is heated by the sun and evaporates, it becomes a gas and that gas is less dense than air until it rises to very high altitudes. It is cooled at which point it re-condenses and starts to become denser than air again. Once enough water vapor has condensed into clouds and the clouds move away from the source of water, the water vapor will eventually condense enough that the cloud and is denser than the air. Then water falls to earth as rain and the process starts up again.

Density also relates to the study of oceans. When teaching thermohaline (ocean) circulation and deep water currents, understanding density is essential. Some parts of the ocean turn over and others do not. This is related to temperature as well, but ultimately density is the biggest variable. When fresh water sources like the Amazon or Nile reach a salt water body it changes the density of the surrounding water. Density (salt content) determines life in the oceans too.

In plate tectonics density is also a huge concept. Mid ocean ridges form, deep sea trenches form, continents collide, plates move and create subduction zones in direct correlation to the density of the adjacent plate. Continental plates are less dense than oceanic plates. Creating earth's new crust depends on the density.

Pollution is a topic that was studied in Mary's class during several lessons and it is one of many contexts that illustrate both relations and recursion. On the point of relations, students were asked to explain the causes of algae blooms and their impact on an ecosystem. In one of the lessons, students learned that the introduction of *Nitrogen and Phosphorus* into the environment cause algae blooms to become overactive. Due to an over abundance of Nitrogen and Phosphorus, algae multiply to a harmful bloom stage. The harmful bloom stage takes oxygen away from fish which is the negative impact on the ecosystem. In a second lesson on pollution, students were asked to explain how farmers can impact the quality of fresh water. It was discovered that pesticides and fertilizers have an ill effect and when they are spread on land they run-off into water areas. This causes a negative impact on the drinking water in the environment. In a third lesson, students learned how the Great Lakes get toxins or pollutants from the air. Polluted air has a negative impact on the air that humans breathe. The conclusion drawn is that pollution is destructive and it occurs in the environmental systems of the world—air, water, and land. When studying pollution it is an integration of many sciences—chemistry, physics, biology, and earth science and the concepts of each are relational or woven together. The problem of pollution and the associated scientific concepts used to study it, occur over and over again, overlapping, and in a larger matrix make it recursive. The theme of pollution in and of itself is recursive because it happens over and over again in various forms—land, water, and air. Humans cause pollution and this became the common thread or theme that was woven,

throughout several lessons. The mistakes that humans make as they pollute, recursively impact the environment, negatively.

Doll's (1993) construct of rigor involves the complexity of uncertainty that requires students to examine a host of conceptualizations and then form critical interpretations from them. Students interact powerfully, in such a way that new, emergent, ideas develop. Each new layer of conceptualizations emerges and it is nested or resides in, the previous layer producing a more complex or multi-layered set of concepts, resulting in greater rigor.

During the focus group interview, teachers were asked if they felt that rigor was an important aspect of their lessons. One teacher responded, "Rigor to me implies that students have to work really hard. Our labs are not like that. Learning is attainable and achievable." Mary too, felt that science inquiries or labs were not set up for students to work laboriously. According to her:

The best way to look at our labs is that they are designed for success instead of being designed for students to be puzzled for long periods of time. Labs are not created for students to work through taxing problems because they're created for the student to have success and learn the concepts from the MI core curriculum.

Fieldnotes and observations support Mary's observation that lessons are attainable and achievable. The intent of the lessons was a desired result and they were planned accordingly. The lessons did not show proof of the rigor that takes place during authentic scientific investigations. Certain elements of scientific practices surfaced, such as thinking about a scientific question, or making a hypothesis, but they never rose to the level of rigor as practiced by the scientific community where students would actually have to plan a study given a scientific problem or question for investigation and carry out a detailed study by planning an experiment,

collecting data, analyzing and interpreting data, or developing a model for explanatory purposes. Theories were predetermined.

The problem of building rigor into science lessons was further explored with Mary during an interview during which she gave an example of the change needed to carry out an open-ended inquiry, with rigor:

The science labs would definitely have to change because they would require more independent thinking for our students. The labs would need to be opened ended and allow for more true inquiry to be undertaken and completed. Students would likely need additional resources or materials to get them from Point A to Point B. Instead of providing a “canned” macro-invertebrates lab, a possible lab might be for students to actually perform a water quality test on a creek near the school.

Mary also indicated that she had found an online lesson that she would like to undertake that would have rigor built into it:

The lesson includes the conceptual link to pesticides and fertilizers and their connection to the negative impact on watersheds and runoff. Students gather their own specimens. This lab includes a control group and students don't often have a chance to use a control other than when they do the science fair projects. This lab would require several days to introduce and complete.

When teachers were asked, during the focus group interview, about building rigor into science lessons, they were really being asked to elaborate on their science inquiry practices. Rigor implies that scientific practices include studying a scientific problem, asking a question,

developing a hypothesis, designing a study, doing an experiment, gathering data, creating a model from the data, analyzing it, and drawing conclusions or proposing theories from the data results. Practices would also include making revisions to the study and performing it again if needed (NRC, 2012).

During the focus group interview, Chris added some of the reasons for the lack of rigor in the middle school science classroom: “One of the problems encountered is that the students don't always want to put in the rigor, because in many cases from prior classrooms, if they complained enough teachers just gave the answers.” Other teachers agreed that sometimes it's a challenge to let students try to investigate and figure out answers to scientific problems. They realized that rigor means students would study a challenging science problem and they indicated that this does not happen.

**Classroom (SI) practices connected to Doll's (1993) construct of Story.** The construct of story is also present in Doll's (1993) interpretation of the way in which science needs to be taught in the classroom. The story of science is filled with narration or a sense of unfolding of the concepts associated with the subject matters. The story is a fine curricular complement to the scientific, analytic, rational, and logical that needs to be recognized and used by science teachers and students. These modes are of equal importance and they complement each other in building a rich science curriculum.

During one of the interviews with Mary, she was asked to contemplate the plausibility of science concepts being taught in a story context. Mary thought about Earth Science and responded:

Sure there is a story. A formation of the earth could be a story beginning, middle, and end. Probably one of the oldest stories of the universe begets the question asked by many people: “How was the earth formed?” First, by the best scientist estimates it occurred over 4 billion years ago before any life appeared. Scientists have no eyewitness accounts to use as evidence, so the best we can do to develop our knowledge, is to look at the geologic record and the stars. These will assist us in getting answers to our questions.

She added:

Although we do not have a complete picture of it, we do have a good idea and it starts with how stars are born. Stars are formed from clouds of gas in space. Scientists call these nebulas. As time passes, gravity causes the atoms of gases and space dust to come together or gather. Gases gain more mass over time and with it stronger gravity. This is a process that may take millions of years. Hydrogen fuses in a nuclear reaction and a star is formed.

Mary continued on with her knowledge of the formation of the sun:

Next, was the formation of the sun that was formed from left over gases and heavier elements. The gravity of the Sun caused these leftovers to flatten, fuse and form a disk. These were planetesimals and planetoids which in time would make up the planets. Planetesimals collided and that is how the earth was formed. That is a story!

**Classroom (SI) practices connected to Duschl and Grandy’s (2008) theoretical frameworks.** The most authentic form of thinking, essential to the scientific community is model-based reasoning because it deepens understanding of any scientific subject matter (Duschl

& Grandy, 2008). Students need to use scientific models as a means of a complete theoretical representation of a system that is not well defined. A theoretical representation includes important parts of the system, rules and relationships of parts, and it must break parts down into simpler units. This type of reasoning requires an empirical investigation that includes development of a research question about science phenomena, making observations, generating a hypothesis, designing an experiment, collecting data, managing and displaying the data, analyzing the data, drawing conclusions, and the development of a model or theory (NRC, 2012). According to Duschl et al. (2008), when using model-based reasoning, arguments include inquiry by use of data, analysis, and questioning aspects of the model. This includes claims made about the model, challenges about the coherence of model, and acceptance of alternative explanations. Discourse about the inquiry is framed by the theorized entities and properties and relationships posited in the model. If there is discontinuity between observations and theoretical perspectives, then multiple possible models with varying points of view need consideration. Scientific models are used as the means of a complete theoretical representation of a system (Duschl and Grandy, 2008).

The following Duschl and Grandy's (2008) constructs were also used to analyze the data in this study: development of research questions, generating hypotheses, designing or performing experiments, data collection, displaying data, analyzing data, use of models, and arguments based on evidence.

Table 9 (below) provides teacher responses to statements 35-46 in the survey based on the constructs of (Duschl and Grandy, 2008).

Table 9

*Scientific Inquiry Practices Related to Duschl and Grandy (2008)*

	Disagree % (1,2)	Neutral % (3)	Agree % (4,5)
35. Scientific inquiry involves observations, measurements, and interpretations.	16.7		83.3
36. Students should have opportunities to develop research questions about some science phenomena.	16.7		83.3
37. In science class students should have opportunities to make hypotheses.			100
38. In science classes students should have the opportunity to test their own hypotheses.	16.7		83.3
39. In my classes students have opportunities to design experiments based on research questions.	41.6	16.6	41.7
40. My students have opportunities to gather data and manage data.	16.6	16.7	66.7
41. In my classes students have opportunities to look for patterns in data.	8.3	25.0	66.7
42. I introduce data tables & graphs as an instructional technique to help my students learn to manage and display data.	8.3		91.7
43. In my classes students develop data tables and graphs as a means of recording and analyzing data that has been collected during SI activities.	16.7	8.3	75.0
44. When my students explain or argue their positions about natural phenomena they must use evidence (e.g., data tables, graphs, and models).	16.7	8.3	75.0
45. I give students opportunities to develop theories associated with scientific models that they have developed.	50.0	33.3	16.7



46. In my classes students revise scientific explanations and models using logic and evidence.	50.0	33.3	16.7
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As the results in table 9 indicate, 100% of the teachers felt that “in science class students should have opportunities to make hypotheses” (statement #37). The great majority (91.7%) of the teachers also indicated that they introduce data tables and graphs as an instructional technique to help students learn to manage and display data” (statement # 42). Three other survey statements received equal level of teacher agreement (83.3%): “scientific inquiry involves observations; measurements and interpretations” (statement # 35); “students should have opportunities to develop research questions about some science phenomena” (statement # 36); and “in science classes students should have the opportunity to test their own hypotheses” (statement # 38). Two other statements received significant level of teacher agreement (75%): “in my classes students develop data tables and graphs as a means of recording and analyzing data that has been collected during SI activities” (statement # 43) and “when my students explain or argue their positions about natural phenomena they must use evidence (e.g., data tables, graphs and models),” (statement # 44). The next statements that received strong teacher agreement (66.7%) included: “students have opportunities to gather data and manage data” (statement # 40) and “they have opportunities to look for patterns in data,” (statement # 41). Two statements received the least level of agreement (16.7%): “I give students opportunities to develop theories associated with scientific models that they have developed” (statement # 45) and “In my classes students revise scientific explanations and models using logic and evidence” (statement #46).

**Science inquiry practices: Generating questions.** The National Science Education Standards (NSES) (NRC, 1996, 2000, & 2012) explicitly indicate that in science students should

be generating questions of their own for research projects (Duschl and Grandy, 2008). Questions need to be empirically answerable and scientific, and they must promote investigation of natural phenomena. Fieldnotes from classroom observations, indicate that Mary did have students develop a research question that was written on the top of the PRARP form. The form has these steps: prewrite, restate, answer with two details, relate, and draw a picture. Mary placed a dry stream bed picture on the overhead projector. The water had dried up. Mary explained that the stream bed is only really very active in the spring and in the summer and the stream bed was about 3 to 4 inches deep. This would be during the rainy season or when there is snow melt occurring and it fills up again. The picture had a riverlet that was about 6 inches wide, and it had merged off of a larger stream bed. Looking around the picture on both sides of the riverlet was ice and snow. Clearly there was a change in the rock which is due to minerals that are found in the water. Mary asked, "What do you want to know about this picture?" From the picture, students did a prewriting exercise and developed scientific questions. The students were told to share their questions in the four person groups. However, the student research questions were not shared aloud in class, although Mary collected and graded the PRARP forms.

During a debriefing interview after this lesson, Mary was asked if students were ever given opportunities to share the research questions aloud and to get feedback from their classmates about their choice of question as to whether or not it was a researchable question. Mary stated, "Oh, no. We just don't have time to share all those questions. We move pretty fast!"

**Science inquiry practices: Developing and testing hypotheses.** After developing an answerable scientific question students generate and test a hypothesis (NSES) (NRC, 1996; 2000; & 2012; Duschl and Grandy, 2008). Data from classroom observations showed that

students were involved, to some extent, in hypothesis testing and sharing as indicated by the excerpt below from one of Mary's lessons during which the students did *A Short Weathering Lab*. Mary's directions were as follows:

This is a short weathering lab. You will receive a tray with (9) cubes and a shake jar on it. Look at Part 1: *Let's Shake It Up!* What do you think will happen to the 5 cubes after you shake them? Make a one or two statement hypothesis about this and share it with your partner.

During the lesson's debrief session, Mary was asked why she had asked students to share their hypotheses with their partners and whether the students would have the opportunity to share with the whole class, so that all classmates hear each other's hypotheses. Mary responded, "As you could tell, yesterday's lab was crunched for time. No! Not all classmates will hear all hypotheses. It is likely a few hypotheses will be shared orally, or they will be shared in the four person groups."

Mary had a few students read their hypotheses aloud:

Student 1: Cubes will be broken down from shaking!

Student 2: Sugar will be scraped off from the shaking!

Student 3: Shaking the cubes will cause a chemical change!

Mackenzie cleared this up and added, "there would be no chemical change because nothing reacted with the cube. It was the bumping or scraping that created the sugar crystals!"

Fieldnotes from classroom observations indicate that students wrote hypotheses in unit packets on several occasions, shared them with table partners but did not design a study related to the testing of their own personal hypotheses.

**Science inquiry practices: Collecting, analyzing and interpreting data.** Students collect, record, analyze and interpret data produced in the investigations and they will derive meaning from them (NRC, 2012). Investigations produce patterns in data that may be managed, represented and analyzed in data tables and graphs.

During the same classroom observation of the, *A Short Weathering Lab: Let's Shake it Up: Part 1*, students gathered and managed data. Fieldnotes indicate that students followed procedure Number 1, which involved getting the mass of their sugar cubes. Students used 4 triple beam balances in the back of the room and retrieved the mass, in grams, of the 5 cubes. The data table asked, "How much do your cubes weigh?" Students were reminded that the X stood for whatever the measurement was. Students then drew a cube. Students were observed placing the 5 cubes in the jar. Students then shook the jar 20 times, one, two, three and four. They dumped out all of the cubes and weighed just the cubes. Students recorded how much all 5 cubes weighed. Students drew what the cubes looked like after each increased number of shakes. Student repeated this procedure five times so that they shook the cubes a total of 100 times. Students were reminded to weigh only the cubes, not the dust.

*A Short Weathering Lab: Let's Shake it Up: Part 2* was also observed. The teacher presented the scientific question: "Does temperature and the form of the sugar change how fast the sugar cube will dissolve? Mary said, "Again, when you have your partner time you can share your hypothesis." Students went to the sink and filled beakers with 200 ml. of water. Students used a stop watch to time the melting. At the same time, students dropped in a crushed cube and a whole cube. They watched them dissolve and wrote down the time. The second time students had 2 beakers; a cold beaker and a hot beaker. Students dropped in whole cubes and measured the time it took the cubes to dissolve. Students were once again reminded to weigh, draw, and

shake and they were also reminded that they should have already had an idea about this. Mary asked, “In what type of climate does weathering occur more rapidly?” The connection is warm weather causes erosion more quickly.

During the analysis of the data students determined that as they continued to draw the cube, the size of the cube was reduced. Mary asked, “What else can you generalize about the cubes?” Alleija responded, “Mass decreased with each consecutive measurement.” Mackenzie stated, “This was a physical change.”

Mary discussed the fact that when students wrote hypotheses, temperature was also considered as a variable. She asked students to state some of the temperature related hypotheses:

Sara: “Warmer or cooler will make it quicker or slower.”

Shawn: “Hot water will dissolve it faster.”

Mary indicated that many students chose the variable of temperature for their hypotheses. She asked the class, “What does form mean?”

John: Crushed cubes will dissolve faster!

Mary probed by stating that the crushed form is different and she asked the students to think of a math word to describe the forms: crushed or solid.

Shawn: “Mass!”

Mary clarified with further questions: “Is the mass the same for crushed and solid cubes? If I have a quart of milk in my hand and it is dropped on the ground, what is the difference? It is

surface area. Write down surface area. The crushed cubes had more surface area and will weather more quickly than the solid.

Students concluded that warm water caused the cubes to dissolve more quickly.

Students had other opportunities to collect, analyze and draw conclusions from data. For example an experiment on erosion called *Shrinking Rocks*, Smartie candies were placed in the students' mouths three times following these steps: (1) no movement for action (2) tumbled for action and (3) bite and then tumble for action. These actions were timed to see how long it took for the Smarties to dissolve in each instance. Students timed how long it took for Smarties to dissolve and data was recorded on a table and then transferred into a graph. At the end of the experiment they analyzed their results and drew conclusions using the data they had collected.

Mary also used other approaches to involve her students in data analysis. In an assignment called *Global Water Distribution* students were given three tables with percentages of distribution sources of water for each: Earth's Water, Fresh Water, and Surface Water. Students were asked to create a pie chart or bar graph for each that included a title, legend and data labels. In this case, students were not responsible for gathering this data.

Mary used several other assignments that gave students the opportunity to gather data, manage data and look for patterns in the data (Duschl and Grandy, 2008). Mary assigned *Strawberry Creek Stream Monitoring Lab* to determine the quality of water in a town. Students examined, via a website, the macroinvertebrates sensitivity to pollution in a water sample. Students generated tables by using the *Stream Data Collection Form and a Biodiversity Table*. Students had to identify specimens from the creek, record macroinvertebrate data, and determine the water quality rating for the sample stream by using three index values: sensitive, somewhat

sensitive, and tolerant for the rating scale. The assignment is an example of an empirical investigation and the collection of evidence in order to draw conclusions related to a real work situation (water quality).

**Science inquiry practices: Developing models.** Data from classroom observations indicate that Mary used models in various ways. She used several prepared models to explore, explain and argue science concepts. For example, in one of the lessons, Mary used a model called *Crumpled Paper: Watershed* and the following questions to help students understand the connection between the parts of the model and the phenomena it represented:

1. What does the paper represent? Answer: A watershed.
2. What does the dropper represent? Answer: Rain—Precipitation.
3. What does the water that runs down the creases represent? Answer: Runoff.
4. What does the brown ink represent? Answer: Dirt, exposed soil, and erosion.
5. What causes water to flow in a certain direction? Answer: Gravity, elevation, ridges and slope.
6. How does the red marker affect the water around the area? Answer: The red color is the contaminant or pollutant and it is harmful.
7. Where does water tend to accumulate? Answer: On the flat points.

*The Stream Table Lab* assignment was another example of use of a scientific model to represent natural phenomena. Using a graduated cylinder, students poured water over sand with several variations to create a model of young, mature and old rivers. Students were asked to demonstrate and explain each of the rivers. According to fieldnotes, there are three stages of stream development: young, mature and old. The young river is narrow, v-shaped, has steep

sides, pot holes, no flood plains, and has prominent erosion and deposition. A waterfall is a good example of a young river. A mature river is an in-between stage, u-shaped, has a narrow flood plain, displays lateral erosion, and is near a hilly landscape. This river is great for canoeing. The old river has a broad u-shape, a shallow gradient, is wider than deep, meanders or has a curved shape, has deltas and moves small sediments.

Mary also used conceptual models for teacher demonstration purposes for three separate assignments. She used a chart of the *Great Lakes Water System Profile*. The system profile included depth and elevation of Lake Superior, St. Mary's River, St. Claire River, Lake Michigan, Detroit River, Lake Erie, Niagara River, Niagara Falls, Lake Ontario, St. Lawrence River, Gulf on St. Lawrence, and Atlantic Ocean. In another assignment, Mary used a Venn diagram illustrating *Deltas and Alluvial Fans of the Amazon River*. Students learned that deltas form from water moving over land and alluvial fans are formed from water moving down mountains depositing sediment over land. Both deltas and Alluvial fans are formed from moving water. A Venn diagrams was used for the instruction on *Point and Non-Point Pollutants*. Point source pollution flows from pipes, industrial plants, sewage treatments, and storm water drains. Nonpoint source pollution comes from construction sites, lakeshores, crops, plowed fields, and parking lots. Both are sources of water pollution.

During debriefing, Mary was asked to reflect on her lessons and to elaborate on the ways in which they illustrated the elements of scientific inquiry as suggested by Duschl and Grandy (2008). Mary used the following lessons as best examples, illustrating elements of scientific inquiry:



The *Shake It Up Lab* was also on weathering. Students completed all steps of the inquiry process. They began with a problem, made a hypothesis, followed a procedure for experimentation, and made personal observation that analyzed results of erosion on the sugar cubes. The observations were noted in word and drawing form. Students wrote full conclusions stating the problem, restating the hypothesis, summarizing the experiment, noted their evidence, and discussed possible errors.

In a second *Weathering Lab (2)* the students followed portions of scientific inquiry procedures. Students hypothesized how long it would take the Smartie candies to dissolve for three different problem sets. After completing the procedures, students created a data table to record their findings. This lab did not have a conclusion report.

Most recently, the students completed a *Crinkled Paper Lab: Demonstration of a Watershed*. They completed the experiment and procedural portion of the lab with partners, made observations and responded to questions. Again a formal conclusion was not used.

Mary also shared:

I believe my students have many discussions, information gathering opportunities, and opportunities to generate a hypothesis, and create tables even when it is not part of a full lab with full procedures. Even these small activities contribute to the students' understandings of the inquiry process.

## **Development of Teachers' Understandings and Skills Related to Teaching Science as**

### **Inquiry: School District's Role**

Data on the role that the district played in the development of teacher's knowledge and skills related to teaching science as inquiry was obtained from an interview with the district's math and science coordinator, a focus group interview with the teachers, and four statements in the survey.

**School district's math and science coordinator responsibilities.** Jonathan is the math and science coordinator for the district and his role has been referred to as "HERO SUPPORT". Hero support means that the math and science coordinator is expected to do anything that may help math and science teachers perform their duties in the classroom. To this end, Jonathan attends the necessary meetings, gathers new information, brings trends back to the district, and disseminates information to the administration and teachers. Jonathan also oversees alterations, variations, or modifications to the curriculum and he facilitates meetings by working alongside the teachers. He assists in making improvements in the curriculum and provides teachers with teaching tools to enhance their performance for teaching science as inquiry. Jonathan's focus is always on ensuring that teachers teach the core standards successfully and that there is an increase in student achievement. In Jonathan's words, "I am the conduit that brings changes and innovations to the district and fosters the ongoing development of quality science instruction for students."

**District math and science coordinator preparation.** Jonathan's path to a secondary teaching certificate was the results of his experience teaching a college level calculus class while pursuing an engineering degree at one of the local research universities. According to Jonathan, "I fell in love with teaching, received a teaching endorsement, and changed my major to math

and minor to physics.” After teaching mathematics in the district for 9 years, and undergoing two-year leadership training, he became the district’s math and science coordinator in 2012. In addition to his 9 years of experience as a mathematics teacher and leadership training. Jonathan mentioned a number of other activities that have contributed to his development as a district curriculum coordinator, in particular, three curriculum groups in the three county-wide area, organized by the county’s Intermediate School District’s Director of Science Instruction. The purpose of the meetings was to advise educators on the delivery of instruction and meeting needs of K-12 students’ learning in math and science. The three groups include: (1) *Science Leaders Network*, (2) *St. Claire Science, Technology, Engineering and Mathematics (STEM) Hub*, and (3) *Project Lead the Way (PLTW)*. These groups’ meetings are all day pull-outs and districts that do not have a math and science coordinator send one to two teachers to learn the dynamics of curriculum development and then disseminate the information to their respective districts. In the past Caseland School District sent a few teachers from each grade span to the meetings, in addition to the curriculum coordinator. However, because of budget cuts in the past two years, teachers no longer are able to attend meetings. In addition to the three county wide meetings, Jonathan also attends the annual conference of the Michigan Science Teachers’ Association (MSTA), which he feels has been an invaluable resource to his education as a science leader.

**Science Leaders Network.** The *Science Leaders Network* consists of sessions designated by grade levels K-5, 6-8 and 9-12. The sessions are designed to meet specific needs and interests of science educators in these grade spans and include content-specific topics such as, curriculum alignment, assessment, classroom modeling, and analysis of student writing, technology integration, and lab classroom facilitation. At this time, Jonathan is the sole

representative from his district at these meetings which greatly decreases the effectiveness of his work as a science curriculum leader:

I attend *Science Leaders Network* grade level sessions for science when possible, but I am also responsible for attending math sessions. Additionally, I am responsible for planning professional development for math and science in the district. PD planning and conducting the training itself, takes up a fair amount of time particularly because I am being pulled in two directions: math and science. Sometimes, I can't attend all three of the grade level sessions offered by the *Science Leaders Network* and they are quite involved. For example, each session is specifically geared toward a grade level span such as K-5 math and what they need. Occasionally, I am asked to facilitate one of those meetings which also requires planning and presentation time on my part. Each time I am working on one grade level span, it takes time away from other grade level spans and from additional meetings that I could be attending. The problem is compounded because I am trying to cover two content areas: both math and science.

**St. Claire Science, Technology, Engineering, and Mathematics (STEM) Hub.** The St. Claire Science, Technology, Engineering, and Mathematics (STEM) Hub meetings are led by a cohort of teachers from the Intermediate School District (ISD) level, local colleges, high school, and middle school levels. During the interview, Jonathan explained that he has just begun attending these meetings and stated that participating in such meetings is essential because science education is constantly changing which requires educators to be up to speed on relevant innovations in the field. As the math and science coordinator for the district, Jonathan helps “build bridges or make connections between the old way of doing things and the newer

methods of teaching science”. Jonathan explained the importance of the STEM Hub meetings with the following comments:

STEM is the predominant concern now in science education! It is huge! The Next Generation Science Standards (NGSS) are expected to be adopted by the Michigan State Board of Education this year. The adoption has been postponed to allow for the legislative issues surrounding the Common Core to be settled. This year, I will be trying to bring more STEM type lesson activities into the curriculum to address *science as inquiry*. Project based learning and meeting the demands of (NGSS), is what we will be working on soon. I am just getting involved with STEM now, and I will soon find out what direction to take to deal with STEM standards.

**Project Lead the Way (PLTW).** Project Lead the Way (PLTW) is ranked as a world-class curriculum and high-quality teacher professional development model. It involves a network of engaged educators and community representatives interested in having students develop the necessary skills to succeed in a global economy. PLTW is present in some way in all 50 states and has a focused approach to help students develop critical thinking skills, through project-based learning. Although Jonathan had just recently become involved in STEM and Project Lead the Way he had a clear understanding of its value:

PLTW involves student collaboration. It is research and evidence based. It follows the Understanding by Design approach to develop a cohesive and coherent instructional path for students of science (McTighe and Wiggins, 2004). It is problem-based and uses activity, project, and problem based experiences to prepare students to solve problems. It

creates scaffolding for student learning and provides the *rigor* and relevance that is designed to engage and empower the students as they practice science inquiries.

Jonathan added:

PLTW is out in the forefront of concerns about science education and it runs along-side STEM issues. PLTW courses that are offered to teachers are aligned with Common Core State Standards in math, English Language Arts, and the Next Generation Science Standards. It appears that all teachers involved with PLTW will complete a two-week training session for each PLTW class and at that point, they will be prepared to teach students in the classroom with STEM standards in place. By attending these meetings and finding out what other coordinators are doing in their work related to STEM, I will be provided with a wealth of resources from all over the state that will be brought back to the district. The breakout sessions that take place involve the work of many districts and I learn about what they are doing. This helps me and gives me numerous ideas related to my job!

According to Jonathan the PLWT Gateway program is for middle school science teachers and it is divided into eight, nine-week independent units, for 45 minute class periods, taught in conjunction with a rigorous academic curriculum. Some of the topics explored include robotics, flight and space, and DNA crime scene analysis. There are three phases of training for science teachers: (1) Readiness Training focuses on preparation of teachers' basic technical and content knowledge (2) Core Training focuses on building STEM education, activity, project and problem-based learning as it relates to instruction and unit specific STEM content, and (3) ongoing training consists of on-line learning resources.

**Science and math coordinator's understanding of scientific inquiry.** During the interview, Jonathan was asked to explain his understanding of scientific inquiry, given the important role he plays in the planning of professional development activities related to this topic. Jonathan began his explanation stating:

One thing that's important is that the old way of teaching the scientific inquiry processes is not true. The old way of looking at SI is that it was a very linear approach. I don't think it is a linear approach with locked steps. That's not the way it works because scientists don't work like that. At any step along the way, scientists can spiral back to a previous step.

He added:

The new STEM standards will be integrated into the science standards and SI will be a brand new approach. Performance based standards, such as these, are going to adjust how we teach a science curriculum. Teachers are going to expect students to be able to demonstrate their understanding of science inquiry. For the inquiry, teachers will give students a problem and give them some background on the problem. Teachers might lead students into searching for background information on their own about a particular concept. Students will pose a hypothesis as to what they think is going to happen in a study. Teachers will then let students design an approach or create a model illustrating how they would solve the problem. Students design an experiment and test out their hypotheses. The model will help students explain their theory of what is going on during the experiment.

Jonathan continued:

I think we need to get our students communicating with each other, collaborating in teams, and doing less as individuals because scientists don't work alone. They work in groups. I think that we need to teach students to work on global type problems that affect a larger population, because now days, problems are much bigger than dealing with local issues. In today's world, there are many teams working together on the same problem or project.

Part of the inquiry process is being able to answer a question by communicating with others, sharing ideas, and using all the technology that we have even at the most basic level. Maybe it is as simple as reading a Google document and sharing the information or your results that you found. Designing a study is a key aspect of science inquiry. Students need to develop an experiment from the hypothesis to test it out. They must do whatever need to be done in the study to determine if the hypothesis is correct. Students have to be able to identify flaws in their design plans. If something isn't right, students need to go back to the drawing board and adjust their thinking. We have to teach students that it is alright to adjust a hypothesis if it is not efficient and does not fit the study. Students can run the study again. Then they can draw conclusions once everything fits.

Jonathan's response indicated an understanding that classrooms are highly specialized communities, and classroom interactions of the community form the process of curriculum. Experience is not a private affair but needs to be reconstructed or transformed via public interaction and this is precisely what Duschl and Grandy (2008) meant by epistemology in science education. The integrity of a theoretical position has been and will always be that which comes from having a dialogue with other scientists to find out whether or not there is consensus



of opinion or to find out if one is correct in one's thinking (Doll, 1993). Knowledge begins with the thinking of the individual, but one must present ideas to others, through dialogue, to find out whether one is right (Holton, 2005). Jonathan's comments also clearly indicated an understanding that students need to have opportunities to adjust their original plans if necessary. This signifies the concept of "chaos" and the nonlinear aspects of science inquiries. Students will be forced to reexamine a problem situation and recognize the need for changing plans. A study may have to be reorganized or redesigned to fit the research problem or question and this is what Doll (1993) meant by the occurrence of perturbations during the learning process. When Jonathan indicated that students "must do whatever needs to be in the study to determine if the hypothesis is correct" is exactly what Doll (1993) meant by "currere" or running the course until the problem is solved.

**Curriculum development process at Caseland School District and its connection to SI.** According to Jonathan, the Advisory Curriculum Council (ACC) is the governing body for curriculum and instruction in the Caseland School District. The ACC has been in action since its inception in 1993, and has undergone minor adjustments or modifications, but ACC remains the primary source of all decisions that pertain to curriculum and instructional planning in this district. ACC is a highly structured set of curriculum planning processes that include school improvement measures and professional development strategies for teachers. The administration believes that ACC and the School Improvement processes drive both professional development for science teachers in the district as well as controlling how time is spent during professional learning communities. Teachers are provided little deviation from the structures of ACC and the School Improvement processes in their professional development.

The Advisory Curriculum Council, (ACC) is comprised of teachers, from all grade levels and all subject areas, school board members, all curriculum coordinators, and the assistant superintendent of curriculum and personnel. The council is chaired by a teacher and one of the curriculum coordinators, on a rotational basis, who oversee and conduct the meetings. Curriculum development in each grade span (e.g., middle school science) includes Phases 1-7, one phase of curriculum planning at a time, although groups may span various grade levels when needed.

Jonathan explained that K-6 science is one large group, but they have 7 different curriculum maps used in curriculum development. *Understanding by Design (UBD)*, by McTighe and Wiggins (2004) was the genesis for the development of the curriculum map used by the district. The curriculum map also dictates what teachers will work on during professional development. Each group starts with Phase I as the teachers develop their curriculum from the big ideas of the core science standards, followed by a set of unit course essential questions and essential understandings (McTighe and Wiggins, 2004). Teachers simultaneously look at the common core standards and develop “ICAN” statements which are based on student understandings and skills. This is the first phase of curriculum design and it is the basis for any future lesson plans pertaining to science as inquiry. Teachers participate in professional development sessions to examine what they have to teach and to organize content into units. Phase I and Phase II of curriculum development are closely tied together; it is usually a two year process; and these phases are the foundation from which any science inquiries may be built because they demonstrate understanding of the principles of the science content being taught. Jonathan explained the process:

Teachers are represented by a curriculum coordinator, such as me, whose responsibility is to present the work that teachers have done from Phases I and II, to ACC. ACC and the science coordinator go through the Phase I and II information and determine if it is approved. It will be approved if content has been coherently organized into units and the units demonstrate a sound understanding of the basic principles of the content being taught. If not, ACC will recommend that revisions be made by the group that submitted it. The group would make revisions and send it back to ACC for a second review. Phases I and II must be in place and show, in this case, coherence in science subject matters before moving on to the next phase.

According to Jonathan, once all revisions have been made in Phases I and II and approved, the process moves on to Phase III. Phase III is a cost and purchasing phase and includes non-consumables such as textbooks, technology, equipment, supplies and other related materials.

During the focus group interview the teachers pointed out that ACC's Phase III procedure used for purchasing materials for instruction does not always work for teachers. The Phase III budget ranges from \$20,000 to \$40,000 spread out over eight years which means that teachers buy materials every eight years. The teachers would prefer that the district make installments throughout the year or every couple of years.

According to one of the teachers, Chris:

Teachers are kind of between a rock and a hard spot. The problem is that you have to buy everything all at once. If you forgot something you are in trouble. Exactly! Then you are stuck because the money is gone and you can't make the necessary changes that

crop up! Purchasing one time over eight years is difficult versus distributing money over time.

Mary added:

Books are a huge cost taken from the budget for Phase III planning. Books absorb most of the money. In addition to the Phase III budget, there is a small annual budget. It is about \$200.00-\$300.00 per year, per room, if we are lucky. That is not a big chunk of change!

Teachers also recognized that curricula change when state content standards change, which leads to necessary adjustments. Furthermore, adjustments are most disruptive when Phase III has just been completed because the money has already been spent on materials such as textbooks, which might now be obsolete. New content might require new science experiments and labs, which might require new supplies for which there is no longer money.

Sometimes the budget also gets cut midstream during curriculum planning as stated by Chris:

A problem occurred when we were beginning to plan Earth Science Units. We were in the beginning stages of planning in the first year of teaching Earth Science when we had to figure out how to spend our money. This occurred before the curriculum became solid. Suddenly, our budget was cut and we did not get to spend the money on anything.

By Phase IV a discussion has already taken place about what teachers need to teach based on core curriculum UBD (McTighe and Wiggins, 2004). Now, the district must determine if students comprehend what they are being taught. Therefore, Phase IV focuses on assessment.

Teachers create formative assessments to determine whether students are understanding information along the path of learning and summative assessments at the end of units of instruction. Although teachers have some freedom in planning formative assessments, they are required to have common unit summative assessments. During Phase IV, which is spread out over a period of two years, teachers have the time, through professional development, to create performance based assessments together.

Both teachers and the science coordinator commented on the benefits of planning common summative assessments:

I think there are some assessment tools that come out of ACC meetings that are beneficial. Teachers need to administer assessments in order to find out what the students have learned. During this phase, we have to analyze the assessment tools to see if they are working for us. This aspect of ACC is good and probably necessary because it allows for adjustments in what we are teaching and what the students are learning. Our assessments prepare the students for state assessments.

Jonathan indicated that teachers' assessments need to be connected to state assessments particularly because of the ACC School Improvement objective which states that by 2013-14: 38% of the students will demonstrate proficiency in state assessments.

By Phase V, teachers have talked about what students have to know and how teachers are going to determine if they know it. Phase V focuses on lesson planning and the pedagogical approaches that will be used to teach the material. In this phase, teachers work together during professional development to determine instructional practices that are most appropriate to help students develop the understandings and skills that will be assessed. According to Jonathan,

“This is also an opportunity for teachers to plan some of these ‘scientific inquiry based approaches’ that will be coming along with STEM standards.”

In Phase VI of curriculum development teachers formulate and examine a Depth of Knowledge (DOK) Levels Matrix that was developed by Norman Webb (2006), from the University of Wisconsin. Teachers received professional development on the DOK Levels matrix, which includes Learning Styles: (Verbal/Linguistic, Visual/Spatial, and Bodily/Kinesthetic) and Depth of Knowledge: Levels: I (Recall), II (Skill/Concept), III (Strategic Thinking) and IV (Extended Thinking). Under each of the levels, action verbs associated with student performance are listed and teachers are to incorporate them into their science lessons as described by Jonathan:

Level One (Recall) involves these skills: recite, recall, repeat, tell, state, calculate, define, draw, identify, memorize, list, label, illustrate, measure, report, tabulate, use, quote and match. During PD time, teachers planned how to incorporate opportunities for students to become adept with these skills because they are needed to conduct empirically based science inquiry studies. Level Two (Skill/Concept) involves a different set of skills: classify, relate, graph, cause and effect, make observations, collect and display, identify patterns, construct, predict, interpret, and summarize. Also during PD time, teachers planned scientific inquiry activities that revolve around these practices. PD time has been spent on Level Three (Strategic Thinking) planning of lessons for students that will have them: formulate; critique, develop a logical argument, use evidence, investigate, compare, construct, assess and draw conclusions. These practices are aligned with NRC standards; are used by scientists to develop models to explain conceptualizations; and students must learn to use them during science inquiries. Teachers planned during PD

time, Level Four (Extended Thinking) strategies that would be incorporated into science inquiry lessons and they involve: Design, connect, synthesize, apply concepts, critique, analyze, create, and prove. Here, teachers will plan projects during professional development that require students to specify a problem, design and conduct an experiment, analyze data, and report to their science classmates.

Planning of science lessons during professional development opportunities is focused on whether or not teachers' instruction will support students' learning in such a way that they will be able to demonstrate their understandings at the various cognitive levels. The DOK Matrix allows the district to determine if there is a good balance of learning experiences for students. As Jonathan pointed out:

Teachers need time to sit down, during professional development, and look at all the things that they are doing in the class and determine what is needed or missing. Are students calculating, identifying patterns, investigating, hypothesizing, or designing in any of the science activities? Do the learning experiences meet the needs of the students and are they spread out over all the levels on the matrix?

**Professional development opportunities for teachers.** Professional Development is an essential tool designed to address the needs of teachers by providing opportunities for them to build their knowledge of science practices. Like students, teachers need to view learning as a lifelong process because ongoing scientific research leads to continuing changes in our understanding of the world. An understanding of inquiry is vital for understanding of how science is done and what conclusions can be drawn from scientific studies.

Four statements in the survey were used to gauge teachers' perspectives on the level of professional development and support related to teaching science as inquiry provided by the school district.

Table 10

*School District's Role in the Development of Understanding and Skills Related to Teaching Science as Inquiry*

	Disagree % (1,2)	Neutral % (3)	Agree % (4,5)
27. My school district has provided good professional development related to teaching science using inquiry.	66.7	25.0	8.3%
28. My school district provides the necessary resources for teaching science using inquiry.	25.0	41.7	33.3
29. My school administration encourages science teachers to use the best methods for teaching science.	16.7	8.3	66.7
30. My school administration encourage teachers to work together to plan creative lessons.	25.0	8.3	66.7

As indicated in Table 10, although most of the teachers (66.7%) felt that their school administration encouraged them to use the best methods for teaching science and to work together in the development of science lessons (statements 29 & 30), they also felt that the school district has provided little professional development and resources for teaching science as inquiry (statements 27 & 28).

Furthermore, even though teachers have some professional development opportunities during some of the phases related to the district's curriculum development approach, these may



not be sufficient, particularly as it relates to teaching science as inquiry. Indeed, according to the teachers, professional development in the district focuses on three areas: ACC phase work; School Improvement; and the DOK Matrix. Teachers felt that too much time is spent on these three areas and more time needs to be allotted for professional learning communities that allow teachers to plan science inquiries. The quotes below from the focus group interview illustrate their frustration with the lack of professional development:

The total amount of time we're spending on ACC phase work is unnecessary and we just found out that our curriculum is going to be changing again! Of course, all units, lessons and assessments have to be changed. It's kind of heart wrenching for us to think that we poured so much time and effort into planning curriculum units and lessons that might be obsolete!

What's happened is that there is a shift now in what we do during workshops, inservices and professional learning communities. Instead of teachers having time to change our science curriculum and actually discuss it with high school teachers, or elementary teachers we do phase work. The time for sharing is gone!

Most of our time during PLC's is put into the ACC phase work rather than planning hands-on activities, minds-on activities, or inquiries for science. We're just spending 90% of our time doing phase work rather than using the time to communicate with colleagues about our experiences of teaching science. Communication and sharing is where the rubber meets the road! I think communicating is what affects my teaching abilities and students' learning.

Personally, I think because the district does of all this phase work, there is a problem in the district. I understand why the district's doing the phase work but I don't agree with the amount of time spent on it.

When the teachers were asked about what they knew related to STEM standards, one of them replied, "Nothing" and added:

I would say I have received nothing from the district in terms of training on STEM. Short of my methods classes, which were 20 years ago, I don't feel that we have had any real science training, lately. About 3 years ago, we did something called Michigan Education Environmental Curriculum (MEEC). Again, that was two or three years ago. Michigan Education Environmental Curriculum was offered by Cranbrook. They had their own curriculum and we went over it with them. I would say we have had a couple of conferences.

Josi added, "We went to a *Metropolitan Detroit Science Teachers Association* (MDSTA) and it was focused on science."

Chris explained:

We went to Oakland Schools for a visitation last year. It was more of a field trip rather than training and we got some hands on activity ideas. It did not teach us how to present the activities in the classroom. Basically, it was a presentation on a way of teaching plate tectonics by having zero knowledge. They presented a few strategies that could be used in the science classroom such as starting a study by having students look at a poster. Then eventually students would look for trends. Next, students would report back to the group

so they were teaching one another. The teacher acted as a facilitator or guide on the side. I felt like that was really inquiry, but not really all the elements of inquiry.

Jodi clarified:

We also had a little instruction on *Solid Earth*. It was presented by a man named Mike Gallagher, the coordinator for science at Oakland Schools. That was three or four years ago. We have not had anything recently.

Notes from a debriefing session with Mary confirm the lack of professional development activities that teachers have had:

I have been in the science department for five years. I have never been sent to or received ANY training related to teaching science as inquiry. The district has not sent any of the current 8<sup>th</sup> grade teachers for training. 8<sup>th</sup> grade teachers have attended MAMSE for middle school teachers for week-end break-out sessions and they were not related to science.

The teachers also spoke about the lack of sharing opportunities or what they call “common core time.” In the past, teachers were given a day and sometimes a week to get together with the science department during which they shared their practices, engaged in valuable discussion and planning time. In their opinion, departmental meeting time was a “true professional learning community” and it helped everyone with their understanding and practices of how to teach science as inquiry. The teachers gave examples of how lack of departmental planning time and lack of communication with colleagues has affected the curriculum:

We now have students in 8<sup>th</sup> grade that study some topics that piggyback onto 7th grade. In 8<sup>th</sup> grade we're supposed to go more in depth with the topics. Our curriculum in 8th grade changed before 7th grade, so there was a year or two gap where we could not go into greater depth with 7<sup>th</sup> grade subject matter. So now we have students coming in 8th grade saying you know what, we did this last year.

6<sup>th</sup> grade has tons of concepts from our curriculum, but I don't even know how they teach it. I can't even name one of the teachers that teach it! If we had set meetings in place all the time, then this would have come out and the 8<sup>th</sup> grade would have understood what 7<sup>th</sup> grade was doing. Then we could move on to something else.

We need meetings where we can actually talk to other grade level science teachers and at least have discussions about what they've done. Then we can bring those topics up in our class, review what the teachers have done with the topics, see what students remember and go from there. We could plan labs around that information or fill in the gaps if needed. We're so swamped with the other things, like phase work, that finding out what's been done just doesn't happen.

These statements indicate that science teachers welcome more professional training related to science teaching practices in the form of workshops, inservices, and as professional learning communities. According to the teachers the professional learning communities are designed to build a culture of collaboration among teachers -- share values and vision, collective learning, and shared practice among teacher colleagues.

During the interview, Jonathan was asked to elucidate on the types of professional development activities or workshops planned for science teachers. He explained that (2012-

2013) was his first year as the math and science coordinator for the district and that *there was little professional development done related to science education*. He stated that the most important reason for the delay was uncertainty connected to the Michigan Board of Educations' adoption of the Next Generation Science Standards (NGSS):

NGSS were postponed to allow for the legislative issues surrounding the Common Core to be settled. For that reason, science did not move forward in (2012-2013) in this district. The district kept the status quo and kept doing what they were doing.

According to Jonathan part of the math and science coordinator's training has been to assess what is needed and he plans to move forward with the development of after-school professional development opportunities for science teachers. According to him, he looks forward to:

Creating PD on the literacy and science standards for Common Core, Next Generation Science Standards rollout, Science Technology Engineering & Mathematics type ideas, science as inquiry, or the science practices. Professional development will be the avenue I will use to get the updated information to the teachers and to ensure that they get training where needed. Also, science professional development may be part of the school improvement process because science improvement and science scores is part of our school improvement plan. The goal is that 38% of all Caseland students will demonstrate proficiency by (2014-2015) as measured by the state science assessment. In March (2014), I'm going to do a professional development at one of our elementary schools on STEM and talk about the paradigm shift that has to take place in teaching science as

inquiry. One building at a time, I'm going to show teachers how we can start embedding SI within our curriculum.

However, because of budget cuts, the district is limited in how many teachers they can send to activities such as conferences:

There is district cost when it comes to planning professional development for teachers; conference registration fees for teachers in the district must be paid; teachers' daily rate of pay must be paid during the conference period; and substitute teachers must be paid. The administration would prefer to pay teachers a regular curriculum hourly wage to attend the professional development after school. If we pay teachers, that is their incentive to come. This too can be difficult because at that point, it's not a required professional development that teachers must attend.

Jonathan also realized the after school demands that teachers already face:

Teachers are already being asked to participate in trainings after school for the other content areas in English, Social Studies, and Math. You're not going to get teachers to come every day after school, in addition to grading papers, conferencing with parents and performing other teaching responsibilities. It's not only the budget cuts that affect the training process, but it's the amount of time and the amount of workload that teachers already face that makes it a challenge. We have to be careful, because you cannot get credit for a training topic twice. In other words, a training session can't be used for both professional development credit and continuing education.

**Barriers to teaching science as inquiry.** During the interview with Jonathan and the focus group interview with teachers, they were asked to discuss some of the reasons for teachers' reluctance related to teaching science as inquiry. Their answers revealed four reasons: (1) concern over coverage of science content material (2) loss of control over what students learn (3) apprehension about standardized test results and (4) impact on teacher evaluation. Jonathan explained:

There is a false perception in the district, among teachers that we have to cover material and our district is working very diligently to get away from this idea. Teaching is so much more than covering material. It is really not what you teach, but it is what the students learn that counts.

During the focus group interview, teachers expressed concern over staying on a timeline with course content:

We want to make sure we get through the science material in the curriculum. There is a testing schedule that we have to stay on. Common assessments are given on the same day at the same time. If we don't get through the material the students can't pass the tests.

The expectation is that all science teachers at a grade level, both 7<sup>th</sup> and 8<sup>th</sup> grade, will teach the same subject matters at the same time and be prepared to have students take their common assessments. One teacher commented, "Let's face it! We're rushed to get through everything, because we have midterms and a final common assessment at the end of the year!"

Teachers also reiterated, more than once, that test results have an impact on teacher evaluations:

We are evaluated on test scores! We do have to get through the material because it impacts the outcome on the assessments. The evaluation piece is a threatening document! You have to show student growth! If you can't document your students' growth and learning on assessments, then you are in a threatening position. Two teachers lost their jobs because of lack of student growth.

Jonathan was aware of these concerns:

The district is also driven by common assessments and standardized tests whether the tests are accurate or not. Even though the tests may not truly reflect what students understand or even if they are not an indication of how students will perform in the real world, their hands are tied because school funding is still driven by standardized tests. Confounding the issue is that teacher evaluation now is driven by test scores. If a teacher cannot show gain or improvement in the test scores of their students they may very well lose their jobs.

Teachers' loss of control was another issue that Jonathan attributed teachers' reluctance to teaching science as inquiry:

Whenever you put students into inquiry or exploratory learning, you are relinquishing control and who is responsible for that learning experience. I think the teacher's perception is that when you start letting a student explore and dive into their learning, you really don't know what they're getting out of it. The teacher does not feel in control. You can, however determine what the outcome is with formative assessment and so on. The information that students receive is all driven by the teachers. It really is.

He added:



Even though new teachers are fresh out of college and we expect they have all these great and fresh ideas they don't. They are still apprehensive about trying out or stepping out of the boundaries of the textbook. They are comfortable with textbooks because the theories have already been proven. To deviate from the text, means you run the risk of your students not doing as well on standardized tests.

## CHAPTER 5

### DISCUSSION, CONCLUSION AND IMPLICATIONS

This chapter provides a discussion of the results presented in the previous chapter and their implications. The discussion that follows is organized around the three research questions that frame the study.

#### Sources of Teachers' Knowledge and Skills Related to Teaching Science as Inquiry

The results of this study indicate that for most of the teachers, science content courses, experimenting on their own, and attending workshops were the three leading sources of personal knowledge and skills related to teaching science as inquiry. Interestingly, only 50% of them felt that science methods courses had played any role in this area. Moreover, the teachers also felt that student teaching experiences were the most important aspect of their teacher preparation in terms of helping them in the development of their teaching abilities. As one of them pointed out, "My personal experience as a science teacher has led me to understand that you can learn philosophy all you want, but you have got to be in there, practicing in the classroom to know what you are doing!"

This teacher's comment exemplifies the need for teacher preparation programs to develop close links between the theories discussed in university courses to the practices in their students' field experiences. Barksdale-Ladd and Rose (1997) indicated that linking coursework and practices should be a long-standing goal for teacher education programs and Merrill (2002) stressed that learning is promoted when knowledge is applied and integrated in the real world. According to Merrill, "most instructional design theories advocate application of knowledge and skill as a necessary condition for effective learning" (p. 6). Others point out that learning is

enhanced when teacher candidates are provided with multiple opportunities to apply what they have learned in meaningful contexts (Gagne, 1985; Gardner, 1999; Perkins & Unger, 1999). As a result, teacher candidates must be provided with increased opportunities to successfully apply what they are learning in their university courses within the context of the classroom (Hillman, Bottomley, Raisner & Malin, 2000). This approach requires university faculty to collaborate with one another and with their school partners to purposefully integrate course content and experiences within the practicum setting as well as across relevant courses (Hillman et al., 2000).

As established in the literature review for this study, “scientific inquiry” must be considered as a science content topic. When science is taught using inquiry, scientific knowledge is linked with science processes. If the process begins with students developing scientific questions about natural phenomena that is based on conceptual principles and knowledge and they use the information to guide scientific inquiries, then teachers must learn how to do this in their science courses. If students are expected to know how to use a team approach, be actively involved with key concepts within the content subject matter, and collect and use evidence that justifies answers to the questions they investigated, then teachers must develop these skills in their courses. If students are asked to obtain and provide both historical and current perspectives of content knowledge and be able to provide clear interpretations of the data that they have collected, then teachers must have practice doing this in their coursework. Clearly, this means deemphasizing the memorization of technical vocabulary in science courses and providing teachers with opportunities to learn how to conduct inquiries in the science classroom that link theory to practice.

*Content knowledge* includes knowledge of the subject and its organizing structures (Shulman, 1986b, 1987). Without content knowledge it is difficult to develop the second

category of knowledge called *curricular knowledge*. *Curricular knowledge* is represented by the full range of programs designed for the teaching of particular subjects and topics at a given level. Middle school science teachers, in this study, confirmed that science curricular knowledge development takes place in the classroom. It comes from a teacher's first-hand foundational knowledge of science content—science content courses that are associated with science subject matters and scientific principles. Shulman also stated that, “Teachers curricular knowledge involves the variety of instructional materials available in relation to those programs, and the set of characteristics that guide teachers in choosing to use or not use particular curriculum or program materials in particular circumstances” (Shulman, 1986b, p. 10). Teachers, in this study, felt that experiential knowledge obtained through science coursework, working with, and manipulation of the various scientific principles provided them with the foundation of content knowledge and curricular knowledge that led to the development of their pedagogical content knowledge. These teachers had confidence in their judgment that the attributes of *content* and *curricular knowledge* are critical to science instruction. The science teachers observed in this study had a solid foundation for content knowledge and curricular knowledge related to fluid earth, but had difficulty adopting science inquiry as a part of science content knowledge and curricular knowledge.

According to Schulman (1986b, pp.7-9), pedagogical content knowledge (PCK) is the last, and possibly the most influential of the three content-related categories of teacher knowledge. Teachers' knowledge of content—subject matter knowledge and pedagogy are not mutually exclusive. Pedagogical content knowledge bridges content knowledge and the practice of teaching. PCK refers to both discussions of content relevant to teaching and discussions of teaching that are directly tied to content. The science teachers in this study felt that science

methods courses had contributed important pedagogical content knowledge related to their teaching practices. This included implementation of science lessons, science activities, science laboratories that focused on the scientific method, and science assessments. Science methods courses also provided uses for powerful analogies, illustrations, examples, explanations, and demonstrations. These were seen as useful methods of representing and formulating the subject that make it comprehensible to others. However, the teachers in this study did not associate the science methods courses with skill development in teaching science as inquiry. Moreover, teachers in the study were skillful with curricular knowledge, but were lacking in areas related to pedagogical knowledge that allowed them to help their students to learn science as inquiry.

According to Keys and Bryan (2001), “more research is needed in teachers’ knowledge bases for implementing inquiry, teacher inquiry practices, and students’ science learning from teacher inquiry-based instruction” (p. 632). In his study Windschitl (2003) also found that although some teachers had a reasonably realistic view of inquiry, others viewed inquiry as a linear or sequential process. Researchers believe that teachers have not acquired skills in these areas and these skills are not in their repertoire of pedagogical practices. The results of this study support existing research indicating that many teachers have unsophisticated understandings of scientific inquiry and related practices.

Research indicates that there are three useful professional development strategies that reflect approaches to teacher learning (Loucks-Horsley, Stiles, Mundry, Love & Hewson, 2010). These strategies are designed for teachers to deepen their science content and pedagogical content knowledge and their understanding of standards and research. These strategies are curriculum topic study, immersion in inquiry in science and problem solving, and content courses. Curriculum topic study, immersion in inquiry in science and problem solving, and

content courses are grounded in research and indicate that teachers' learning is enhanced through direct experience with science content and the processes of inquiry and problem solving. A teacher in the focus group pointed out that the best knowledge of the practices related to teaching science as inquiry comes from daily, first hand experiences and "experimenting on your own". Teachers were also mindful that keeping abreast of new information through inservices and workshops is vital due to periodic curriculum changes. In addition to the three strategies, teachers need to understand the progression of content knowledge from grade to grade. Furthermore, teachers need to recognize what content is difficult for students and commonly held conceptions that may impede learning (American Association for the Advancement of Science [AAAS], 2001, 2007; Bransford et al., 1999; NCTM, 2003a; National Research Council [NRC], 1996). Most teachers argued that the wealth of experiences provided by taking graduate courses, inservices, and workshops from years of practice with newly learned concepts, gave them invaluable knowledge that makes them informed teachers.

Unfortunately, the teachers in this study rated rather low inservice training that could have helped build teachers' repertoire of experiences and contribute to their understanding and skills related to teaching science as inquiry. These results are consistent with the lack of professional development experiences that their district has provided, which had been limited to: 1) ACC curriculum planning, 2) a Michigan Educational Curriculum (MECC) fieldtrip offered by Cranbrook, 3) a Metropolitan Detroit Science Teachers Association (MDSTA) inservice, and 4) a visitation to Oakland Schools., none of which addressed the real issue of how to teach science as inquiry.

While ACC was a powerful mechanism for curriculum planning in the district, when a teacher says, "I have been in the science department for five years and I have never been sent to

or received ANY training related to teaching science as inquiry”, it is a good indication of the lack of professional development activities available to these teachers. Indeed, teachers spoke of their need and interest in professional development in the areas of teaching science as inquiry, STEM, and NGSS.

### **Teachers’ Practices Related to Teaching Science as Inquiry**

As previously pointed out, Doll’s (1993) and Duschl and Grandy’s (2008) frameworks were used to analyze the data related to teachers’ practices related to teaching science as inquiry, obtained through classroom observations and focus group interviews.

**Mystery, complexity and aliveness in school curriculum.** Doll (1993) spoke about the significance in the “*spirit*” of science that involves a curriculum built upon: 1) mystery—investigating the unknown, 2) complexity — building a complicated study, and 3) aliveness—the organic, naturally unfolding, evolving production of scientific ideas. He elaborated upon these three elements as they are embedded in the investigations of scientific problems or questions associated with learning about natural phenomena. The practices of scientific inquiry that encompass “spirit” are inherent to the scientist just as the “art of teaching” is inherent to the skillful classroom teacher. Interpretation of science instruction through the lens of Doll (1993) has led us to believe that students of science must vivaciously conduct scientific investigations with the same level of intensity that scientists do because this is a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed (Dewey, 1920). Although the teachers in this study reported that they felt teaching science as inquiry is important, it is doubtful that their students’ scientific investigations rose to the levels of intensity in mystery, complexity, or aliveness as stated in Doll’s (1993) work.

Complexity involves the embodiment of simplicity within complexity, and complexity within simplicity, and *recursively* the two repeat themselves when studying science subject matters (Doll, 1993). Complexity is characterized by self-organization and emergence of knowledge as learners strive to move from a simple order, toward an ever evolving more complex order. The key idea of complexity is that nature, life, and organization all occur when there are sufficient, but simple levels of complex interactions among science students.

In this study, the science lessons progressed from simple to complex concepts of earth science. For example, students began with simple knowledge of ocean and atmospheric movement and transfer of energy around the planet, how these movements affect climate and weather, and how severe weather impacts society. Students then moved into complex knowledge of features and processes related to surface and groundwater, and described the sustainability of systems in terms of water quality and quantity. They studied the complexities of the features in surface water systems and ground water systems and compared and contrasted surface water systems such as lakes, rivers, streams, wetlands and groundwater in regard to their relative sizes as Earth's freshwater reservoirs and the dynamics of water movement (inputs, outputs, residence times, and sustainability). Students also explained how water quality, in both groundwater and surface systems are impacted by land uses decisions. Students explored the major causes for the ocean's surface and deep water currents, including the prevailing winds, the Coriolis effect, unequal heating of the earth, changes in water temperature and salinity in high latitudes, and basin shape. Students investigated how interactions between the oceans and the atmosphere influence global and regional climate, and complexities within the system such as major concepts of heat transfer by ocean currents, thermohaline circulation, boundary currents, evaporation, precipitation, climatic zones, and the ocean as a major CO<sup>2</sup> reservoir.



The potential for advanced study of some of these topics was present in the science classroom. However, the lessons moved quickly and lacked, in some cases, depth and/or complexity because little opportunity was provided for student interaction that would allow greater knowledge production. Teachers needed to strive for the development of more complex conceptualizations through greater student interactions. When students were studying the concepts it seemed as though the lessons were presented in accordance with Sandoval and Reiser's (2004) rationale of teachers teaching final form science whereby, theoretical ideas are presented as fact. Students need to be producers of scientific knowledge rather than simply relying on the authorities within various content areas derived from textbooks. Often what occurs in this situation is that students accumulate numerous facts that describe the world only to forget much of the information because it is not retained. Complex simple interactions among students, when combined, compound the information and create new and more complex levels of understanding of nature, life and organization (Doll, 1993). Complex projects further promote the concept of recursion in science studies due to a cyclical repeating of testing, retesting, revising, and occasional discarding of theories when students change ideas about nature. Students are forced to change their thinking as they encounter new experimental evidence that does not match existing explanations, thereby causing the practices to be repeated and not necessarily being performed in a particular order (Duschl & Grandy, 2008). This yields greater conceptualization of both science content and use of contemporary methods used in the production of scientific knowledge. This form of complex interactions about key conceptualizations of the science subject matters was not present during the classroom observations because students were not given much time to explore, examine, discuss and innovate using the content to build science projects.

Doll's (1993) Complex Adaptive Systems Theory (CAS) includes: a) the theory of a driving force of development—the cultivation of perturbations, b) the theory of firm formlessness—a curriculum that emerges continually and often out of antagonistic parts; and c) the theory of chaos—dynamism of action, reaction and interaction (Doll, 1993). Classroom observations did not show opportunity for this intense, somewhat “chaotic” examination of scientific ideas that would be presented by students. The teachers indicated that science lessons are not designed for students to labor over scientific problems or questions very long, but in their words the science lessons were “attainable”, “achievable” and designed for students to feel “successful”. Mary stated, “Instead of designing the lesson for students to be stumped or think for long periods of time to work through tough problems, they are created for students to have success and learn the science concept.”

Teachers reported several reasons that students did not frequently perform scientific inquiry investigations of complexity or those that promote “rigor” (Doll, 1993). As stated earlier in this study, rigor implies using every possible scientific instrument or resource (both mental and physical) to investigate a scientific question (Doll, 1993) and it also means applying logical reasoning and understanding of a concept to formulate theory laden experiments as explanations of models and revised models (Duschl & Grandy, 2008). Furthermore, rigor implies that students explain what happens in the world which comes partly from what they observe and partly from what they think (Doll, 1993) and that students must make multiple observations, create scientific—researchable questions, design experiments, collect data, and use theoretical and mathematical models in drawing conclusions (Duschl & Grandy, 2008).

According to Windschitl (2009) teachers must have deep interconnected understanding of conceptual principles and knowledge associated with various science disciplines—physics,

chemistry, biology, and earth science; the full gamut of the natural sciences. Science teachers must have good command of essential concepts or conceptual principles that underlie various branches of science and the relationships that tie them together. This includes a solid foundation of factual and theoretical knowledge that guide student inquiries. These principles of understandings of science content directly influence science teaching and the strategies that science teachers employ in the classroom (Windschitl, 2009).

It is significant to note that teachers in this study rated knowledge of science content very highly. More importantly, understanding how to manipulate, direct or control the content and how it is presented is crucial in science education. It is also significant to note that teachers in the study understood that beyond the introduction of content is the relevance of “*relations*” among the science concepts within the various science systems being studied such as: the quality of our fluid earth system has an impact on various ecological or biological systems (Doll, 1993). Doll (1993) explained that there is a need for the integration of science concepts that cut across science domains, and those concepts and variations of concepts will appear in several subject matters being taught. In this case, as Mary indicated, the study of fluid earth repeatedly uses the concept of density. There are thousands of connections or relations in particular systems like the atmospheric system and also in many others such as biological systems.

**Collaboration and community in the science class.** There is a call for *collaboration and conversation* in the field of science curriculum (Doll, 1993). In this conversation, teachers need to consider the accumulation of knowledge that students have gained from their life experiences and they must spend less time on specialized curricularized methods or procedures. When students converse with each other about science concepts, they develop an understanding and respect for the opinions of others. Teachers need to encourage and incorporate this value

into instruction. During classroom observations, students sometimes discussed their ideas in dyads or in four person groups using approaches such as Jigsaw comprehension of reading assignments, Think Pair Share for interpretation of reading concepts, and Turn and Tell to share hypotheses. These activities provide opportunities for students to listen to each other and gain practice in defending their position, or possibly changing their own thought processes as groups work toward consensus. The results of this study reveal uncertainty that “conversation” between students was substantive of the arguments based on evidence or having the validity of an explanation that is a function of the type and amount of evidence that supports a theory as suggested by Duschl and Grandy; (2008).

The integrity of a theoretical position comes from having a dialogue with others to find out whether or not there is consensus of opinion or to find out if one is correct in one’s thinking. Knowledge begins with the thinking of the individual, but one must present ideas to others, through dialogue, to find out whether one is right (Holton, 2005). This is the idea of transformative experience where interaction helps us transform our thoughts into disciplined inquiry and intellect. There is uncertainty as whether or not enough dialogue took place among students in the science class observed in this study to accurately depict their experiences as “transformative”.

According to Doll (1993), *community*, the most important C of all, is reconceptualizing humanity as we re-generate understandings of human experiences. Community has a high degree of care and critique and emphasizes a high degree of trust. The social-cultural aspect of learning, in the science classroom community, cannot be ignored because of its value for great potential in learning. What students learn on their own must be shared with others in order that information may be validated for its truthfulness. The processes of student interaction,

cooperation, and collaboration are powerful, essential tools for the process of learning in science. Every possible effort was made during the science lessons to have students interact with each other while studying science concepts. The challenge for the classroom teacher was the opportunity for students to take advantage of the reservoir of experiential and creative knowledge that resides in students. Doing science involves creativity, imagination, and logical thinking to generate and test the validity of ideas. It is unclear from this study as to what took place during partner collaborations. Also, most often, there was minimal student dialogue in larger classroom forum. Information, for the most part, was presented as fact.

**Use of scientific inquiry domains.** Scientific inquiry is the synthesis of three integrated domains (Duschl & Grandy, 2008). The first domain is the cognitive domain where students must be able to use scientific reasoning that applies conceptual structures and cognitive processes that support or expand existing theories (Duschl & Grandy, 2008). An example taken from the science classroom was when the teacher discussed how decaying plants dissolve minerals in rocks. She asked, “What factors may affect the process?” Students reasoned that in Brazil or the rainforest, tropical plants decompose faster due to increased temperature. Students also surmised that rapid heat and moisture cause decomposition to occur faster and this supports the theory that heat causes rapid decomposition. They also scientifically reasoned that decomposition is a chemical change because acids from plant roots deteriorate rock that it surrounds causing erosion. Students practiced reasoning in many instances such as this in the science classroom.

The second domain is development and evaluation of scientific knowledge based on an epistemic framework. This includes the foundation, scope and validity of the scientific knowledge (Duschl & Grandy, 2008). In the “Scientific Inquiry Power Point Slide Presentation

(2013)” that all science teachers used as part of the mandatory school improvement plan for science education, students were told to obtain information or background on the scientific problem because prior knowledge of the area being studied was important. Knowledge of the problem combined with scientific reasoning allowed students to form logical hypotheses. Students are required to obtain and document at least 2-3 pieces of information as evidence and foundation for an understanding of the science problem they are studying. After acquiring knowledge of the scope of the problem, students were then required to define the problem in their own words and to develop a question from it. The teacher in this study used guided-inquiry to help students through the process, and even though students wrote down questions, the students, for the most part, responded to teacher generated questions, and from those responses, the teacher guided the direction that their study took.

The SI Power Point presentation reminded students to use the background, define the problem, and develop a fitting question that that they would answer in the inquiry. This supports Duschl and Grandy’s (2008) theory that students must acquire knowledge of the kinds of questions that can be studied. The presentation drew the connections between a well defined problem, the research question, and development of a hypothesis just as any scientist would do, but there was limited opportunity for students to do this. It indicated that a hypothesis is an educated (well-thought out) guess as to what will happen in the experiment that will be conducted. The hypothesis would be developed based on the information gathered and it was to be focused on answering the scientific question posed in the beginning of the process.

In this study, students were occasionally asked to write down research questions in their unit packets and to share them with their partners. However, it could not be ascertained that the questions were developed from any particular sources of evidence. Furthermore, not much

verification indicated that student questions promoted divergent thinking or that student comments were used to shape the lessons. The students did communicate answers to teacher questions, but it was apparent that there was little expectation for contribution other than confirmation of the expected answer.

Next, the SI Power Point presentation told the students to set up an experiment. The teacher guided the experiment and was sure of the intended outcome. The experiment followed a set of procedures and students conducted experiments to test the hypothesis. The experiment had to be a detailed account of what students would be doing. Students were reminded that the factor being tested is known as a single variable and that it was critical to have only one variable, so that students would know the factor that caused differences in the results. Students were told that observations would be made in the experiment, recorded and used as evidence and this aspect of the lesson reflects Duschl and Grandy's (2008) position, that science learning should be designed to provide a science classroom environment that permits students' scientific work to demonstrate evidence supporting their inquiries. In this study, students did not plan or design their own experiments as this information was always provided by the teacher and there was certainty of the intended outcome.

The third domain, suggests that scientists and students of science must embed themselves in the social processes that shape how knowledge is communicated, represented, argued and debated (Duschl & Grandy, 2008). Duschl and Grandy (2008) also suggest that an understanding of methods that are accepted within the science discipline must be applied. The methods include legitimate forms of data collection, data interpretation, scientific explanations, and use of models in performing all of these. The models used in this study were physical models that were mostly prepared for the students. The SI Power Point presentation indicated

that students used graphs, tables, charts and notes as acceptable methods for data collection, analysis and interpretation, and that for any numerical value, students must include the unit of measurement. Students were required to use all of these methods as legitimate forms of data collection and analysis, however, in most instances the teacher gave the students the data because as she explained later, she wanted everyone to have the correct answers and time-wise it would be impossible for her to sift through all the numerical data as it would be vastly different, in many cases, from what she recorded as the accurate results.

Duschl and Grandy (2008) denote that inquiries include the formulation of and revision of theories associated with science concepts. The SI Power Point presentation included a section on the “conclusion”. Students stated the problem again, summarized the experiment, restated the hypothesis, told whether or not the hypothesis was correct or not, provided evidence of what they learned using the data they collected, and had to discuss possible errors made during the experiment. Although the SI presentation made these recommendations and teachers were to follow them, there was little evidence of these types of discourse, because the labs were pre-planned and the results were already known. At best, students were asked to write down their hypotheses once or twice, and told to discuss them with their partners and minimal data was collected. The data were not necessarily generated by students because after they attempted to collect some data (which was not discussed as a class), the teacher always gave them a handout that included what she called “the correct data” and they used it for the remaining assignments. Although Duschl and Grandy (2008) point out that the science educator’s goal is to design science curriculum and endorse effective science learning environments that promote think tank research classrooms similar to the authentic scientific community, in this study students had limited opportunities for discourse of this nature to take place.



**Model-based reasoning.** The most authentic form of thinking, essential to the scientific community is model-based reasoning because it deepens understanding of any scientific subject matter (Duschl & Grandy, 2008). The nature of the explanation about a model is like a storyline, illustrated by experience and theoretical conjectures (Duschl & Grandy, 2008). Somewhat similar, is Doll's (1993) perception of story as being a narration or interpretation of a science idea which is further defined and based on cultural experience. Duschl and Grandy (2008) posit that models are connected to experiences through the practices of inquiry and application, whereas, Doll (1993) attributes the understanding of models to personality, interpretation or stories. Duschl & Grandy (2008) reason that if there is discontinuity between observations and theoretical perspectives then multiple possible models with varying points of view need consideration. Unfortunately, students did not plan a study of their own that would afford them the opportunity to construct a model that would be used to defend their ideas. The results from this study indicate that there was little evidence of student scientific discourse, argumentation, socially constructed knowledge, or negotiated meaning. The teacher in the study rarely asked students to identify the assumptions in their explanations, nor did she ask students to provide skeptical criticism of their classmates' explanations. There was little need for formulation of and revision of student theories associated with science concepts because the teacher rarely made use of any suggested alternative solutions to problems being studied. Student generated conjectures or different ways of interpreting evidence did not surface much. Students had little opportunity to provide and receive constructive criticism pertaining to their ideas as lessons were rather cut and dry and moved along quickly.

Duschl et al. (2007) indicated that when using model-based reasoning, arguments include inquiry by use of data, analysis, and questioning aspects of the model. An example of students

questioning the aspects of a model was shown when the students were given directions for making “A Source Pollution Model”. Although, students did not create their own model design, they were able to make claims about their models, challenge the coherence of the models, and there was some opportunity during the discussion for acceptance of alternative explanations of their classmates. In this case, there was some student discourse about the inquiry that was framed by the theorized entities and properties and relationships posited in the *Source Pollution Model*.

The characteristics of scientific explanations are unique to the science community and meet a specified set of empirical standards, logical arguments and cynicism. Scientists’ explanations come from a combination of what they observe and what they think. First and foremost, explanations from experimental and observational evidence, about nature, must produce accurate predictions of the system being studied. Explanations or arguments must be logical and adhere to the rules of evidence, in other words, claims must be backed up by evidence and scientific principles. Students, just as scientists, need practice testing scientific claims by using observations, experiments, theoretical, and mathematical models. Moreover, students need to practice developing arguments based on evidence must be open to criticism or debate and students must include a report of methods and procedures when making knowledge public to classmates. The nature of science means that scientific ideas must be substantiated by experimental and observational data and the findings must be evaluated by peers.

### **School District’s Role in Teachers’ Understandings and Skills Related to Teaching Science as Inquiry**

The National Staff Development Council (2001b) has acknowledged the strong link between effective policy and effective practice that profoundly impacts teacher learning, thereby

profoundly impacting student instruction and learning. If teacher knowledge is the lever for transmitting knowledge, then each school district has the duty of translating policies to support professional development activities that have the greatest benefit, and are grounded in the knowledge of core values of teaching science as inquiry. As the results of this study indicate, this school district had done little, particularly in the recent past, related to helping its teachers develop understandings and skills related to teaching science as inquiry, or any other important areas of teacher practice.

Berns and Swanson (2000) point out that external supports for teachers such as resources and preparation time are rare and Blumenfeld, Krajcik, Marx and Soloway (1994) found potential problems for teachers such as lack of resources and district curricular policy. This study shows that teachers value science as a core subject; would like to see greater district recognition and commitment to learning how to teach science as inquiry; need resources to learn the SI strategies; and need time to work together to plan SI lessons. As indicated by Jonathan, teaching science as inquiry needs to be based on the Next Generation Science Standards (NGSS) which encourage students to engage in scientific investigations. The teachers in this study would like to see less professional development related to School Improvement Goals and curricular phase work and more time spent on (NGSS). The teachers also mentioned a need for professional development on how to implement (STEM) standards that encourage students to be problem solvers, innovators, and inventors. Both the district math and science coordinator and the teachers knew that they needed to learn how to teach in a manner that allows students to become logical thinkers.

Unfortunately, the teachers in this study rated rather low inservice training that could have helped build teachers' repertoire of experiences and contribute to their understanding and

skills related to teaching science as inquiry. These results are consistent with the lack of professional development experiences that their district has provided, which had been limited to: 1) ACC curriculum planning, 2) a Michigan Educational Curriculum (MECC) fieldtrip offered by Cranbrook, 3) a Metropolitan Detroit Science Teachers Association (MDSTA) inservice, and 4) a visitation to Oakland Schools., none of which addressed the real issue of how to teach science as inquiry.

While ACC was a powerful mechanism for curriculum planning in the district, when a teacher says, “I have been in the science department for five years and I have never been sent to or received ANY training related to teaching science as inquiry”, it is a good indication of the lack of professional development activities available to these teachers. Indeed, teachers spoke of their need and interest in professional development in the areas of teaching science as inquiry, STEM, and NGSS.

According to the National Partnership for Excellence and Accountability in Teaching (2000), the one major reason for failure of school-wide change models is the lack of teacher time focused on the right things during professional development. Teachers in this study implied that the district needs to provide good professional development related to teaching science using inquiry. Teachers explained the time consumption surrounding school improvement goals and curriculum phase work and did not feel the district had provided the necessary resources for teaching science using inquiry. According to them, they needed opportunities or common core time with colleagues to share ideas and practices and engage in valuable discussions and planning. However, the district math and science coordinator was moving in a positive direction and planned to create PD on the literacy and science standards for Common Core, Next

Generation Science Standards rollout, Science Technology Engineering & Mathematics type ideas, science as inquiry, and the science practices.

### **Perceived Barriers to Teaching Science as Inquiry**

Doll (1993) denotes that students just as scientists will perform in whatever manner it takes— “currere,” or run the course to develop a plan that will work in answering the scientific question. Teachers, in this study, could not employ such complexity or the rigors that scientist use because they were concerned with: 1) Science Standard content coverage, 2) the requirement of remaining on a rigid testing schedule, 3) concern about increases in student test scores, 4) results of teacher evaluations and 5) student ability to perform inquiries. There seemed to be anxiety about each of these dimensions which posed barriers for teachers to teach science as inquiry. Each of these barriers is discussed in the section that follows.

Anderson (2002) claims that teachers must learn to overcome and control cultural dimensions that present barriers in teaching. Barriers are critical in implementing change that could result in teachers adopting science inquiry practices. Moreover, a number of researchers (Anderson, 2002; Blumenfeld, Krajcik, Marx, & Soloway, 1994; Keys & Bryan, 2000) found in studies of teacher learning and change, that teacher beliefs are a key factor as to whether or not instructional practices will be changed, implemented, and sustained. This study supports these findings, and revealed several barriers that impacted the teachers’ delivery of science instruction as inquiry: (1) Teachers’ concern over coverage of science content material and loss of control over what students learn. Teachers experienced tension between knowing what they would like to explore with students in terms of science inquiries and what they have time to do based on the amount of content they must cover. (2) Teachers felt pressured because of a rigid testing schedule. Content coverage is directly related to the next grade level, state, and national test

performance. If teachers do not get through the content or if the content is not covered well, students do not perform well on all assessments. (3) Teachers have apprehension about standardized test results. Students' grades and test scores must show improvement or increase per the district school improvement plan. (4) Teachers were worried about the impact of test results on teacher evaluation. (5) Teachers were concerned about lack of student ability to perform science inquiries.

Anderson and Helms (2001) found that in order for teachers to implement reform-based practices such as inquiry based learning, they must have district support. Teachers in this study indicated that the district had not provided adequate professional development related to teaching science as inquiry. The math and science coordinator was planning PD, some future professional development activities related to both STEM and NGSS. The district math and science coordinator was aware of these barriers and as indicated in the interview, he was working hard to address these kinds of issues.

Teacher evaluations are based on student achievement and the teachers in this study expressed fear of losing their jobs more than once. They stressed that if they have too many students failing, they do not have time for *rigor* in pursuance of complexity. Chris seemed saddened, "The reality of low test scores dominates, and it is a very negative stigmatism against teachers." The teachers claimed that they sought a balance between challenging the students and having them pass with good grades. Teachers indicated that most often it was a challenge to allow students time to investigate and figure out problems. The most telling comment was from the teacher who reported, "Rigor implies something challenging, and we are evaluated on student grades and test scores. If you have too many students failing there just isn't time for rigor." The

teachers recognized a need for a balance between routine problems that ensure success and challenging students with rigorous complex problem solving activities.

Students' ability determined the degree to which more intense activities could be incorporated during science instruction. Teachers hold a set of beliefs about student ability and this form of instruction may be too difficult for some students. Teachers discussed the fact that they could lose some students during lessons that were too difficult for them. The teachers mentioned *Project Green* and the *Science Fair* as inquiries, but these investigations were only performed by top notch students in the district. Evidence shows that there was a belief that student ability determined the degree to which activities such as these could be incorporated during science instruction. One teacher commented, "Water testing was done through Project Green or Flint Green. I do that with the honors students." She went on to say that she had attempted this with some 7<sup>th</sup> grade students, but it was impossible to manage all the data. A second teacher commented:

One thing that honors classes participate in is a Science Fair Project. It's an honors level requirement to do a project. The project is very much using the practices of scientific inquiry. Students have to come up with a project or an idea to study. They develop a question, form a hypothesis, and then actually design their own experiment, collect data, analyze data, draw conclusions and develop a model. They have to use the models and write up explanations to defend results. It is a pretty high level thinking scenario.

A third teacher also mentioned that higher achieving students are 'better behaved' and that makes them more capable of performing inquiry activities. Beliefs related to student ability were identified by Anderson (2002) as a cultural barrier to reform and classroom management issues were identified as technical barriers to reform. Lotter, Harwood, and Bonner, (2007) also

found that teachers' conception of their students' ability could hinder the use of inquiry-oriented strategies.

According to the teachers, some students will hit a frustration level quicker than others and they will “check out” in terms of concentration. Teachers reported that students with learning problems sometimes shut down if things become too difficult. Chris commented, “If we had perfect students, then students could be hit a lot more in terms of rigor!” The teachers agreed that this is where the science for honors comes into play rather than in the classroom. According to Chris, “Honors students have the ability for rigor! They have the motivation and stamina for it. They can carry out long-term projects and they have desire to do so!”

This study's results support other researchers' conclusions that middle school science teachers do not use inquiry approaches because time and material demands are significant barriers to open-ended inquiry (Staer, Goodrum & Hackling, 1998). The teachers in this study also mentioned some of these reasons. However, they tended to be less inclined to perform open-ended inquiries because of lack of time to lack of materials, time to organize materials, storage and space issues with materials, the purchasing procedure for buying materials, and lack of time to plan with colleagues.

## **Conclusion**

The middle school science teachers in this study do have some level of understanding of the practices related to teaching science as inquiry. As indicated in the survey results, what they know in terms of personal experience has been limited to science content courses and experimenting on their own. While teachers did agree that student labs with inquiry facilitated student learning of science concepts, classroom observations indicated the labs were both guided



and structured, ignoring the possibility for use of open-ended inquiries because teachers have had no training on how to conduct them.

Open-ended inquiries were promoted in three special cases: 1) honors classes with students of high caliber academic abilities, 2) an after school inquiry investigation conducted in the local community surrounding the district with a select few top-notch students, and 3) with students participating in science fair inquiry projects that are a requirement of honors students. “Rigorous” investigations of this nature, that allowed students to plan their own investigations to solve a problem and develop a research question, were not used in the science classroom. The teachers cited the following barriers to teaching science as inquiry: time constraints, lack of materials, extra planning time, and lack of professional development on how to teach science as inquiry.

The teachers illustrated some understandings and skills related to teaching science as inquiry in their practices that included understanding of the core curriculum and the “relations” of the apparent subject matters associated with it. Students’ laboratory experiences were built around this premise. In addition, teachers promoted collaboration, conversation, and community among their science students during science lessons. The teachers also provided time for their students to make observations, make predictions, create scientific questions and hypotheses, conduct experiments, use both physical and conceptual models, collect data, use technology, analyze data, and draw conclusions. Although these are components of scientific inquiry, these processes were limited to guided and structure inquiries, use of pre-planned models, and already formulated theoretical premises with an intended outcome or result already in place. There was also a very limited use of the epistemic value for students to use scientific explanations of their own.

The school district in this study has undergone a transition in two ways: 1) they hired a new math and science coordinator who is learning a new job, and 2) the district was placed in a holding pattern as they waited for changes in the core curriculum to be determined by the state that would indicate what subject matters to teach. These issues combined with budget cuts resulted in lack of professional development activities for district teachers. However, the math and science coordinator had plans for future inservices and workshops that will enhance teachers' science teaching performance in the classroom as related to teaching science as inquiry.

### **Implications for Practice**

Scientific inquiry refers to the various ways in which scientists study the natural world. This is the stance that we would like students of science to emulate. This study illustrates that an inquiry stance is difficult for teachers to take in the science classroom particularly when they have had little or no experience learning science through inquiry, or have had little training in this area. Even though the teachers in this study felt methods courses had helped, they also felt such courses did not necessarily teach them how to teach science as inquiry. Therefore, it is important that teacher training institutions help teachers develop the understandings and skills related to best practices. If teachers are to teach science as inquiry, they must master such skills during their teacher preparation program.

A small number of the teachers in the study felt that they had experienced little support from university researchers. Yet, university researchers can be an important source of experiences related to scientific inquiry. As a result, school districts and universities must develop partnerships that allow teachers to participate in meaningful research experiences that illustrate learning through inquiry. With new standards such as common core and NGSS,

teachers will need a variety of professional development opportunities to help them translate such standards into classroom practice.

Teachers know that scientists' work, authentic science, is based on a particular set of scientific inquiry practices. These practices are integral to the core work of science and they are organized around the development of evidence-based explanations of the way the natural world works (Longino, 1990). Teachers are also cognizant that authentic science involves the creative process of developing hypotheses from theories or models and testing these against evidence derived from observation and experimentation (Giere, 1991; Longino, 1990). The teachers in this study seemed to recognize these features as well, but may not necessarily know how to employ all of them in the science classroom. Teachers need professional development on SI practices that are crucial to learning science and the trajectory teachers follow to practice scientific inquiry with students may be diverse as they learn to adopt them into routine pedagogical practices. Teachers must gain confidence in the deployment of the practices of inquiry, and most importantly, include the naturally occurring organic process that develops from students to unfold. The somewhat chaotic, unpredictable, organic process is suspended over the regular curriculum, and from this emanates creative thinking! From this creativity, ingenuity of discovery transpires. Teachers must come to know that a science curriculum involves the discovery or wonder about science concepts, requires logic and reasoning, has a storyline or narrative that may be told, and most definitely has spirit or vitality that makes it come alive for students. Just as a vibrant tapestry produces the beautiful palette of an artist, inquiry is to the student of science. Just as the set of lyrics create a song for the musical composer, inquiry is to the student of science. Just as the sonnet inspires emotion from a poet, inquiry is to the student

of science. Scientific inquiry is the essence of science— the spirit of science! These are the values we want to instill in our science students.

The amount of content teachers are expected to cover and students must learn makes it difficult to incorporate long term projects into the science classroom which are desperately needed. Science teaching must focus less on content coverage and more on examining, in depth, a smaller number of concepts (Romance & Vitale, 2001). Perhaps this approach would allow teachers to plan at least one long-term project that would engage students in the planning and implementation of investigations that employ scientific inquiry practices.

Although, this study examined only one district, it is apparent that the problems or barriers experienced by these middle school teachers regarding teaching science as inquiry are very likely experienced by teachers in other school districts. Teachers' reluctance to teaching science as inquiry, in this study, does come with justification.

## APPENDIX A: SCIENCE TEACHER SURVEY: SCIENCE INQUIRY

**Directions:** Please check the response that best describes you.

1. **Gender:** M \_\_\_\_\_ F \_\_\_\_\_

2. **Certification Level:** Elementary (K-8) \_\_\_\_\_ Secondary (6-12) \_\_\_\_\_

3. **Certification Areas (check all that apply):** all subjects (K-5); \_\_\_\_\_ Science (6-8); \_\_\_\_\_

Math (6-8); \_\_\_\_\_ Language Arts (6-8); \_\_\_\_\_ Social Studies (K-8) \_\_\_\_\_

**If your certification is at the secondary level, please list your area(s) of certification:**

---

4. **How long have you been a teacher?** \_\_\_\_\_

5. **Grade Level(s) you are currently teaching:** \_\_\_\_\_

6. **Content areas (e.g., science, math, LA, etc.) that you are currently teaching:**

---

7. **List your favorite subject(s) in college** \_\_\_\_\_

8: **In the space below explain your understanding of scientific inquiry. Feel free to provide examples.**

**Directions:** For the questions below please check the box that best reflects your situation.

**9. Which contributed most to your basic knowledge of teaching science?**

	Low				High
	1	2	3	4	5
a. science content courses	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. science methods courses	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. experimenting on my own	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**10. Which of the approaches below are most beneficial in facilitating student understanding of science?**

	Least				Most
	1	2	3	4	5
a. lecture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. cooperative learning	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. teacher demonstrations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. student labs with scientific inquiry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**11. What has helped you the most in learning “new knowledge and skills” for teaching science?**

	Least				Most
	1	2	3	4	5
a. working with university researchers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. attending workshops	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. inservice training by my school district	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Directions:** For the following questions check the response that best reflects your level of agreement.

	Strongly Disagree			Strongly Agree	
	1	2	3	4	5
12. I enjoy doing structured-inquiry learning with my students in science class.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13. I enjoy doing guided inquiry experiments in my science classes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14. I enjoy doing open-ended inquiry experiments in my science classes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15. I prefer lecture as the method of teaching science.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16. Lesson planning for scientific inquiry takes a lot of time.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17. Organization of materials is very important when teaching science using inquiry.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18. I have few materials & support for teaching science inquiry lessons.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19. Lack of time to plan with colleagues is a problem when preparing science inquiry lessons.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20. Before I teach a science inquiry lesson I practice it to ensure everything will go as intended.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21. I test science inquiry activities before class.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22. Classroom management skills are very important when doing science inquiry lessons.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23. Student interaction is to be expected when students do science inquiry experiments.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24. I am “a guide on the side” when teaching science using inquiry.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

25. Knowledge of the practices of science is important when teaching science as inquiry.
26. Understanding of the Scientific Method is important in performing scientific inquiry.
27. My school district has provided good professional development related to teaching science using inquiry.
28. My school district provides the necessary resources for teaching science using inquiry.
29. My school administration encourages science teachers to use the best methods for teaching science.
30. My school administration encourage teachers to work together to plan creative lessons.

Please Rate the following:

- |  | Least Important          |                          |                          | Most Important           |                          |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|  | 1                        | 2                        | 3                        | 4                        | 5                        |
| 31. My knowledge of subject matter or content is essential when teaching science as inquiry.                                     | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 32. My knowledge of scientific inquiry Content Standards, Benchmarks and (GLICKS) is important when teaching science as inquiry. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 33. I enjoy planning science inquiry lessons with colleagues.  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 34. Teaching science as inquiry promotes collaboration and interaction among students.   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 35. Scientific Inquiry involves observations, measurements, interpretations.   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 36. Students should have opportunities to <i>develop research questions</i> about some science phenomena or problem.             | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| 37. In science class students should have opportunities to make <i>hypotheses</i> .  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |



38. In science classes students should have the opportunity to test their own *hypotheses*.
39. In my classes students have opportunities to *design experiments* based on research questions.
40. My students have opportunities to *gather data and manage data*.
41. In my classes students have opportunities to look for *patterns in data*.
42. I introduce data tables, graphs, as an instructional technique to help my students learn to *manage and display data*.
43. In my classes students develop data tables and graphs as a means of *recording and analyzing data* that has been collected during scientific inquiry activities.
44. When my students *explain or argue* their positions about natural phenomena they must use evidence (e.g., data tables, graphs, models).
45. I give my students opportunities to *develop Theories* associated with scientific models that they have developed.
46. In my classes students *revise* scientific explanations and *models* using logic and evidence.

47. Which of these statements best describes you as a teacher? (circle all that apply):

- |   |   |
|---|---|
| A1. I <i>teach science</i> to students            | B1. I <i>do science</i> with students.                |
| A2. I <i>provide information</i> .                | B2. I <i>provide experiences</i> .                    |
| A3. I seek to <i>control the lesson</i> .         | B3. I watch the <i>lesson unfold</i> .                |
| A4. Students need to <i>explore my thinking</i> . | B4. Students need to <i>explore their thinking</i> .  |
| A5. Students must ask <i>what to observe</i> .    | B5. Students trust their <i>own observations</i> .    |
| A6. My students <i>memorize facts</i> .           | B6. My students <i>reflect on ideas</i> from lessons. |

**APPENDIX B: DISTRICT SCIENCE COORDINATOR INTERVIEW PROTOCOL****Sample Questions**

1. What are the overall responsibilities of the science coordinator in this district?
2. What types of training prepared you to perform in this job capacity?
3. What types of activities do you plan for your science teachers? –additional questions based on the answers (e.g., types of workshops; topics; when given; etc.).
4. Are you familiar with the concept of “teaching science as inquiry?”
  - a. What approaches does the district use to help teachers develop teaching skills related to science inquiry? (Ask for concrete examples).
5. How much autonomy do science teachers in the district have related to how they teach science? (Response may lead to additional questions).
6. What is your opinion about the quality of teaching in your district? (Additional question related to answers).
  - a. What role has the district played in the quality of teachers in the district?
  - b. What things stand in the way of teachers doing their best?

### APPENDIX C: SCIENCE TEACHER FOCUS GROUP INTERVIEW

1. What are the overall responsibilities of the science teacher in this district, regarding the updating of professional knowledge about teaching science?
2. In your opinion, what are the general expectations for the K-8 science teacher in developing knowledge and/or skills for the teaching of science?
3. What types of training (professional development opportunities or otherwise) have prepared you to perform in this job capacity?
  - a. Who has provided those PD opportunities?

**Discuss the last PD activities you participated in:**

- b. Topics?
  - c. Who delivered them?
  - d. Usefulness?
4. Have you ever attended any PD related to teaching science, in particular “teaching science as inquiry?”
  - a. Topics?
  - b. Who delivered them?
  - c. Usefulness?
5. In what areas of your practice would you like to receive more professional development? Why?
6. What priorities drive the curriculum in this district/school?
  - a. How do these priorities affect the way you teach science?
7. What kinds of procedures are in place within the district to assist science teachers with the implementation of the science curriculum? By this I mean, how are changes in Science Standards, Benchmarks and Grade Level Content Expectations and/or subject matters within the domain of science addressed in the district?
8. Is there one thing that stands out in your mind as a contributor to successful teaching of science within the district?

## APPENDIX D: CLASSROOM TEACHER INTERVIEW ON SCIENCE LESSONS

### Beginning of the science unit:

1. In your opinion, what is science and why should we teach it?
2. What is the value of teaching science?
3. How do students learn science?
4. What are your plans for teaching this science unit? What are students learning about and please give as much detail as possible.
5. How much or what types of special preparations have gone into the planning of this unit?
6. Have you had any professional development to guide you through the development of the lessons related to this topic?
7. How does this unit relate to Michigan Educational Science Standards? Goals? Objectives? GLICKS?
8. What is the “big idea”, core concepts or science ideas behind the teaching of this unit?
9. What activities have you planned in your lessons to help the students understand the concepts related to the “big idea?”

**Lesson Debriefing** - Debrief at the end of each lesson to assess the *reasons for the teacher doing* what she/he did in the lesson.

**Possible Questions:** (used at different times during the debriefing).

10. How are your plans moving along in the teaching of this unit?
11. Are students beginning to grasp some of the major science concepts of the unit? How do you know? Can you elaborate on this?
12. Did any particular preparations for the unit, influence its success, one way or the other?
13. Has the material selection been working for you, or have there been some adjustments that you had to make thus far?
14. What has been the most difficult thing when teaching this unit? What has been the easiest thing in the teaching of this unit?
15. Did any unpredictable things take place, as of yet, while teaching this unit?

16. What is your favorite lesson so far? Please describe it and tell me why you liked it so well.

**End of the Science Unit:**

17. The best lesson of this unit was\_\_\_\_\_ and what made it so?

18. What were the greatest difficulties in teaching this unit? Were there problems with certain lessons?

19. What were the most positive experiences from the teaching of this unit?

20. What recommendations can you make to anyone who is preparing to teach this unit for the first time?

21. (If observed) How important are scientific inquiry activities to gaining knowledge of the basic science concepts?

22. (If observed) Were the scientific inquiry activities motivating for your students?  
Elaborate.

23. Were there any unpredictable events that took place during the teaching of the science unit?

24. (If observed) How successful were the data collection activities? Please elaborate.

25. (If observed) How did you make use of models (e.g., diagrams, sketches, conceptual maps, physical models)?

26. In what ways did you integrate technology in this unit?

27. How will you assess (formative or summative) whether or not students mastered the major science concepts of the unit?

28. What changes to the unit would you make (if any) for next time you teach the unit?

**Additional Questions:** (only if I do not observe these things taking place during the presentation of the unit).

29. How do you feel about students learning through investigations?

30. What is the role of scientific inquiry in the curriculum (specifically in this unit)?

31. What was the role of technology in this science unit?

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**ABSTRACT****AN EXPLORATION OF MIDDLE SCHOOL SCIENCE TEACHERS'  
UNDERSTANDINGS AND TEACHING PRACTICE OF SCIENCE AS INQUIRY****by****MARGARET ANN CASTLE****August 2014****Advisor:** Dr. Maria M. Ferreira**Major:** Curriculum and Instruction (Science Education)**Degree:** Doctor of Philosophy

Concerns have been raised that the U.S. is not meeting the demands of 21<sup>st</sup> century skill preparation of students, teachers, and practitioners in the areas of science, technology, engineering, and mathematics (STEM). Middle school is a critical point in students' science education and it is in middle school that they begin to dislike science. Research indicates that when students learn science through inquiry their interest in and understanding of science increases (Akkus, Gunel & Hand, 2007; Gibson, 2002; Liu, Lee & Linn, 2010). As a result, it is important to explore middle school science teachers' understandings and practices related to teaching science as inquiry.

This study was an exploration of the experiences that contributed to middle school science teachers' understandings of the practices related to teaching science as inquiry as put forth by STEM reform documents. It was also an investigation of the ways teachers' understandings and skills, related to teaching science as inquiry, were reflected in their practice, and the role that their school district played in the development of the teachers' understandings and skills.

An exploratory case study design using a mixed-method approach was used in this study. Data were collected through a survey and focus group interview involving science teachers teaching grades 7, and 8; an interview with the District's Science Curriculum Coordinator and classroom observations of an 8<sup>th</sup> grade science classroom for the duration of four weeks.

The study's results indicate that most teachers experienced little or no explicit training related to teaching science as inquiry, nor had they received such training through their district's professional development program. Indeed, the greatest source of teacher knowledge in this area was "experimenting on their own." The study also revealed several barriers that impacted the teachers' delivery of science instruction as inquiry: (1) Teachers' concern over coverage of science content material and loss of control over what students learn. Teachers experienced tension between knowing what they would like to explore with students in terms of science inquiries and what they have time to do based on the amount of content they must cover. (2) Teachers felt pressured because of a rigid testing schedule. (3) Teachers' apprehension about standardized test results. (4) Teachers' concerns about the impact of test results on teacher evaluation, and (5) teachers' concerns about lack of student ability to perform science inquiries.

Recommendations include: 1) Teachers need to learn the skills and practices of teaching science as inquiry during teacher preparation programs, 2) School districts and universities must develop partnerships that allow teachers to participate in meaningful research experiences that illustrate learning through inquiry.

## **AUTOBIOGRAPHICAL STATEMENT**

Margaret Castle's professional experience includes teaching as an adjunct faculty instructor for the University of Michigan, Flint, in the College of Education, since 2011. She was previously a Technology and Science classroom laboratory teacher, at the Intermediate Level (Grades 5-6), for Davison Community Schools, at Hahn Intermediate School in Davison, MI, from 1998-2010. In addition, to teaching technology and science classes for (Grades 1-5) at Siple and Hill Elementaries, from 1986-1998, Margaret was also the Web Page Coordinator, taught after school workshops in technology and was a fourth grade classroom teacher from 1978-1982 for Davison Community Schools, at Siple Elementary School, in Davison, MI.

Margaret served on the Davison Community Schools' District Technology Committee from 1986-2010 and worked as part of a leadership team, instrumental in passing a bond proposal that resulted in the purchase and design of a state of the art technology lab and science lab facility at a new school, Hahn Intermediate, in Davison, MI.

In 2009-10 Margaret designed and implemented a Mathematics Intervention program for Intermediate students in grades 5-6, at Hahn Intermediate School, in Davison, MI as part of an improvement plan that resulted in positive outcomes and/or increased math proficiency for students with special needs in mathematics instruction.

Margaret has earned several academic degrees including: an Education Specialist (Ed.S) degree in Curriculum and Instruction with two Minor Cognates: Elementary School Administration & Technology Education, a Master of Arts (MA) degree in Curriculum and Teaching, and a Bachelor of Arts (BA) degree with a Permanent Certification in Elementary Education: Certified K-8 All Subjects and a Highly Qualified—No Child Left Behind (NCLB) (6th Grade Social Studies, Science, & Mathematics) endorsement, all in the College of Education, from Michigan State University, at E. Lansing, MI.