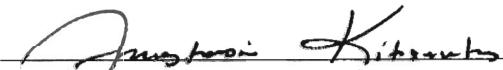
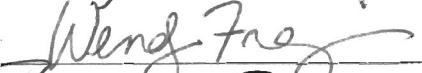
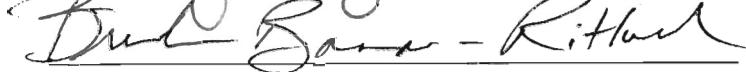
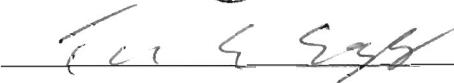
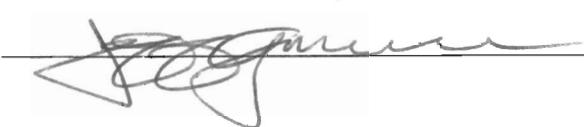


THE EFFECT OF NATURE OF SCIENCE METACOGNITIVE PROMPTS ON  
SCIENCE STUDENTS' CONTENT AND NATURE OF SCIENCE KNOWLEDGE,  
METACOGNITION, AND SELF-REGULATORY EFFICACY

by

Erin E. Peters  
A Dissertation  
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of  
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The Effect of Nature of Science Metacognitive Prompts on Science Students' Content  
and Nature of Science Knowledge, Metacognition, and Self-Regulatory Efficacy

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## ABSTRACT

### THE EFFECT OF NATURE OF SCIENCE METACOGNITIVE PROMPTS ON SCIENCE STUDENTS' CONTENT AND NATURE OF SCIENCE KNOWLEDGE, METACOGNITION, AND SELF-REGULATORY EFFICACY

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The purpose of the present quasi-experimental mixed-method design is to examine the effectiveness of a developmental intervention (4-phase EMPNOS) to teach the nature of science using metacognitive prompts embedded in an inquiry unit. Eighty-eight (N=88) eighth grade students from four classrooms were randomly assigned to an experimental and a control group. All participants were asked to respond to a number of tests (content and nature of science knowledge) and surveys (metacognition of the nature of science, metacognitive orientation of the classroom, and self-regulatory efficacy). Participants were also interviewed to find problem solving techniques and shared experiences between the groups. It was hypothesized that the experimental group would outperform the control group in all measures. Partial support for the hypotheses was found. Specifically, results showed significant gains in content knowledge and nature of science knowledge of the experimental

group over the control group. Qualitative findings revealed that students in the control group reported valuing authority over evidence, while the experimental group reported that they depended on consensus of their group on the interpretation of the evidence rather than authority, which is more closely aligned to the aspects of the nature of science. Four-phase EMPNOS may have implications as a useful classroom tool in guiding students to check their thinking for alignment to scientific thinking.

## 1. Introduction

The purpose of this study is to identify the effect of an intervention focused on nature of science metacognitive prompts on eighth grade students' content knowledge, nature of science knowledge, metacognition, self-regulatory efficacy, and approaches to problem solving. Student understanding of the factual knowledge as well as how the knowledge is generated and validated was gathered to determine any relationships to the intervention. Other factors such as self-regulatory efficacy and metacognition were measured to determine any differences in student mental constructs from interacting with the intervention. Approaches to problem solving were examined to determine any mechanisms for possible changes due to student interaction with the intervention.

### *Background of the Problem*

One of the most prominent reforms in science education is inquiry science (American Association for the Advancement of Science, 1993; National Research Council, 1996). Educators who teach inquiry science strive to improve student understandings and explanations about the real world, the enactment of the nature of science. Too often, inquiry science is taught as either the scientific method or as “hands-on,” disconnected activities (Bybee, 2004) rather than the enactment of the nature of science. The need for student understanding of the relationship between inquiry and the nature of science has been discussed in science education documents for approximately

100 years (Lederman, 2004). Teachers seldom have access to how science operates as a discipline (Hogan & Maglienti, 2001) and revert to teaching science solely as a collection of facts. The result of the lack of knowledge about the nature of science is classrooms where science is transmitted as a rigid body of facts to be accumulated, instead of a way of knowing (vanDriel, Beijaard & Verloop, 2001).

National documents such as the *National Science Education Standards* (1996) or *The Benchmarks for Science Literacy* (1993), even though written for the audience of science teachers, tend to give ambiguous guidelines for teaching science inquiry (Lederman, 2004) and attempts to improve students' understanding of the scientific endeavor have been inadequate (Aikenhead, 1973; Bady, 1979; Lederman & O'Malley, 1990; Mackay, 1971; Mead & Metraux, 1957; Rubba & Andersen, 1978). Reform efforts in science education encourage teachers that inquiry learning is more effective, but are deficient in giving teachers access to the process of teaching inquiry. Additionally, in the current environment of standards-based education, it is easy for science teachers to slip into the mode of disseminating information rather than teaching the ways of knowing that categorize the discipline of science (Duschl, 1990). Leaders in the field of science education call for a more prominent role of the nature of science in curriculum in order to relieve this predicament (McComas, Almazroa, & Clough, 1998), although specific suggestions for implementations in the classroom have not been offered.

### *Statement of the Problem*

Authentic inquiry in a classroom requires the teacher to understand how science operates as a discipline (American Association for the Advancement of Science, 1993;

National Research Council, 1996). If the teacher does not understand how knowledge is obtained and verified as scientific knowledge, then inquiry in the classroom is limited to teaching process skills instead of teaching an understanding about science. If a teacher understands the nature of science, he or she is better able to pose questions to students about *why* they are doing process skills, and establish an environment that allows students to construct meaningful scientific knowledge.

Many teachers have only a surface understanding of how science operates as a discipline (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Bianchini & Colburn, 2000; Chin & Brown, 2000). A metaphor of travel can be used to illustrate the implications of teachers' practical knowledge about the discipline of science. If a person from America travels to France but will only eat at fast food restaurants, they come away with a skewed version of French food. This person would think that France has a very limited selection of food, because it was difficult to find the restaurants he desired. Didactic teaching of science is like fast food, in that didactic teaching offers inadequate pedagogy in order to communicate the nature of science. Inquiry lessons that teach process skills without teaching the rationale behind these skills to the importance of the construction of scientific knowledge offer only a surface understanding of the culture of science. If students are offered "fast food" versions of how science operates as a discipline, students will leave the classroom understanding that there is a collection of facts that are scientific, but not much else (Chin & Brown, 2000; Crawford, 2005; Crawford, Kelly & Brown, 2000; Gijlers & deJong, 2005; Hogan, 1999).

### *Purpose of the Study*

Student understanding of the nature of science provides a conceptual framework to connect the factual knowledge traditionally taught in science (Duschl, 1990; McComas, Almazroa, & Clough, 1998). Learning and applying the aspects of the nature of science helps students to see and think about their world using a scientific way of knowing. Students who use explicit metacognitive skills can evaluate their thinking (Brown, 1987) to determine if it aligns with the rigorous requirements of science. This study used an intervention involving 4-phase embedded metacognitive prompts based on the nature of science (4-Phase EMPNOS) to find out if students can be taught to think scientifically on a metacognitive level utilizing self-regulatory strategies.

The attempt to teach the nature of science didactically is a fruitless one. Students need to think deeply about the nature of science in order to have more than a rote understanding of the discipline of science. Teaching the nature of science out of the context of scientific knowledge and inquiry does not give students access to the important connection between scientific knowledge and knowledge about science (Duschl, 1990). Research shows that teaching teachers about the nature of science by didactic, disconnected or implicit means has limited success (Abd-El-Khalick & Akerson, 2004). Even teachers with an elaborate understanding of the nature of science and who are motivated to teach their students about the nature of science have unproductive outcomes when trying to explicitly identify aspects of the nature of science during inquiry activities (Akerson, Abd-El-Khalick & Lederman, 2000). Abd-El-Khalick and Akerson (2006) have done preliminary work on developing metacognitive strategies to elicit pre-service

elementary teachers' conceptions of the nature of science through concept maps, interviews, and scenarios. Their preliminary work has shown to have some promise in getting teachers to explain their views on the nature of science. The purpose of this study expands on and combines other studies regarding the nature of science and metacognition to better understand if students can be trained to think about their scientific thinking processes through a series of developmental steps leading to independent student self-regulation about aspects of the nature of science.

Students who are self-regulated are metacognitively, motivationally, and behaviorally active participants in their own learning process (Zimmerman, 1989). Metacognition is the ability to think about and evaluate your own thinking processes (Brown, 1987) and is a part of being a self-regulated learner (Zimmerman, 1989). In order to accomplish the goal of learning about the nature of science, students can perform inquiry activities, think about why they are conducting certain processes, and evaluate their thinking in terms of the way a scientist might think about the processes and outcomes. Most research in the field of metacognition and science has been focused on allowing students to conduct scientific activities and listening to group conversations or asking students to talk aloud about their thinking. These types of activities are passive and do not give the students the modeling they may need to understand the aspects of the nature of science. A typical student is not exposed to the culture of science (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Bianchini & Colburn, 2000; Chin & Brown, 2000), so the teacher needs to provide the scaffolding that will illustrate how scientists think and operate. Metacognitive prompts built from the

identified aspects of the nature of science (McComas, Almazroa & Clough, 1998) gives teachers a vehicle to scaffold scientific thinking to students who are underexposed to this type of thinking. Actively prompting students to evaluate their scientific thinking brings them closer to the types of thinking required for effective, authentic scientific inquiry.

Developing metacognitive skills should also be an explicit activity in the science classroom and should focus on personal, behavioral and environmental influences on learning understood through social cognitive theory (Zimmerman, 2000). Research shows that self-regulated skills can be developed through four phases: observation, emulation, self-control and self-regulation (Zimmerman, 2000). Observation entails vicarious induction from a proficient model. In the case of an inquiry unit exploring electricity and magnetism, a teacher can ask students to observe by placing a sample observation in the laboratory worksheet. For example, when asked to rub objects together to make static electricity, this statement should be included in the laboratory worksheet as a proficient model. "Observation: Rubbing the silk on the glass 50 times produces more sparks when pulled than when the silk was pulled from the glass only 10 times." Emulation is an imitation of the general pattern of the model. In the inquiry unit, students can be prompted to emulate the data the scientist generated in the observation phase, "Now use the silk and glass to create static electricity and write an observation using the scientist's description as a model." Self-control shows a guided practice of the mental skill. Students should practice writing an observation and compare it to a similar observation made by a scientist. "Rub the wool and plastic to produce static electricity and write an observation of your findings." After the student writes an observation, they can be presented with a

checklist of the factors a scientist would consider in making the description of the observation: 1) The observation can be reproduced by another person, 2) the observation does not use judgmental language such as, this is good, bad, ugly, 3) my observation has qualities that are measurable such a standard measuring system, instead of a relative comment such as big or small, 4) my observation is descriptive and has no pronouns such as “it”, 5) I would be able to understand my observation months or years from now. Self-regulation is the adaptive use of the mental skill. Students at the final phase, self-regulation, should be able to explain their thinking in terms of a scientific way of knowing. An example of a metacognitive prompt at this level would be “Are your observations relevant to the purpose of the investigation?” A student who progresses through all phases of the self-regulatory model should be able to think about and evaluate their ideas according to a scientific way of knowing. Since metacognition is a part of self-regulation, the four stages can be adopted to help students monitor their thinking in terms of a scientific way of knowing. Instead of expecting deep student thought from merely asking questions that expect students to automatically generate metacognition, students should be gradually scaffolded to the ultimate goal of metacognition using observation, emulation, self-control and self-regulation.

### *Significance of the Study*

The perception of the culture of science is passed down in the general public from generation to generation through science classes. If each generation receives the idea that science is purely a body of knowledge and has no access to knowledge about how science generates and verifies knowledge, the public’s understanding of science will be distorted.

Education has a responsibility to teach students how to think like a scientist in order to continue to be progressive, critical thinkers in our technological future.

To date, only a few specific, measurably successful suggestions for pedagogy resulting in a deeper understanding of science have been proposed (Akerson & Abd-El-Khalick, 2003; Beeth & Hewson, 1999; Davis, 2003). Perhaps this has occurred because the nature of science has been taught as content knowledge rather than as an epistemology. This study takes the perspective that the nature of science is a way of knowing, an epistemology and utilizes metacognition strategies as a method to develop student metacognition about thinking processes and validation of knowledge. Some evidence for incorporating metacognition as a learning component for epistemology comes from the ThinkerTools curriculum (White & Frederickson, 1998; White, 1993). The ThinkerTools curriculum incorporated a reflective piece within an inquiry unit to encourage monitoring the scientific rigor of the specified outcomes. Students using ThinkerTools showed increases in content knowledge and inquiry skills.

The present study combined and extended the understandings found in the literature regarding the nature of science, metacognitive processes and self-regulatory processes. Recently there has been convergence in the literature about the important aspects of the nature of science, and this study attempts to implement the seven identified aspects of the nature of science in learning modules to guide student thinking processes to become more scientific. This study also incorporates findings from recent literature that students are able to think metacognitively (Davis, 2003), and adds to the current research which tends to expect students to independently generate metacognition by creating and

implementing active, developmental prompts for students. This study also attempts to operationalize Zimmerman's ideas that four stages can be used to train self-regulation. This study extends Zimmerman's ideas into the realm of metacognition. The results of this study could illustrate processes and interactions that will help scaffold metacognitive thinking in naïve scientific thinkers to become more proficient.

The field of the nature of science still requires a great deal of exploration. In order to fully understand how people learn to understand epistemologies such as the nature of science there needs to be more dialogue between the scientific community and science teachers (Glason & Bentley, 2000), more understanding of student views of the nature of science (Zeidler, Walker, Ackett & Simmons, 2002), and more understanding of how teachers who have a sophisticated view of the nature of science can incorporate these ideas into classroom practice (Akerson & Abd-El-Khalick, 2003). Several researchers have begun to take a non-traditional view of the nature of science in order to expose some of the mechanisms to understanding. Wong (2002) suggests that science educators and science education researchers abandon the search for commonalities in the nature of science and begin to embrace the diversity of the nature of science in order to translate ideas to the classroom. Bell and Lederman (2000) looked at scientists who had sophisticated but different views on the nature of science to see how they made decisions based on their views. Their research showed no differences in decision making due to the surprising result that the scientists made their professional decisions based on personal values, morals/ethics and social concerns. Bybee (2004) calls for less of an emphasis in teaching strategies regarding the nature of science and more attention to the relation of

the nature of science and contemporary learning theory. The field of the nature of science has been successful in defining operational elements of the nature of science and now it is time for the field to progress into cognitive science domains. To this point, scholars have taken a fluid topic such as the nature of science and have identified aspects of the field that are relevant for the K-12 setting (Abd-El-Khalick & Lederman, 2000; Lederman, 1992) but have had little success in teaching these aspects to teachers (Akerson & Abd-El-Khalick, 2000; Bell, Lederman, Abd-El-Khalick, 2000; Schwartz & Lederman, 2002) and students (Akerson, Flick, & Lederman, 2000; Clough, 1997; Hogan, 2000; Hogan and Maglienti, 2001). The incorporation of self-regulatory strategies may serve as an effective alternative for teaching the nature of science because self-regulatory strategies provide necessary feedback to students regarding their thinking structures.

### *Definitions*

*Inquiry teaching:* Inquiry teaching sets an environment and interactions that result in the involvement of students that leads to understanding. Involvement in learning implies possessing skills and attitudes that permit students to seek resolutions to questions and issues while the students construct new knowledge.

*Nature of science:* The phrase “the nature of science” characterizes the epistemology of science as the values and beliefs inherent to the development of scientific knowledge (Abd-El-Khalick & Lederman, 2000; Lederman, 1992).

*Epistemology:* Epistemology is defined as the study of knowledge and justified belief.

*Observation:* Observation is the first of a four phase series of self-regulatory processes. Observation occurs when a student notes the process of a model throughout a specific task.

*Emulation:* Emulation is the second of a four part self-regulatory process. The emulation phase occurs when a student attempts to try to be like the model and receives support.

*Self-control:* Self-control is the third of a four part self-regulatory process. The self control-phase occurs when the student independently uses the strategy in similar contexts

*Self-regulation:* Zimmerman (1998) has identified three socially mediated levels that contribute to a person's self-regulatory strategies: behavior, person, and environment. A person behaves within an environment and reacts based on the consequences of his or her behavior.

*Metacognition:* Metacognition can be defined as the executive functions that control actions or the ability to recognize thinking patterns and evaluate them (Weinert, 1987) and is a portion of the continuum of self-regulation. Metacognition is the ability to think about and evaluate your own thinking processes (Brown, 1987) and is a part of being a self-regulated learner because self-regulatory strategies provides the mechanisms for students to regulate their cognition and learning (Zimmerman, 1989).

*Content Knowledge:* Content knowledge is a term used to represent the sum total of all knowledge in an area expertise, in this case science.

*Self-regulatory efficacy:* Self-regulatory efficacy is an impression that one is capable of performing in a certain manner or attaining certain goals by monitoring the outcomes. The term is used in this context in terms of self-regulatory efficacy of the ability to learn a topic in science.

## 2. Literature Review

This chapter reviews selected literature related to teacher and student learning about the nature of science. The first section discusses the aspects of the nature of science that are most appropriate for the K-12 setting. The second section discusses current findings in teacher understanding of the nature of science, the delivery of the nature of science by teachers in a classroom, and the resulting student learning outcomes. The next section discusses the role of self-regulatory processes in developing ways of knowing about science in students. The last section addresses how metacognition can be used to check student understanding with guidelines given by the scientific community on scientific knowledge.

### *Consensus on the Nature of Science*

The phrase “the nature of science” characterizes the epistemology of science as the values and beliefs inherent to the development of scientific knowledge (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). Philosophers, historians, scientists and science educators have no consensus on the specific aspects of the nature of science (Bell, 2004). However, the disagreements that are still present regarding the definition of the nature of science are not relevant to the K-12 setting (Lederman, 2004). For example, the argument of the existence of an objective reality is not as appropriate in the K-12 setting as the discussion of how knowledge is verified in the scientific realm. Science

educators and researchers have converged on the more general aspects of the nature of science, and more recently there has been an agreement on the elements of the nature of science (Driver, Leach, Millar, & Scott, 1996; Matthews, 1994; McComas et al., 1998; Smith, Lederman, Bell, McComas, & Clough, 1997). The nature of science can be understood as the culture of science. Scientists have inherent, agreed upon processes and assumptions (Lederman, 1999) that help them to construct meaningful knowledge. For example, workbench scientists use their creativity and inquire to expand the current scientific body of knowledge. Workbench scientists present their findings to professional scientists for verification (Magnusson, Palinscar, & Templin, 2004). In this way scientists work as a community to uphold the processes and assumptions that comprise the nature of science. The literature converges on seven aspects of the nature of science that defines science as a discipline: a) scientific knowledge is durable, yet tentative, b) empirical evidence is used to support ideas in science, c) social and historical factors play a role in the construction of scientific knowledge, d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, f) science is a creative endeavor, and g) science and technology are not the same, but they impact each other (Lederman, 2004; McComas, 2004).

The majority of the educational research dealing with the nature of science is in agreement with the aspects, but disagrees with what constitutes knowledge of the nature of science. Some researchers envision student knowledge of the nature of science as explicit description of the aspects, while others judge student knowledge to be more

implicit in their reasoning (Bybee, 2004; Deboer, 2004). Evidence of these aspects of the nature of science as the foundation for how science operates as a discipline can be found in science education research journals, books about the philosophy and epistemology of science, and practitioner handbooks (American Association for the Advancement of Science, 1993; National Research Council, 1996).

### *Pre-service Teachers' Concepts of the Nature of Science*

The majority of the recent research in the nature of science lies in examining teacher conceptions regarding the nature of science and how this translates to students through inquiry activities (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000; Akerson & Abd-El-Khalick, 2000; Bell, Lederman, Abd-El-Khalick, 2000; Schwartz & Lederman, 2002). This research attempts to provide guidance to further the development of successful teacher training programs designed to move the scientific education community to more of an understanding of science as both factual knowledge and how the factual knowledge is built and away from an understanding of science as solely a body of factual knowledge.

Much of the focus of research projects is on pre-service teachers, and many of these studies have shown to be only moderately, if at all, effective. In a qualitative exploratory study focusing on pre-service science teachers who had naïve views of the nature of science, researchers provided an intervention that consisted of explicit reflective instruction on the nature of science that showed to be somewhat effective. The *View of the Nature of Science Questionnaire-Form B* (VNOS-B) was used to determine prior knowledge of the pre-service teachers. The intervention consisted of readings that

presented more informed views of the nature of science, and eleven activities that helped the pre-service teachers examine their understandings of the nature of science. Small and large group discussions followed the activities and focused on metaconceptual discourse of the nature of science. Following the intervention, the VNOS-B was given to the participants and exit interviews were held. Data sources included the pre-test VNOS-B and the post-test VNOS-B as well as transcripts from interviews. Although only a minority of pre-service teachers had informed views of the nature of science, the participants showed substantial changes in their cognition of the nature of science. However, four of the twenty-eight participants showed no change in their conceptions of the nature of science. Researchers report that the main influences on success were motivation, cognition and worldview of the pre-service teacher (Abd-El-Khalick & Akerson, 2004). Pre-service teachers who had high motivation, more prior knowledge in the nature of science and a broader worldview had more success in learning about the nature of science from the intervention.

In a similar study, elementary pre-service teachers who held naïve views on the nature of science gained substantially in targeted nature of science concepts except in empirical, subjective, and social aspects of the nature of science (Akerson, Abd-El-Khalick, & Lederman 2000). Fifty pre-service teachers in an elementary science methods course were asked to engage specifically in ten nature of science activities that addressed aspects of the empirical, tentative, subjective, imaginative and creative, and social and cultural nature of science. *Views of the Nature of Science Questionnaire (VNOS)* (Lederman, 1992) was used to assess any prior knowledge of the participants. Classroom

discussions as well as reflective writing assignments followed the nature of science activities and explicitly addressed the seven aspects of the nature of science. At the end of a semester of instruction, the *Views of the Nature of Science Questionnaire* was given and exit interviews were conducted. The data sources included pre- and post- instructional answers from the *Views of the Nature of Science Questionnaire*, transcripts from the exit interviews, and reflective writing samples. Before instruction, the majority of the participants had naïve understanding of the nature of science. There were substantial gains in understanding of the tentative, observation versus inference, and the relationship between laws and theories aspects of the nature of science. However, smaller gains were had in empirical, subjective, and social and cultural aspects of the nature of science.

Some success in learning aspects of the nature of science was found in a study where pre-service teachers learned first about the nature of science and then separately learned how to teach the elements of the nature of science in their instruction (Bell, Lederman, Abd-El-Khalick, 2000). In a study involving two beginning secondary science teachers, it was found that more extensive content knowledge in science influenced the participants' understanding of the nature of science. However, this understanding of the nature of science was necessary but not sufficient in the ability to connect aspects of the nature of science into classroom lessons (Schwartz & Lederman, 2002). Data for the two beginning teachers was collected as they progressed through their Masters' program and into their first year of teaching. Data sources included *Views of the Nature of Science Questionnaire - Form C*, interviews, lesson plans, and classroom observations. One teacher in the study had less developed content knowledge and found it difficult to

recognize when it was appropriate to incorporate nature of science aspects into lesson plans. The other teacher in the study found it easier to incorporate nature of science aspects into lesson plans that were in a content area in which he was familiar.

In another attempt at teaching pre-service teachers about the nature of science, researchers examined the effects that taking a history of science class had on pre-service teachers' conceptions of the nature of science (Abd-El-Khalick & Lederman, 2000). They found that taking a history of science course does not support nature of science concepts. Although there has been a great deal of study attempting to understand knowledge of the nature of science in pre-service teachers, there is not a definitive positive intervention developed that greatly increases a pre-service teacher's awareness of the nature of science.

#### *Explicit Instruction of the Nature of Science*

Many of the studies regarding the nature of science reported gains in teacher understanding through interventions involving explicit instruction where the nature of science was made visible within instruction (Bianchini & Colburn, 2000; Gess-Newsome, 2002; Khishfe & Abd-El-Khalick, 2002). In an action research study, an experienced teacher worked with an experienced researcher to identify aspects of the nature of science taught in an inquiry activity. Small group inquiries in the classroom and whole class discussions of the inquiry were videotaped during three units of inquiry study in the experienced teacher's classroom. The twenty hours of videotape collected were analyzed separately by the researcher and the teacher. The study found that it was difficult to present cogent and coherent instruction on the nature of science through inquiry and

illustrated the teacher's pivotal role in designing class discussions in what science is and how scientists work (Bianchini & Colburn, 2000).

Some success in teaching pre-service elementary teachers was found in an intervention that involved explicit instruction in the nature of science. Teachers were assigned one journal question per week for five weeks on the following topics: student conceptions about science teaching; the definition, nature and organization of science; goals of science instruction; role of the teacher; and gender and equity issues in science teaching. A final journal entry asked participants to compose a philosophy of science. The papers were analyzed by first organizing the conceptions into one of five categories: product views, process views, blended views, unclear views, and no answer. An initial agreement level with another researcher of the data sort was 84%. Following a second data sort, the agreement level rose to 92%. Participants of the study views changed from science as primarily a body of knowledge to a more appropriate blended view of science as a body of knowledge generated through active application of science inquiry (Gess-Newsome, 2002).

In a comparative study, researchers taught the same science content to two groups of sixth grade students (n=62). A six-item open ended questionnaire was given to the students in tandem with individual interviews to determine their understanding of the nature of science. The control group received only implicit instruction of the nature of science via the content, and the experimental group received explicit instruction of the nature of science. A purposeful group, eight participants from the control and eight participants from the experimental group, was chosen for follow up interviews. All

students were given the questionnaire after the intervention. Interview transcripts were coded separately by the researchers and then compared for consistency. There was a 95% agreement with the researchers' analyses. The control group showed no significant gains from naïve to informed knowledge of the nature of science, but the experimental group showed significant gains in the aspects of tentative, observation vs. inference, empirical and creative nature of science (Khishfe & Abd-El-Khalick, 2002). Although it is intuitive to think that just by conducting inquiry that students will understand how scientists operate, there is a body of research that demonstrates explicit instruction in the nature of science has been found to be more effective.

#### *Comparing Scientists' Thinking with Student Thinking*

A purpose of inquiry is to provide opportunities for students to reason scientifically in a way that is authentic to the practice of science. Hogan and Maglienti (2001) examined the criteria that middle school students, non-scientist adults, and scientists use to rate the validity of conclusions drawn by hypothetical students. The 45 volunteer participants in this study were 24 eighth graders, 21 non-scientist adults drawn from one workplace, and 16 science professionals. Students' achievement level was assessed using a five-level scale and the adults' achievement level was inferred from their credentials, which were documented on a questionnaire. Each participant evaluated 10 conclusions that hypothetical students made based on a given body of evidence. The participants were interviewed, probing for their criteria for determining a valid conclusion. Analyses focused primarily on how participants explained and justified their ratings of each conclusion, from which a coding scheme was developed. The responses of

students and non-scientists differed from the responses of scientists because the scientists emphasized criteria of empirical consistency or plausibility in the conclusions. The study found gaps in the processes of reasoning that scientists and non-scientists, including students, used to build new knowledge and that the levels of rigor and specificity were lower with the non-scientists. New ways of teaching students how to think conceptually like scientists are desirable for progress to be made in this area (Hogan and Maglienti, 2001). This study illustrates the need for students to be explicitly exposed to the inherent guidelines that govern how knowledge is acquired and verified in the scientific community. When students can adequately understand the nature of science, they can proceed in meaningful inquiry in the classroom.

#### *Translating Knowledge of the Nature of Science into Classroom Practice*

Even with modest gains in understanding of the nature of science, teachers still fail in translating this knowledge into classroom practice. A study of fourteen pre-service teachers with adequate knowledge of the nature of science showed that there was not much instruction involving the nature of science due to a preoccupation with classroom management and the mandated curriculum (Abd-El-Khalick, Bell & Lederman, 1998). The selected pre-service teachers had completed a BS degree or MS degree in their scientific discipline and were pursuing a master of arts in teaching degree, so all participants in the study had adequate content knowledge in science. First the pre-service teachers were given a seven item open-ended questionnaire in conjunction with individual interviews and then participated in fifteen nature of science activities. Data sources included copies of all participants' daily lesson plans for the 12-week student

teaching period, classroom videotapes, supervisors' clinical observation notes, and each participant's portfolio. After the student teaching period, the researchers interviewed the participants in order to validate responses on the nature of science questionnaire and to generate in-depth profiles of the participants' views. The researchers independently analyzed three identical, randomly selected samples of each of the data sources. More than 90% agreement was achieved for explicit references to the nature of science. The teachers' views of the nature of science were consistent with traditional teachings of the scientific enterprise, and did not include an informed understanding of the nature of science. Further, analysis of the participants' lesson plans showed very little evidence of planning to teach the nature of science. Even pre-service teachers who have a great deal of content knowledge have difficulty translating the overarching understanding of the nature of science into their lessons.

In a study involving pre-service teachers in Spain, researchers found that there was no correspondence between teacher conceptions of the nature of science and classroom practice (Mellado, 1997). Two groups of pre-service teachers, elementary level specialists and science graduate students, were examined to see if their content knowledge influenced their behavior in the classroom. Four teachers, two from each group, were selected for the study. Data sources included microteaching lessons, tape recordings of semi-structured interviews, personal documents and classroom observations. These sources were analyzed in terms of the participants' conceptual understanding of the content and of the nature of science, and in terms of the participants' classroom practices. In all four cases, there was a lack of reflection on the nature of

science which led to contradictions in their philosophy of science and a lack of coherence in their content knowledge.

In Australia, a study showed that even when both teacher and students believed science to be an evolving discipline, the status quo in the classroom was in direct contrast to this belief (Tobin & McRobbie, 1997). This interpretive study sought to find out what was happening in a science class and why the students and teacher acted as they did. The researchers visited the school each day for four weeks to gather data in the form of videotape of classes, field notes and analytic memoranda, interviews with the teacher, six students, teacher colleagues, and administrators. A twenty item survey selected from *Views about Science* was administered to the teacher and students at the beginning of the study in order to inform the questions for the interview. The class was taught with a traditional lecture format, and teachers and students alike were comfortable with the format although it was opposed to their belief about how science is done. Although the teacher and students felt that science is a dynamic discipline, the expression of science in the classroom was consistent with scientism. The scientific knowledge was presented in the classroom as beyond question and criticism and that the information presented was in its final form. Further, the students had somewhat of an understanding that scientific knowledge was tentative, but were satisfied with information being transmitted in an authoritarian model.

Even college science faculty members who had very sophisticated understandings of the nature of science, when collaborating on the development and implementation of a integrative non-major science course, did not offer any explicit instruction in the nature

of science during the course (Southerland, Gess-Newson & Johnston, 2003). This research focused on three scientists' beliefs and actions as they designed and implemented an integrated science course for non-majors with a focus on the nature of science. Seventeen planning sessions, a fifteen week period of class sessions, ten class debriefing sessions, and instructor interviews after the course were used as data sources. Three stages of coding were employed in the analysis: open, axial, and selective. The open coding brought forth the themes of the data, the axial coding grouped together different sources of the data into the respective themes, and concept maps were made during the selective coding phase to show any interconnections. The researchers acknowledge that it is difficult to differentiate between beliefs about the nature of science and beliefs about teaching the nature of science, and that they were mindful of this complexity when in the analysis phase of the study. The scientists beliefs were categorized as science as problem solving, science as a good story, and science as inquiry. Although their beliefs about the nature of science were sophisticated, the outcomes of the planning sessions of the class resulted in an emphasis in process skills, rather than in the nature of science. Several of the sessions of the course showed promise in explicitly instructing students in the nature of science, but the majority of the sessions were conducted using traditionally didactic methods.

In a case study of an experienced teacher who sought help from researchers in how to apply her sophisticated understanding of the nature of science to her fourth grade classroom had difficulty explicitly teaching any elements of the nature of science (Akerson & Abd-El-Khalick, 2003). This fourth grade teacher sought help from the

researchers in teaching the inferential, tentative, and creative aspects of the nature of science to her students. This interpretive study used analytic induction for collecting data over the period of one year. The primary data sources were weekly observations and videotapes of the science lessons, assessments of the teachers' nature of science views as measured by the *Views of Nature of Science Questionnaire- Form B* before, during and after the study, individual interviews, and a weekly reflective log. It was found that although the teacher had the necessary prior knowledge to teach the chosen aspects of the nature of science to her fourth grade students, her knowledge was not sufficient in translating this knowledge into practice. The teacher had difficulty identifying appropriate moments to interject the nature of science, even with model lessons being taught by the researcher. Apparently, the mechanisms that help operationalize the understanding of the nature of science into classroom instruction are poorly understood (Mellado, 1997; Tobin & McRobbie, 1997; Southerland, Gess-Newson & Johnson, 2003).

#### *Teacher Competence in the Nature of Science*

There is consensus about the more important features of the nature of science, and there is insight to some of the factors that contribute to developing an understanding of the nature of science in teachers. These include experience in science teaching, an active role in translating nature of science knowledge into classroom practice, and explicit instruction of the concepts of the nature of science. Beginning science teachers do not have the experience to develop a set of knowledge and beliefs, which is usually consistent with how teachers act in practice (van Driel, Beijaard & Verloop, 2001).

The next step is to examine the research that looks for ways to develop teacher competence in the nature of science. One study examined in-service teacher for factors involved in competence in teaching the nature of science (Bartholomew & Osborne, 2004). They found five critical domains necessary for competence 1) teachers knowledge and understanding of the nature of science , 2) teachers conceptions of their own role in the classroom, 3) teachers' use of discourse, 4) teachers' conceptions of learning goals, and 5) the nature of classroom activities. Bartholomew and Osborne (2004) developed a continuum that helps to identify the amount of competence teachers have in each of the domains. Teachers continue to develop their views of the nature of science through their professional experiences (Nott & Wellington, 1998), as a result continuous, quality professional development may be key in emergent competence in teacher knowledge of the nature of science. A professional development activity involving the communication of recent developments in the field of biotechnology by scientists to teachers showed that scientists demonstrated a strong commitment to empiricism and experimental design, but not necessarily the nature of science (Glason & Bentley, 2000). Developing a competence in teaching the nature of science is indeed a complicated endeavor when the scientific community itself has difficulty in expressing the nature of science comprehensively. However, continued professional development of in-service teachers in the nature of science has shown some gains in nature of science knowledge. As previously mentioned pre-service teachers have had limited gains in knowledge of the nature of science because they are more occupied with issues such as classroom management. However, it has been shown that in-service teachers have shown some gains in this type of knowledge. Most

professional development attempts in the literature use lectures or activities to teach. Perhaps professional development that utilizes principles from learning theory to teach teachers the nature of science as a way of knowing would produce larger gains in teaching understanding of the nature of science.

### *Student Understanding of the Nature of Science*

Investigations into student understanding of the nature of science originate in different realms, but tend to converge on the same finding, that students need to experience cognitive dissonance in order to eliminate archaic conceptions of the nature of science. When students were presented with discrepant events in a long-term setting, their notions of the nature of science began to conform to professional scientists' understanding of the nature of science (Clough, 1997). Drawing from six years of experience teaching high school, Clough presents an argument for sustaining students' dissatisfaction with archaic notions of the nature of science. Some of the suggested strategies include initiating disequilibrating experiences, maintaining pressure on students' misconceptions, and the teacher's role as an influence in setting up an environment that is conducive to the nature of science.

Students in another classroom instructed in canonical understanding of science did not show maturity in their understanding of the nature of science, but after incorporating student ideas, including exploration of misconceptions, into instruction the students showed gains in their understanding of the nature of science (Akerson, Flick, & Lederman, 2000). This study explored whether and how primary teachers recognize student ideas, and whether and how they react to student ideas. Two experienced teachers

and one intern teacher were videotaped as they taught an eight week unit on astronomy. Data sources included pre- and post- interviews, a mid-point stimulated recall interview, and classroom videotapes. It was found that the more experienced teacher used methods that elicited student ideas that were not yet developed, and that the least experienced teacher used methods that dismissed student ideas. Again, it has been shown that less experienced teachers such as pre-service teachers are not yet ready to develop student ideas about how science is a way of knowing.

Hogan (2000) suggests that science education researchers can gain a better understanding of how students operationalize the nature of science by dividing up their knowledge into two categories: distal knowledge, how students understand formal scientific knowledge, and proximal knowledge, how students understand their own personal beliefs and commitments in terms of science. Hogan believes that by seeing how the two categories of knowledge intersect, researchers can gain access into how to better develop student understanding of the nature of science.

Other researchers have found that students feel that the absolute “truths” of science can be derived through diligent observation (Bell, 2004). This “common sense” epistemology is characterized by children’s belief that knowledge can be generated directly through observation and that the discipline of science is a collection of facts (King & Kitchener, 1994; Kitchener & King, 1981; Kuhn, Amsel, & O’Loughlin, 1988). The propensity of science curriculum to present disjointed activities without any overriding schema describing the role of the nature of science may reinforce students’ absolute views about scientific knowledge (Bell, 2004).

Information about how students acquire knowledge during discovery learning processes is important to examine due to the social nature of science inquiry and use of the nature of science. Giljers and de Jong (2005) conducted a study investigating the relationship between prior knowledge and students' collaborative discovery learning processes. In this study, 15 pairs or dyads of students 15 and 16 years old worked on a discovery learning task in the field of physics. The students took pretests probing their generic and definitional knowledge of physics. Students then worked in pairs on a computer assisted unit where they were instructed to talk with their partner. The face-to-face discussions were recorded and analyzed first for utterances, a distinct message from one student to another, then categorized as on-task or off-task. The findings show if both students assume the proposition was true and it was not, it is more difficult to resolve the misconception. If the zone of proximal knowledge was ideal within the dyad, then the pair was more successful in the discovery task, but if high ability students are paired with low ability students, the zone is too distant, and the low ability student does not benefit from the dyad communication. The implication for teachers from this study is that the teacher must observe group processes and intervene when frustrating situations occur. This study also offers a possible mechanism for teaching in teaching students the nature of science.

In another study of student understanding of the nature of science, it was found that students views depended greatly on moral and ethical issues, rather than in newly presented material (Zeidler, Walker, Ackett, & Simmons, 2002). In phases one and two of this three part study, eighty-two students were identified from 248 high school students

represent “critical cases” of contrasting ethical viewpoints. In phase one of the study, 248 students were asked to respond to open-ended questions on the following aspects of the nature of science: tentativeness, empirical, social and cultural, and creative. Phase two of the study began one week after answering the phase one when students were presented with a socioscientific scenario based on their moral reasoning or ethical beliefs. Phase three of the study began after the selection of 41 pairs of students that had conflicting moral views. Students were probed with questions designed to elicit participants’ epistemological reasoning, facilitate their explanations for causal justifications of evidence, and to engage them in challenging other participants’ reasoning. The data were analyzed for their convergence, agreement, and coverage of the emerging themes. The study showed that participants, even when engaged with structured argumentation, still see science as static and fixed, non-subjective, not influenced by social conditions, and rote rather than creative. Instead of changing their archaic notions of the nature of science, students tended to hang on to their prior understandings even when presented with conflicting information.

Undergraduate science majors were found to change their conceptions of the nature of science during a long-term project that offered many opportunities to discover conflicting information (Ryer, Leach, & Driver, 1999). In a longitudinal interview study, eleven undergraduate students were asked questions about the nature of science as they worked on a long-term project. Data emerged in three themes: the relationship between data and knowledge claims, the lines of scientific enquiry, and science as a social activity. Student showed development in their ideas about empirical evidence supporting

claims in science, as well as understanding how theoretical ideas in science can change over time due to new data. However, the idea that scientists work as a community were underrepresented in this study. It appears from the research that students will change their conceptions of the nature of science to more sophisticated through long-term exposure to discrepant information, but before that can be accomplished more information about student processes in learning the nature of science is needed.

#### *Attempts to Measure Understanding of the Nature of Science*

For over thirty years the development of teachers' and students' conceptions of the nature of science has been a major concern (Lederman, Wade, & Bell, 1998). The first formal assessments written in the 1960s, emphasized a quantitative assessment. Many of the instruments used in the research studies regarding the nature of science originated as objective, pencil and paper assessments which subsequently changed into more descriptive instruments. Toward the end of the 1990's several researchers make arguments that traditional paper and pencil assessments would not be adequate in fully explaining what needs to be known about teacher and student conceptions of the nature of science (Lederman, Wade, & Bell, 1998). Researchers responded to this argument by conducting interviews along with surveys or by including several open-ended questions on surveys in order to get more descriptive data. Table 1 shows the progression of nature of science instruments over time.

Table 1

*Nature of Science Instruments*

Date	Instrument	Author(s)
1954	Science attitude questionnaire	Wilson
1958	Facts about science test (FAST)	Stice
1959	Science attitude scale	Allen
1961	Test on understanding science (TOUS)	Cooley & Klopfer
1962	Processes of science test	BSCS
1966	Inventory of science attitudes, interests, and appreciations	Swan
1966	Science process inventory (SPI)	Welch
1967	Wisconsin inventory of science processes (WISP)	Literacy Research Center
1968	Science support scale	Schwirian
1968	Nature of science scale (NOSS)	Kimball
1969	Tests on the social aspects of science (TSAS)	Korth
1970	Science attitude inventory (SAI)	Moore & Sutman
1974	Science inventory (SI)	Hungerford & Walding
1975	Nature of science test (NOST)	Billeh & Hasan
1975	Views of science test (VOST)	Hillis

1976	Nature of science knowledge scale (NSKS)	Rubba
1978	Test of science-related attitudes (TOSRA)	Fraser
1980	Test of enquiry skills (TOES)	Fraser
1981	Conception of scientific theories test (COST)	Cotham & Smith
1982	Language of science (LOS)	Ogunniyi
1989	Views on science-technology-society (VOSTS)	Aikenhead, Fleming & Ryan
1990	Nature of science survey	Lederman & O'Malley
1992	Modified nature of scientific knowledge scale (MNSKS)	Meichtry
1992	Views of nature of science questionnaire	Lederman
1995	Critical incidents	Nott & Wellington
1996	Philosophy of science survey (PSS)	Alters

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One of the first instruments that was widely used to measure the nature of science is the *Test on Understanding Science* (Cooley & Klopfer, 1961). This sixty-item multiple choice test had three subscales used to measure: 1) understanding about the scientific enterprise, 2) the scientist, and 3) the methods and aims of science. A sample item from this instrument follows:

Item #2: Among the hundreds of scientific societies in various countries throughout the world, we find that

- (a) Scientists voluntarily join the societies related to their specific field.
- (b) National governments generally direct these societies.
- (c) Membership is generally restricted to scientists of one nation.
- (d) National governments are seldom interested in these societies.

The *Science Process Inventory (SPI)* (Welch, 1966) is a 135-item forced choice inventory that uses agree/disagree that assesses an understanding of the methods and processes by which scientific knowledge evolves. There are no subscales on the SPI.

The *Wisconsin Inventory of Science Processes (WISP)* (Scientific Literacy Research Center, 1967) contains ninety-three statements which allow respondents to choose from selections as “accurate”, “inaccurate”, or “not understood”. However, when analyzing responses, the choices “inaccurate” and “not understood” are synonymous, reducing the scale to an agree/disagree format. This instrument was designed for and validated by high school students.

The *Nature of Science Scale (NOSS)* (Kimball, 1968) is used to compare science teachers and scientists epistemologies regarding science. It consists of twenty-nine items using a scale of “agree”, “disagree”, or “neutral”. The views of the nature of science on this scale are consistent with Bronowski (1956) and Conant (1951) and makes the following eight declarations: 1) the fundamental driving force in science is curiosity concerning the physical universe, 2) science is a dynamic, on-going activity, rather than a static accumulation of information, 3) science aims at every-increasing

comprehensiveness and simplifications using mathematics as a simple, precise method of stating relationships, 4) there is no “one” scientific method, but as many methods as there are practitioners, 5) the methods of science are better characterized by some value-type attributes than by techniques, 6) a basic characteristic of science is faith in the susceptibility of the physical universe to human ordering and understanding, 7) science has a unique attribute of openness, both of mind and of the realm of investigation, and 8) tentativeness and uncertainty are characteristics of all science (Lederman et al., 1998). The development and validation procedures were performed with college graduates.

The *Nature of Science Test (NOST)* (Billch & Hasan, 1975) is a sixty item multiple choice assessment designed to address the following aspects of the nature of science: 1) assumptions of science, 2) products of science, 3) processes of science, and 4) ethics of science. This assessment has two types of items, one type to measure the individual’s knowledge of the assumptions and processes of science, and characteristics of knowledge, and the other type of item presents situations that require the individual to make judgments that elicit their views of the nature of science.

The *Views of Science Test (VOST)* (Hillis, 1975) is a forty item instrument used to measure an individual’s understanding of the tentativeness of science. The forty items are statements that pose scientific knowledge as either tentative or static. The respondents express their agreement with the statement using a Likert scale.

The *Nature of Scientific Knowledge Scale (NSKS)* (Rubba, 1976) is a forty-eight item designed to measure secondary students’ understanding of the nature of science. It is a Likert scale response format with five choices: strongly agree, agree, neutral, disagree,

and strongly disagree. The view of the nature of science this scale adopts is aligned with nine factors specified by Sholwalter (1974): tentative, public, replicable, probabilistic, humanistic, historic, unique, holistic, and empirical.

The *Conceptions of Scientific Theories Test (COST)* (Cotham & Smith, 1981) is a forty item attitude inventory that provides for a non-judgmental acceptance for alternative conceptions of science. The aspects of scientific theories addressed in the instrument are ontological implications of theories, testing of theories, generation of theories, and choice among competing theories. A sample item from the assessment follows.

Item #35:      When a scientific theory is well supported by evidence, the objects postulated by the theory must be regarded as existing.

The *Views on Science-Technology-Society (VOSTS)* (Aikenhead, Ryan & Fleming, 1989) is a pool of 114 multiple choice items that address science-technology-society issues such as science and technology, influence of society on science/technology, influence of science/technology on society, influence of school science on society, characteristics of scientists, social construction of scientific knowledge, social construction of technology, and nature of scientific knowledge. The VOSTS was developed and validated for grade 11 and 12 students.

The *Nature of Science Survey* (Lederman & O'Malley, 1990) is an open-ended seven item survey designed to elicit participant's aspects of tentativeness in science. It is to be used in conjunction with follow-up interviews. The seven items focus on these aspects of the tentativeness of science: 1) the tentativeness of theories, 2) atomic models, 3) differences between scientific theories and laws, 4) similarities and differences of art

and science, 5) creativity in science, 6) differences between scientific knowledge and opinion, and 7) differing interpretations of data sets.

Several versions of an instrument originally developed by Lederman (1992), the *Views of Nature of Science* (VNOS), have been used mostly by the researchers who focus on pre-service teachers. Items in this instrument ask teachers to explain scientific activities in their classroom. Researchers then use a rubric to identify when teachers explicitly mention one of the seven identified aspects of the nature of science.

The *Modified Nature of Scientific Knowledge Scale* (MNSKS) (Meichtry, 1992) is a thirty-two item instrument used to measure the following concepts: creative, developmental, testable, and unified aspects of scientific knowledge. The MNSKS was developed and validated with 6<sup>th</sup>, 7<sup>th</sup> and 8<sup>th</sup> graders.

The *Critical Incidents* (Nott & Wellington, 1995) is descriptions/scenarios of classroom events designed to bring forth teacher conceptions of scientific knowledge in the context of the classroom. Teachers are expected to answer the following three questions given a scenario: 1) What would you do? 2) What could you do? and 3) What should you do?. An example scenario is a situation in which a laboratory activity does not yield the expected data. The way the teacher answers shows how they interpret the nature of science.

The *Philosophy of Science Survey* (PSS) (Alters, 1996) is a twenty item survey developed to assess philosophy of science issues that are relevant to the science education classroom. The survey has fifteen Likert scale questions with a range of four responses

(strongly agree, agree, disagree, strongly disagree) and five open-ended questions about the nature of science. A sample item from the PSS follows.

Item #9:       Scientific knowledge is tentative, and should never be equated with truth.  
                  It has only temporary status.

Other instruments have been developed to be more descriptive in explaining student achievement in the nature of science such as Scientific Inquiry Capabilities and Scientific Discovery (Zachos, Hick, Doane, & Seargent, 2000). Although the objective, pencil and paper assessments have been altered to include more description of mechanisms, there is still a need for improved assessments regarding both the teacher and student understandings of the nature of science.

#### *Influences of Scientific Epistemology on Instruction*

The way a teacher understands science as a way of knowing greatly influences how the teacher implements instruction and how the students perceive the discipline of science (DeSautels & Larochelle, 2005). Teachers often set up discourse in science as a pattern of question asking, students answer questions and teacher evaluates the student answer (Lemke, 1990). Over years of analyzing discourse of teachers and students in the classroom, Lemke (1990) has established that primarily the following pattern is followed to conduct “discussions” in the classroom: teacher preparation, teacher question, teacher calls for bids, student bid for answer, teacher nomination, student answer, teacher evaluation, and teacher elaboration. When teachers establish such attitudes toward science, they evoke the idea that science is a collection of final facts and that learning science is the accumulation of these facts. Students learn that academic success depends

upon finding the one correct answer that a teacher is expecting (Lemke, 1990). When students are trained to believe that there is only one correct answer, they have difficulty conceptualizing that science is creative and open-ended.

Even when the teacher assures students that there are a myriad of ways to answer science questions, they tend to revert back to the didactic model of learning (Peters, 2006). An exploratory case study done over the course of a year with a 7<sup>th</sup> grade science teacher who had sophisticated understandings of how open ended inquiry is implemented in the classroom and who wanted to have inquiry-oriented classes in order to find out what conditions make inquiry lessons successful. Data sources for the study included pre-, mid-, and post-instruction interviews with the teacher, field notes from the class sessions and focus groups with the students. Grounded theory analysis methods were used to analyze the data and the coding categories emerged from data. Once coding categories were member checked and verified by another researcher, they were condensed into thematic strands in order to make sense of the outcomes. Finding showed that outside pressures such as adherence to standards, expectations of administrators and parents who are anxious about their child's grade led to more didactic teaching methods. Students who are expected to conceptualize the nature of science need to experience the learning of science as open-ended (Duschl, 1999; Bell, 2004; Lederman, 2004). Novice teachers tend to depend on the didactic model of teaching until they gain enough experience to teach students a more open way of learning.

Meyer (2004) found novice teachers discussed knowledge as if it was a static object, and learning was an accumulation of more bits of information while expert

teachers took a more complex view of scientific knowledge. This comparative case study examined pre-service, first-year, and experienced teachers' conceptions of the role of student prior knowledge. The participants completed two semi-structured interviews. The first interview intended to elicit teacher definition of prior knowledge, the role it played in learning, and how it was talked about in their professional circles. The second interview was intended for participants to discuss their planning of a unit on density. It was found that pre-service and first-year teachers held a very limited view of the importance of prior knowledge in learning. The more experienced teachers relied on student prior knowledge in their lessons, although they expected student prior knowledge to be disorganized or not yet developed. Clearly teachers must actively work against a didactic model of teaching and learning so that knowledge about the nature of science is aligned to the underpinnings of the epistemology in the classroom.

#### *Socially Constructed Knowledge through Thinking Aloud*

Methods of teaching that allow students to construct knowledge socially are helpful in developing deeper meaning because thought processes of students are exposed and are easier to understand (Gijlers & de Jong, 2005; Hogan 1999). Social construction of knowledge also aids students in recognizing the processes involved in developing scientific arguments such as cultural experience in scientific communities (Hogan, & Maglienti, 2001). In this study, groups of middle school students, nonscientist adults, technicians, and scientists were asked to rate the validity of conclusions given a rubric. The rubric measured decisions based on how knowledge claims are justified, and as such are integral to their scientific reasoning. Quantitative and qualitative analyses showed that

the responses of students and nonscientists differed from the responses of technicians and scientists. The technicians and scientists tended to emphasize empirical evidence as a basis for the validity of conclusions while the middle school students and nonscientist adults did not use empirical evidence as a validity measure. The groups who were experienced with the culture that produces the inherent guidelines used to validate scientific knowledge were more proficient at developing scientific arguments.

Several studies revolve around an exemplary teacher who uses status words to help students evaluate the scientific merit of their knowledge (Beeth, 1998; Beeth & Hewson, 1999). Some of the techniques of the exemplary teacher are not transferable, but the method she uses to develop student ideas with status words is transferable to other teachers. Intelligibility is the primary criteria students use to determine if an idea makes sense to them. If students find the idea to be intelligible, then they are asked to see if the idea is plausible. To be plausible means that the idea correlates to students' own experiences or experiences they have heard about. The last criteria, the most difficult to determine, is fruitfulness. If the idea can be transferred to different applications, then the idea is fruitful. Some of the research suggests that these strategies are useful for elementary students, but attempts to use them with middle school students were not as successful (Beeth, 1998; Beeth & Hewson, 1999). More sophisticated structures may be needed to elicit social construction of knowledge for middle school students. Four-Phase EMPNOS intervention attempts to develop a more refined, explicit structure to elicit social construction of knowledge through overt metacognitive processes.

### *Argumentation in the Construction of Scientific Understanding*

Another camp of researchers sees the chief metacognitive tool as argumentation, as it is central to the presentation of scientific information. Research from this area has shown that written reports of scientific knowledge do not necessarily indicate the totality of student knowledge (Chin & Brown, 2000). Six eighth grade students who were categorized as having a wide range of approaches, in terms of deep or surface approaches, to scientific content were videotaped during a unit of study. Data sources included before and after instruction interviews to determine their understanding of the content. The differences in the types of learners fell into the following categories: generative thinking, nature of explanations, asking questions, metacognitive activity, and approach to tasks. The students who had approaches categorized as deep tended to elaborate on answers more effectively and were more spontaneous in developing ideas. The students who had approaches categorized as shallow tended to restate questions instead of answering them. Findings include teachers who provide prompts and contextualized scaffolding and encourage students to ask questions, predict, and explain during activities could encourage deep approaches to learning science content.

Students who use written, visual and oral presentations of information are the methods that are most successful in showing the depth of student knowledge, but teachers do not have the pedagogical knowledge to conduct whole class evaluation of arguments that allow students to have a voice in the class (Driver, Newton, & Osborne, 2000). Driver, Newton, & Osborne (2000) in a literature review, call for more professional development in order to evoke progress in this area. When students are allowed to

experience the process of developing and defending arguments, students are better equipped to understanding science as a process of generating knowledge rather than a body of factual information in its final form. One weakness of student argumentation is that younger students have little experience in developing defensible logic structures. Perhaps self-examination of thinking processes could enlighten student into their own epistemologies and become a step toward developing rigorous student argumentation.

#### *Self-regulatory Processes in Developing Ways of Knowing about Science*

Self-regulated learning can be used as a non-didactic instructional tool to relate the aspects of the nature of science to students. Self-regulatory approaches include strategies that students use to monitor, control, and regulate their cognition and learning (Garcia & Pintrich, 1994). A student who self-regulates should be able to think about and evaluate their ideas according to a scientific way of knowing. Since metacognition is a part of self-regulation, self-regulation can be adopted to help students develop scientific thinking. Based on Bandura's theory (1986), Zimmerman (1998) has identified three socially mediated levels that contribute to a person's self-regulatory strategies: behavior, person, and environment. A person behaves within an environment and reacts based on the consequences of his or her behavior. Several measures of academic success have shown improvement using self-regulated processes (Zimmerman, 1989). Among these measures are strategy use (Pressley, Borkowski & Schneider, 1987; Weinstein & Underwood, 1985), intrinsic motivation (Ryan, Connell & Deci, 1984), the self-system (McCombs, 1986), academic studying (Thomas & Rohwer, 1986), classroom interaction (Rohrkember, 1989; Wang & Peverly, 1986), use of instructional media (Henderson,

1986), metacognitive engagement (Corno & Mandinach, 1983), and self-monitoring learning (Ghatala, 1986; Paris, Cross & Lipson, 1984). One reason that teachers as well as students have difficulty understanding the nature of science is their lack of exposure to the same inherent ways of knowing as a scientist (Hogan, 2000). Self-regulated learning strategies could provide a framework that can scaffold naïve views of the nature of science to more developed views of the nature of science.

Self-regulated learning strategies play an important role in improving students' understandings through active developmental phases. This developmental process has potential be used to scaffold students who have no experience with the nature of science (Hogan, 2000) to being proficient in developing scientific knowledge independently. The four developmental phases, from most student dependence on the teacher to least student dependence on the teacher, include observation, emulation, self-control, and self-regulation. Observation occurs when a student notes the process of a model throughout a specific task. The emulation phase occurs when a student attempts to try to be like the model and receives support. The self control-phase occurs when the student independently uses the strategy in similar contexts, and the self-regulation phase occurs when the student can adapt the use of the strategy across changing conditions (Zimmerman, 2000). It has been shown that student understanding cannot occur passively (Akerson, Flick, & Lederman, 2000; Ryer, Leach, & Driver, 1999), so an intervention that is suited to evoke student cognitive change regarding conceptions of the nature of science is necessary in promoting conceptual growth. The developmental nature of self-regulated learning can aid in progressing naïve student views of the nature of science.

Self-regulation can help students monitor their learning progress accurately through frequent feedback. Self-regulated learners adopt learning orientation, whereas naïve learners adopt performance orientation (Zimmerman, 1998). Naïve self-regulators seldom verbalize and are unaware of imagery as a guide and tend to rely on the results from trial-and-error experiences to implement new methods of learning (Costa, Calderia, Gallastegui & Otero, 2000). Four phases which Zimmerman (2000) has identified (observation, emulation, self-control, and self-regulation) help students to develop from going through the motions of an activity to being concerned about understanding their ways of knowing. Providing students metacognitive tools embedded into an inquiry activity to check if they are thinking like scientists may be able to aid student progression from performance orientation to learning orientation.

The four phase self-regulatory strategies have assisted learners in many different domains. A study by Kitsantas and Zimmerman (2006) examine the role of graphing of self-recorded outcomes and self-evaluative standards on the acquisition of a motoric skill (throwing darts) with 70 college students. Three groups participated in the experimental study, a group using the four-phase process, a group that had absolute standards, and a group that had no standards in both motoric skills and motivational beliefs. Results support the ideas that the group who used the four-phase process had higher dart skill and stronger motivational beliefs than participants who did not graph their results.

An exploratory study of the use of self-regulatory strategies for beginning and struggling readers utilizes the four-phase process (Horner & O'Connor, 2006). The authors used a combination of a reading extension process known as Reading Recovery

and the four-phase processes of observation, emulation, self-control, and self-regulation. This developmental process allowed for beginning and struggling readers to become more self-regulatory in checking their understanding of content after reading a passage.

A literature review regarding the use of online resources to promote multi-cultural competency in pre-service teachers emphasizes the effectiveness of the four-phase self-regulatory processes (Kitsantas & Talleyrand, 2005). This review provides a model based on observation, emulation, self-control, and self-regulation to learn about multi-culturalism in a teacher education setting.

Self-regulatory processes have been used in the field of self-assessment in higher education. This study was conducted with fourteen students who had taken a course on self assessment (Andrade & Du, 2007). The students were interviewed in focus groups sorted by gender after the instruction. Several themes emerged from the transcripts: that students had positive attitudes toward self assessment after extended practice; felt they can effectively self assess when they know their teacher's expectations; claimed to use self assessment to check their work and guide revision; and believed the benefits of self assessment include improvements in grades, quality of work, motivation and learning.

A descriptive report by Pape and Smith (2002) establishes a link between mathematical problem solving and self-regulatory strategies. This report encourages the self-regulatory processes of observation, emulation, self-control, and self-regulation be used to scaffold students in mathematical problem solving. The result of this scaffolding has been reported as an increase in mathematic problem solving skills and in further self-regulation in mathematic learning processes. Although the four-phase self-regulatory

processes have been effective in other domains, these strategies have not yet been tested in the field of science.

### *Defining Metacognition*

Metacognition can be defined as the executive functions that control actions or the ability to recognize thinking patterns and evaluate them (Weinert, 1987) and is a portion of the continuum of self-regulation. Metacognition is the ability to think about and evaluate your own thinking processes (Brown, 1987) and is a part of being a self-regulated learner because self-regulatory strategies provides the mechanisms for students to regulate their cognition and learning (Zimmerman, 1989). Current metacognitive research comes from one of two lineages: cognitive psychology (Hart, 1965) or developmental psychology (Flavell, 1979). Hart (1965) was interested in the accuracy of judgments adults made about memory, which revealed that they were valid predictors of behavior. Flavell (1979) was interested in investigating whether children had a conscious understanding of the rules that govern memory and cognition. This research yielded evidence that children had the ability to reflect on their own cognitive processes. As research in these two strands developed, metacognition become known to be either monitoring of cognition or control of cognition. Metacognitive monitoring allows the individual to observe and reflect upon his or her own cognitive processes (Schwartz & Perfect, 2002). Metacognitive control is the decisions, both conscious and non-conscious, that we make based on the output of our monitoring process (Schwartz & Perfect, 2002). Judgments of learning have been used in several research studies (Thiede & Dunlosky, 1999; Son and Schwartz, 2002) to show the teaching of adaptive and flexible control

strategies that lead to improved learning. Metacognitive monitoring and control can be a useful tool in helping students to identify scientific thinking and to check their own thinking for alignment with a scientific way of knowing. Self-regulation consists of the metacognitive processes, behavioral skills, and associated motivational beliefs that underlie youths growing self-confidence and personal resourcefulness in acquiring the skills needed for adulthood. Since metacognition is part of self-regulation, it is possible that self-regulatory processes can help to develop metacognition in students.

#### *Accuracy of Metacognition Measurement*

The accuracy of metacognition was first investigated in the 1960s by Hart (1965), Underwood (1966), and Arbuckle and Cuddy (1969). In his study, Hart (1965) asked participants general information questions and then asked their feeling-of-knowing judgment about each questions, and found that participants' feeling-of-knowing judgments were accurate predictors of correct responses. Underwood (1966) tested participants' judgment of difficulty of test items and found that individuals predicted their own learning (correlations were approximately 0.90). Arbuckle and Cuddy (1969) studied judgments of learning and found that the individuals' judgments were highly accurate. The initial studies have been expanded upon through the years and it is generally felt that metacognition involving judgments are accurate, but far from perfect (Blake, 1973). Further, it has been found that accuracy of metacognitive judgments can be improved upon by delaying the judgment for a brief time after the question is answered (Nelson & Dunlosky, 1991; Weaver & Keleman, 1997). Research gives some evidence for the ability for students to monitor their own thinking accurately in terms of an established

epistemology. Given the guidelines for scientific thinking, it could be possible for students to monitor their own thinking to align with established scientific epistemologies.

### *Metacognition and Content Knowledge*

There has been some evidence that developing metacognition can enhance the incorporation of content knowledge in students. Students were better able to recognize the importance of knowing a few key species in the study of ecology and to be able to use the language of ecology to help them describe and discuss ecology because metacognitive cues were incorporated into lessons (Magntorn & Hellden, 2005). Question-based reflective verbalization, another form of metacognitive prompting, requires students to describe, explain, and evaluate a finished design solution to another person and leads to significant improvements in the solution quality (Wetzstein & Hacker, 2004). Veenman, Kok and Blote (2005) performed a study to establish to what extent metacognitive skill is associated with intelligence and the impact that prompts may have on developing metacognitive skills. The participants' intelligence was assessed using a standardized test, and were then asked to solve six word problems while thinking aloud in an individual session. Three problems were presented without metacognitive cueing and three problems were presented with metacognitive cueing. Adequacies of problem solving and metacognitive skillfulness were assessed. It was found that without cueing, metacognitive skillfulness is the main predictor of initial learning. Implications of this study advocate the early acquisition of metacognition in students. The use of metacognition has also been shown to improve content knowledge (Magntorn & Hellden, 2005), solution quality (Wetzstein & Hacker, 2004), and early acquisition can improve intelligence scores

(Veenman, Kok & Blöte, 2005). Based on the findings of these studies, students may develop more conceptual ideas rather than rote factual knowledge earlier in their student careers in science when they develop their metacognitive skills.

Teachers who are asked to develop authentic science activities for students often interpret science instruction as a series of often disconnected hands-on lessons which in and of themselves do not guarantee student understanding. Using a process called Metacognitive Learning Cycle (Blank, 2000) emphasizes formal opportunities for teachers and students to talk about their science ideas, forming a feedback loop that informs the development of scientific ideas. One study tested the effectiveness of the Metacognitive Learning Cycle by setting up a control group and an experimental group. There was no significant difference in ecological understanding across two treatment groups, but delayed post test mean scores were higher with Metacognitive Learning Cycle group than with control group (Blank, 2000).

#### *Actively Engaging Student Metacognition*

Students who are self-regulated are metacognitively, motivationally, and behaviorally active participants in their own learning process (Zimmerman, 1989). In order to accomplish the goal of learning about the nature of science and science content, students can perform inquiry activities, think about why they are conducting certain processes and, in turn, evaluate their thinking in terms of the agreed upon processes of the scientific community (Dawson, 2000). Most research in the field of metacognition and science has been focused on listening to group conversations or asking students to talk aloud about their thinking (Blank, 2000). These passive activities do not give the

students the modeling they may need to understand the aspects of the nature of science. A typical student is not exposed to the culture of science (Hogan, 1999b), so it is important for teachers to provide the scaffolding that will illustrate how scientists think and operate. Metacognitive prompts built from the identified aspects of the nature of science (McComas, et al., 1998) will give teachers a vehicle to scaffold scientific thinking to students who are underexposed to this type of thinking. Actively prompting students to evaluate their scientific thinking brings them closer to authentic scientific inquiry. There has been some evidence that developing metacognition can enhance the incorporation of content knowledge in students. The use of metacognition has been shown to improve content knowledge (Magntorn & Hellden, 2005) and solution quality (Wetzstein & Hacker, 2004). Based on the findings of these studies, students may develop more conceptual ideas rather than rote factual knowledge earlier in their student careers in science when they develop their metacognitive skills.

Many of the studies in the literature regarding metacognition depend on the spontaneous production of metacognitive skills, although Davis (2003) investigated ways of prompting 178 middle school science students to produce reflection. Two types of prompts, generic and directed, were used in the study. Generic prompts encouraged asked students “stop and think” while directed prompts attempted to direct students to productive lines of thinking. Students in the project were asked to critique evidence and claims in a scientific article. The project involved (a) reading the article, (b) critiquing the evidence being used, (c) critiquing the claims being made, and (d) writing a letter synthesizing the critiques and giving guidelines for future use of evidence. Students who

received the generic prompts become more productive, while students who received directed prompts were poor reflectors.

### *Metacognition, Self-Regulation, and Feedback*

Self-regulation can help students monitor their learning progress accurately through frequent feedback. Self-regulated learners adopt learning orientation, whereas naïve learners adopt performance orientation (Zimmerman, 1998). By giving students metacognitive tools to check if they are thinking like scientists in an inquiry activity, students may be able to progress from performance orientation to learning orientation. Naïve self-regulators seldom verbalize and are unaware of imagery as a guide and tend to rely on the results from trial-and-error experiences to implement new methods of learning (Costa, Calderia, Gallastegui & Otero, 2000). Skillful self-regulators attribute negatively evaluated outcomes mainly to strategy use, learning method, or insufficient practice, where naïve learners tend to attribute them to ability limitations. Students can be taught positive self-regulations feedback loops by teachers who have access to metacognitive prompts that promote the nature of science.

Self-regulation allows students to learn through modeling and attempting a skill. Self-monitoring type feedback enables students keep track of their progress toward a goal. Since students are not naturally familiar with the inherent processes of science, unless exposed to scientists performing their discipline (Hogan & Maglienti, 2001), self-regulatory processes are presumed to be necessary in modeling scientific knowledge construction and validation. Once student understanding of scientific knowledge construction and validation is established, then students are best served by self-

monitoring processes in order to check their epistemologies with scientific ways of knowing.

### *Nature of Science as a Metacognitive Resource*

Literature in metacognition emphasizes the lack of consensus on the mechanisms by which epistemological factors influence student learning (Driver, Newton, & Osborne, 2000; Hogan, 2000; DeSautels & Larochelle, 2005). More research in developing a thinking strategy or ethic to evaluate the scientific merit of information can change how students develop their scientific way of knowing. Many instructors attempt to teach scientific thinking veiled as the scientific method, which is limiting the way students construct epistemologies regarding the nature of science. A large quantity of research cited earlier illustrates student and teacher tendency to cling to prior ideas regardless of contradiction by new data. Cognitive change can be invoked through deep processes such as metacognition. More research in this field will help to produce more fully informed ideas on how epistemological factors influence student learning.

The aspects of the nature of science can be useful in helping students to think about their epistemology. Examining the nature of science can supply characteristics that distinguish science from other ways of knowing and explicitly help students scrutinize their rationale in forming ideas (Duschl, Hamilton, & Grandy, 1992). Teachers can utilize these characteristics in their lessons to help students to examine the information they know and think about how student knowledge is scientific. Educational researchers studying metacognition are in agreement that traditional methods of teaching do not allow students to demonstrate all of their knowledge about science (Driver, Newton, &

Osborne, 2000). Instead of just asking questions that prompt metacognition and hoping students will think deeply, students should be gradually scaffolded to the ultimate goal of metacognition using observation, emulation, self-control and self-regulation. Cognitive change can be invoked through deep processes such as metacognition (Flavell, 1987). More research in this field will help to produce more fully informed ideas on how epistemological factors influence student learning.

To date, few specific, measurably successful suggestions for pedagogy resulting in a deeper understanding of science have been proposed (Akerson & Abd-El-Khalick, 2003; Beeth & Hewson, 1999; Davis, 2003). Perhaps this occurs because the nature of science has been taught as content rather than as epistemology (Duschl & Gitomer, 1991; Kang & Wallace, 2004). One method for teaching epistemology is to develop student metacognition about their thinking processes and how they validate knowledge. Some evidence for incorporating metacognition as a learning component comes from the ThinkerTools curriculum (White & Frederickson, 1998; White, 1993), where students using ThinkerTools showed increases in content knowledge and inquiry skills. The aspects of the nature of science can be useful in helping students to think about their epistemology. Examining the nature of science can supply characteristics that distinguish science from other ways of knowing and explicitly help students scrutinize their rationale in forming ideas (Duschl, Hamilton, & Grandy, 1992). Teachers can utilize these characteristics in their lessons to help students to examine the information they know and think about how student knowledge is scientific.

The field of student learning of the nature of science still requires a great deal of exploration. In order to fully understand how people learn such as esoteric subject as the nature of science there needs to be more dialogue between the scientific community and science teachers (Glasson & Bentley, 2000), more understanding of student views of the nature of science (Zeidler et al., 2002), and more understanding of how teachers who have a sophisticated view of the nature of science can incorporate these ideas into classroom practice. Bell and Lederman (2000) studied scientists who had sophisticated but different views on the nature of science to see how they made decisions based on their views. Their research showed no differences in decision making because the scientists made their professional decisions based on personal values, morals/ethics and social concerns.

Literature in metacognition emphasizes the lack of consensus on how epistemological factors influence student learning (Brown, 1987). More research in developing a thinking strategy or ethic to evaluate the scientific merit of information can change how students develop their scientific way of knowing. Many instructors attempt to teach scientific thinking veiled as the scientific method, which is limiting the way students construct epistemologies regarding the nature of science. Cognitive change can be invoked through deep processes such as metacognition (Flavell, 1987). More research in this field will help to produce more fully informed ideas on how epistemological factors influence student learning.

### *Need for Metacognition in Science*

Despite the efforts of many reform movements, science is usually taught in the classroom as a rigid body of knowledge to be acquired rather than a way of knowing. Many of the reform efforts ignore teachers' existing knowledge, beliefs, and attitudes (van Driel, Beijaard & Verloop, 2001). Science teachers continue to exclusively teach scientific knowledge, ignoring the inherent ideas that guide the attainment of the knowledge (Duschl, Hamilton & Grandy, 1992). Dawson (2000) claims that in the classroom there is usually not enough repetition for metacognitive awareness and student competence level is not usually taken into consideration. Metacognitive prompts encourage teachers to develop knowledge regarding the nature of science and help students to regard the evolving guidelines the discipline of science provide. Duschl and Gitomer (1991) argue that conceptual change cannot occur without a concurrent change in the ways in which knowledge claims are validated. Thinking about thinking can lead teachers away from a depersonalized, context-free, and mechanistic view of teaching in which the complexity of the teaching enterprise is not acknowledged (Doyle, 1990). It has been shown that teacher cognition about the teaching and learning of science are consistent with constructivist ideas, their actual classroom behavior may be more or less 'traditional' (Briscoe, 1991; Johnston, 1991; Mellado, 1998). Metacognitive prompts may give teachers a concrete teaching tool with which to operationalize their cognitive beliefs.

This study attempts to draw from the understandings found in the literature regarding the nature of science, metacognitive processes and self-regulatory processes. Recently there has been convergence in the literature about the important aspects of the

nature of science (McComas, 2004; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), and this study attempts to implement the seven identified aspects of the nature of science in learning modules to guide student thinking processes to become more scientific. This study also incorporates findings from recent literature that students respond more positively to metacognitive prompts that provide a broad-spectrum perspective to the topic (Davis, 2003), and operationalizes Zimmerman's ideas that four stages can be used to train self-regulation. It has been shown that student understanding cannot occur passively (Akerson, Flick, & Lederman, 2000; Ryer, Leach, & Driver, 1999), so this intervention is suited to evoke student cognitive change regarding conceptions of the nature of science. The developmental nature of self-regulated learning can aid in progressing naïve student views of the nature of science. The results of this study extend Zimmerman's ideas into the realm of metacognition, and could illustrate processes and interactions that will help naïve scientific thinkers have access metacognitive thinking.

### *Research Questions*

Student understanding of the nature of science helps students to learn that science is more than a collection of facts. Learning and applying the aspects of the nature of science helps students to see and think about their world using a scientific way of knowing. Developing metacognitive skills should also be an explicit activity in the science classroom. Students using metacognitive skills can evaluate their thinking to determine if it aligns with the rigorous requirements of science. This study used an intervention (4-Phase EMPNOS) to find out if students can be taught to think scientifically on a metacognitive level and sought to answer the following questions:

- (a) What is the effect of 4-Phase EMPNOS on science students' content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy? It is hypothesized that students exposed to the intervention would report a higher level of content and nature of science knowledge, metacognition and self-regulatory efficacy.
- (b) How are the specific constructs of science content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy related to each other when students complete activities with embedded metacognitive prompts? It is hypothesized that science content knowledge and knowledge about the nature of science are positively correlated and that knowledge about the nature of science, metacognition and self-regulatory efficacy are positively correlated.
- (c) What characterizes the shared experiences of students who use 4-Phase EMPNOS and students who do not use 4-Phase EMPNOS?
- (d) In what ways do students approach activities with embedded metacognitive prompts and activities without metacognitive prompts?

### 3. Methods

This chapter describes the research methodology including a description of the study participants, the instrumentation, data collection procedures, and data analysis procedures. Although much research has been done on the nature of science, previous research has not included active metacognitive prompts to introduce students to guidelines of scientific thinking. This quasi-experimental mixed method study was used to determine any differences on identified constructs between and within experimental and control groups.

#### *Study Setting and Participants*

Approximately one hundred science students from an urban middle school in the mid-Atlantic region of the United States participated in the pilot study and approximately one hundred additional students participated in the follow-up study. The middle school serves 928 students, grades six through eight. Seventeen percent of students from this school receive free or reduced price for lunches. The sample population consisted of 7.9% Black students, 10.7% Hispanic students, and 69.2% White students.

A pilot study was conducted on eighty three students prior to this study from the same demographic group. The results of the pilot study informed the current study and the subsequent changes will be noted in the appropriate sections below.

### *Study Variables*

*Dependent variables.* The primary dependent variables are student content knowledge, nature of science knowledge, metacognition, and self-regulatory efficacy. The measures used to gather information on the dependent variables were chosen because of their reliability, validity and successful prior use in measuring identified constructs. Measures that are well-known in the field were chosen when possible, such as the measure for nature of science knowledge, metacognition, and self-regulatory efficacy. When the construct was too specific to be measured by a nationally recognized instrument, an instrument was constructed, field tested, reconstructed, validated and tested for reliability before use in the current study. In addition, the shared experiences of the different groups were investigated using focus group techniques (Maxwell, 2005). The approaches to problem solving were also investigated through the use of think aloud protocols (Ericsson & Simon, 1993).

*Independent variables.* The independent variables were the experimental and control groups. The study was quasi-experimental because the classes chosen for the control and experimental group were already formed. The control group received a two-week inquiry unit on electricity and magnetism without the embedded metacognitive prompts based on the nature of science (4-Phase EMPNOS). The experimental group received the same two-week inquiry unit on electricity and magnetism, but the unit had the 4-phase embedded metacognitive prompts written throughout the unit.

## *Measures*

*Quantitative measures.* Metacognitive Orientation Scale (MOLES-S). The Metacognitive Orientation Scale (Thomas, 2002b) is designed with a social constructivist view in mind and considers that knowledge is not constructed in a vacuum, but is developed through interactions with the learning environment. Thomas (2002a) argues that most measures in the science classroom regarding metacognition involved lengthy interviews and observations and that the development of a large-scale measure of metacognition in the classroom would be useful. Eight aspects of metacognition which were supported by the research literature were measured on the MOLES-S: (1) metacognitive demands, (2) teacher modeling and explanation, (3) student-student discourse, (4) student-teacher discourse, (5) student voice, (6) distributed control, (7) teacher encouragement and support, and (8) emotional support. The MOLES-S is a 67-item instrument that includes the eight aforementioned dimensions based on a five point Likert-scale. The items are organized as short statements that describe the metacognitive orientation of the classroom environment and assignments given in science. That is, the statements are designed to interpret whether the student is given the opportunities to utilize metacognitive thinking. For example, when students are given assignments that allow them the freedom to communicate in different ways, they have more of an opportunity to be metacognitive than if they were given forced answer questions such as multiple choice. Students circle the most appropriate selection for each statement from

the given choices: Almost Always, Often, Sometimes, Seldom and Almost Never. The entire instrument is available in Appendix A.

The initial instrument was administered to 1026 students within the 14-17 year old age group. At the time the instrument was administered, Hong Kong school had five bands of stratification for student ability and achievement. The instrument was administered to equal numbers of students among each of the five groups. The initial instrument was refined used a Cronbach alpha coefficient analysis and was changed from eight scales to seven. The Teacher Modeling and Explanation scale overlapped with the Metacognitive Demands scale and lead to the deletion of the Teacher Modeling and Explanation scale. The refined MOLE-S reported an Alpha reliability ranging from 0.72 to 0.87 for each of the seven scales and all of the scales showed to be statistically significant. The discriminant validity ranged from 0.34 to 0.49 for each scale. The validation data suggested that students have little control over classroom activities, that students are on average in terms of metacognitive ability, and do not tend to discuss the process of learning science with teachers.

*Metacognition of Nature of Science Scale (MONOS).* The MONOS (Peters, unpublished) 16-item survey was designed to test five different student perceptions: a) attitude about the subject of science, b) use of metacognition in observation, c) use of metacognition in data collection, d) use of metacognition in measurement, e) ability to explain reasoning in making conclusions. Each of the topics was chosen because they exemplify skills that are valuable in teaching science as a way of knowing. Students were asked to read a statement that describes a way of inspecting their activities and thinking

in the science classroom with an aspect of the nature of science. Students then choose a number between 1 and 5 to show whether they agreed with the statement (5) or disagreed with the statement (1). An example item from this instrument follows: When I organize data, I first think about the best way to explain what I am trying to show. This item is written to elicit the level of student monitoring of thinking about organizing data for clear communication to an outside audience. If students agree with the statement, it indicates that the student has a high ability to monitor their thinking about that particular aspect of the nature of science. Multiple questions were designed to test the same variable so that instrument subscale reliability could be verified. Questions 1, 3 and 8 tested student attitudes toward science. Questions 2, 4 and 11 tested student perception of ability to have metacognition about observations. Questions 7 and 16 tested student perception of metacognitive ability in measurement. Questions 5, 6, 9 and 15 measured student perception of metacognitive ability in data collection. Questions 10, 12, 13 and 14 measured student perceived ability to reason when making conclusions.

Field tests of the survey were conducted with three high achieving, three average achieving and three low achieving readers from the eighth grade. Feedback regarding comprehension and meaning of the questions provided during the field test interviews after the survey guided the revisions of the instrument. Changes in the statements were made based on the interviews of the students after the draft survey was administered. The students involved in the field test did not take the survey, since they had prior knowledge of the intention of the survey. Reliability as measured by alpha test for the entire instrument is .89. The MONOS can be found in Appendix A.

*Self-efficacy for Learning Form (SELF)*. The SELF scale (Zimmerman & Kitsantas, 2005) is a 19-item survey designed to test student self-efficacy for learning. The items ask students to determine their ability to complete self-regulated learning strategies on a percentage scale divided into increments of ten percent. It is designed to have students self-report on a variety of situations that require academic self-regulatory efficacy such as reading, note taking, test taking, writing, and studying. Students read the statements regarding their ability to complete self-regulated learning strategies and rate their ability using the following guide: Definitely Cannot Do It, Probably Cannot Do It, Maybe Can Do It, Probably Can Do It, and Definitely Can Do It. The guide is placed above the percentage choices to assign meaning to the numbers when students make their choice. High scores on this scale represent a high ability to be self-regulatory in academic strategies. This scale has a reliability coefficient of .97 and was highly correlated to teacher reports on students. The instrument can be found in Appendix A.

The results from the pilot study indicated that more self-regulatory strategies were needed in the intervention to affect any change in self-regulatory efficacy. The next iteration of the study will include self-monitoring checklists after each of the four modules. Students will use a checklist to determine how many self-regulatory strategies they used during the module. Then students will graph the number of strategies after each of the four modules in order to self-monitor strategies. The worksheets for the self-monitoring strategy can be found in Appendix D.

*Test of Electricity-Magnetism Knowledge (TEMK)*. The science content taught during the intervention includes magnetism, static electricity, current electricity, and

electromagnetism. The TEMK (Peters, unpublished) assesses students' attainment content goals at an eighth grade level: (a) behavior of static electrical charges, (b) behavior of electrical current, (c) behavior and internal mechanisms of magnets, and (d) behavior of electromagnetic interactions. The questions on this test are open-ended and assess each of the content goals using visual, logical and analytical forms of communication. Each test was analyzed using a rubric designed to measure for strengths and weaknesses in particular content areas, themes in the way students answer questions, and themes in the way students design scientific products such as data tables or observations. The scoring on the rubric consists of the following: No Answer (0), Naïve Answer (1), Emerging Answer (2), and Proficient Answer (3). When a student scores a Naïve Answer on the TEMK it means that they have a conceptually wrong answer, but a kernel of understanding was communicated. An Emerging Answer on the TEMK means that the student had basically a correct understanding, but still did not communicate the entire answer. A Proficient Answer communicates all characteristics of the correct answer for the question. The instrument is available in Appendix A.

The pilot test informed the next iteration of this study in terms of the content test because during the pilot test it was discovered that there were relevant questions on the National Assessment of Educational Progress (NAEP) test. Two questions on electricity and magnetism were identified and were added to the TEMK. The data gathered in this study was compared to a national sample in order to determine any possible generalizability.

*Comparison of Study Sample with National Sample.* Two questions designed for the National Assessment of Educational Progress or NAEP (National Center for Educational Statistics, 2007) were included on the content instrument because they were aligned to the grade level and content objectives of the study. The NAEP, otherwise known as “The Nation’s Report Card” is given to a random sample of students nationally in order to represent the level of content knowledge for students across the United States (National Center for Educational Statistics, 2007). The first of two questions used in this study from the NAEP is a knowledge level question and asks students to identify common items for the item’s ability to conduct electricity. The second question taken from the NAEP is a synthesis level question and asks students to explain how they might design a test for electrical conductivity for each of the items. The rating criteria for the NAEP were identical to the rating criteria for the TEMK content test for this study. An omitted answer received a 0, a partially correct answer received a 1, an answer that was essentially correct but had a flaw received a 2, and a completely correct answer received a 3.

*The Views of the Nature of Science- Form B (VNOS –B).* The VNOS-B (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) assesses student understanding of science as a way of knowing and consists of seven open-ended questions corresponding to the seven identified aspects of the nature of science: a) scientific knowledge is durable, yet tentative, b) empirical evidence is used to support ideas in science, c) social and historical factors play a role in the construction of scientific knowledge, d) laws and theories play a central role in developing scientific knowledge, yet they have different

functions, e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, f) science is a creative endeavor, and g) science and technology are not the same, but they impact each other (McComas, 2004). Lederman, Abd-El-Khalick, Bell, & Schwartz (2002) argue that due to the nature of information being gathered on the VNOS-B the structure of the assessment should be free-response. Each question is assessed using a rubric on two dimensions, frequency and depth of explanation. The scoring on the rubric consists of the following: No Answer (0), Naïve Answer (1), Emerging Answer (2), and Proficient Answer (3). When a student scores a Naïve Answer on the VNOS-B it means that they have a conceptually wrong answer, but a kernel of understanding was communicated. An Emerging Answer on the VNOS-B means that the student had basically a correct understanding, but still did not communicate the entire answer. A Proficient Answer communicates all characteristics of the correct answer for the question. The VNOS-B assesses both student depth and breadth of understanding of the nature of science. The instrument can be found in Appendix A.

### *Qualitative Measures*

*Student products from inquiry units.* The control group and the experimental groups had identical inquiry units that contained identical science content and science process skills to master. Within the inquiry unit, students answered science content questions and used science process skills to make conclusions about the phenomena. The student products were analyzed using the same protocol as the content test: strengths and weaknesses in particular content areas, themes in the way students answer questions, and themes in the way students design scientific products such as data tables or observations.

*Teacher memos.* Memos are a versatile tool used to in many ways such as helping researchers reflect on events that are occurring during the research study or documenting confusing events for later analysis (Maxwell, 2005). Complications could arise during the interpretation phase of data analysis due to the dual role of teacher and researcher during the pilot study. Memos could help to reduce the confusion in interpretation because they will discuss implicit events during the research study. Memos were written throughout the pilot study and then coded for emergent themes. Field memos were taken during the follow-up study in order to begin to make sense of the qualitative data.

*Think Aloud Protocol.* After the interventions six students were randomly chosen from the control group and six students were randomly chosen from the experimental group and videotaped separately while they perform an investigation from the intervention. Students were asked to think aloud during the videotape in order to elicit their thinking processes during a scientific investigation. Since eighth grade students have little experience in expressing their “inner voices”, an established protocol to encourage three levels of verbal reports will be used, verbalization of covert encodings, explication of thought content, and explanations of thought processes (Ericsson & Simon, 1993). Students were instructed to talk aloud about what they are thinking, and not to explain the answer to the problem. Students were prompted at key points throughout the think aloud to continue their explanation of what they are thinking. The frequency of each level of verbal report was reported as well as the themes that emerge from each level.

The pilot study informed this portion of the study due to the few usable results obtained from the video transcripts. The purpose of the think aloud protocols were to gain

information about the mechanisms the students used to guide their thinking. However, only information that triangulated the quantitative results was gathered during the pilot study. Changes include increased time during the think aloud protocol and more questioning between stages in the think aloud protocol.

*Focus Group Interviews.* After the intervention, six members were randomly chosen from the experimental group and six members were chosen from the control group to participate in a focus group. A focus group was chosen as a method of data collection rather than individual interviews because eighth grade students tend to minimize interactions with adults. A focus group tended to elicit more rich verbal data from the students because they interacted with each other and expanded on each others' ideas. The questions were semi-structured because they focused the conversation without giving up the freedom that was needed to explore phenomena that emerged. Questions used for the focus groups can be found in Appendix A6. Focus group conversations were audio-taped and transcribed using the software, Transana.

The pilot study informed this portion of the study due to the few usable results obtained from the video transcripts. The purpose of the think aloud protocols were to gain information about the mechanisms the students used to guide their thinking. However, only information that triangulated the quantitative results was gathered during the pilot study. Changes include increased time during the think aloud protocol and more questioning between stages in the think aloud protocol.

### *Intervention*

The intervention, 4-Phase Embedded Metacognitive Prompts based on the Nature of Science (4-Phase EMPNOS), consists of four modules that cover the content of electricity and magnetism at an eighth grade level. Each module is based on inquiry methods (NRC, 1996) and asks students to make observations and inferences about phenomena. Module one investigates behaviors of permanent, ceramic magnets. Module two investigates phenomena involved with static electricity. Module three investigates models that explain current electricity. Module four investigates electric and magnetic interactions. Each of the experimental modules includes nature of science metacognitive prompts from one of the seven aspects of the nature of science: a) scientific knowledge is durable, yet tentative, b) empirical evidence is used to support ideas in science, c) social and historical factors play a role in the construction of scientific knowledge, d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, f) science is a creative endeavor, and g) science and technology are not the same, but they impact each other (McComas, 2004). Table 2 shows the content focus and nature of science focus for each module.

Metacognition is developed throughout the units based on Zimmerman's (2000) model of the 4-phases of self regulation: observation, emulation, self-control and self-regulation. The observation phase prompts give examples of how a scientist would answer the question and the rationale behind it. The emulation phase gives a checklist to the student about the aspects of nature of science that should be considered for the task.

The self-control phase gives students a short checklist of major aspects of the nature of science as well as some simple questions about “thinking about their thinking.” The self-regulation phase gives students more advanced questions that ask students to check to see if their thinking is aligned with the nature of science aspect. Each module has each of the four phases for one aspect of the nature of science. For example Module 1 for the experimental group is based on magnetism content and has four sections of embedded developmental phases of metacognitive prompts on the use of empirical evidence to support claims throughout the unit. Metacognitive prompts for all four phases in each of the aspects of the nature of science can be found in Appendix B. Module 1 can be seen in its entirety in Appendix C.

After the completion of each module, the experimental group was asked to monitor their use of the checklists by keeping a tally of the number of checklist items they utilized during the module. After students filled out a tally sheet, they graphed the number on a bar graph. The rationale behind this part of the procedure lies in the increased self-efficacy of students who self-monitor their progress (Kitsantas & Zimmerman, 2006).

Table 2

*Content and Nature of Science Focus for Intervention Module*

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Module Number	Content Focus	Nature of Science Focus
1	Current Electricity	Empirical NOS
2	Static Electricity	Laws and Theories
3	Current Electricity	Accurate record keeping, Peer review and replication of experiments
4	Electromagnetic Interactions	Creative NOS

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*Teacher Training for Intervention*

This study required some training for the teacher who administered the intervention. The pilot study did not require this step because of the dual role of teacher/researcher. Two sessions lasting three hours each were used to explain the instruments and the sequence of lessons to the teacher. The teacher and the researcher went over each of the measures and the interventions page by page and discussed issues about the possibility of confusion on the part of the students. The teacher was given

clarification on the general structure of the experiment and amount of exposure the experimental group should receive on the self-regulatory strategies embedded in the modules. On the first day of teaching of the modules, the researcher attended all classes and co-taught the module with the teacher. This procedure was done in order to ensure fidelity of instruction between the groups throughout the guided inquiry modules. The teacher and the research spoke on the telephone or emailed each other each day the experiment took place. These conversations helped to ensure that the teacher conducted the experiment as intended and that the researcher was informed of any difficulties. One example of a difficulty occurred during the first module because the scissors provided to the students broke during the investigation. Because the conversations occurred daily, a plan to use different materials was put into place immediately. The timeline for the experiment was conducted as anticipated by the researcher.

#### *Data Collection Procedures*

Students from all four classes were given the MOLES-S, the MONOS, the SELF, the VNOS-B, and the content test before the intervention began. Classes were then chosen randomly to be in the control group or the experimental group. The inquiry unit on electricity and magnetism without the embedded metacognitive prompts was given to the control group and the inquiry unit on electricity with the embedded metacognitive prompts (4-phase EMPNOS) was given to the experimental group. Students proceeded with the four modules of the intervention (the inquiry unit) with the guidance of the teacher. Student groups of four used the intervention packets to investigate the learning goals in electricity and magnetism. The teacher acted as a facilitator in student learning

processes and wrote reflective researcher memos throughout the intervention. After the second module was completed, all students took the SELF survey. After all four modules were completed, students took the MOLES-S, the MONOS, the SELF survey, the VNOS-B, and the content test. When students finished the modules, all of their work products were collected. Six students from the control group and six students from the experimental group were randomly selected to participate in a think aloud by performing one investigation from the intervention while being coached to think aloud. The control group performed the think aloud separately from the experimental group. Six students from the control group and six students from the experimental group were randomly selected to participate in a focus group which is designed to elicit their shared experiences in the two different types of inquiry units.

Fidelity of the lessons was maintained by first having the researcher co-teach the lessons with the teacher and later by having visits every three days of instruction. The teacher also emailed the researcher daily to explain any difficulties or successes. In addition to these procedures, a special education teacher who co-teaches with the science teacher participated in the pilot study. The special education teacher co-taught with the teacher administering the interventions and will report any activities that did not align with the pilot test.

### *Research Design*

This quasi-experimental mixed method study is designed to show differences in content knowledge, knowledge of the nature of science, metacognition and self-regulatory efficacy between the control and experimental group. The MOLES-S, the

MONOS, the SELF survey, the VNOS-B and the content test were given as a pre- and post-test so that variances between the control and experimental can be analyzed. The SELF survey was also given at the midpoint of the intervention to determine the pattern of the level of self-regulatory efficacy the students experience before, during and after the intervention. Researcher memos that were written throughout the intervention and student work products were used to back up any inferences made with the pre- and post-test analysis. Focus group results, think aloud results, researcher memos, and student work were used to determine the processes students used to achieve the measured outcomes.

#### *Data Analysis Procedures*

Statistical Package for Social Science (SPSS) 11.0 was used for all statistical analyses. The data was initially assessed for missing data and outliers. Descriptive techniques were used to describe the different quantitative measures between the different groups. Quantitative data were gathered using the MOLES-S, the MONOS, and the SELF survey. The MOLES-S and the MONOS are Likert-scales and the SELF is a percentage scale. Combined, the scales measured the constructs of metacognition, knowledge of the nature of science, and self-regulatory efficacy. The VNOS-B was analyzed using a rubric that determines the comprehensiveness of the knowledge of the nature of science on a scale from 0-3. The content test was analyzed for student comprehensiveness of the content goals on a scale from 0-3.

Inferential statistics were used to analyze the quantitative data. Independent  $t$  – tests were performed on the pre-tests to determine any differences in the groups before

the intervention. Three data points were taken with the SELF, so these data was analyzed using a repeated measures test.

The focus group results were analyzed for common experiences within the groups using a phenomenological stance and the processes that emerge from the common experiences were reported. The think aloud results were analyzed for the frequency of each of the three levels of verbal report discussed in the instrument section of this paper as well as for the processes that students use to achieve metacognition related to the nature of science. The researcher memos and student work products were analyzed for common themes and for processes that students use to achieve metacognition related to the nature of science. All data sources were catalogued in a matrix so that all data can be triangulated.

#### *Validity and Reliability*

Three of the instruments, SELF, MOLES-S, and MONOS, utilized Likert-scale responses and have been peer reviewed for reliability and validity for other samples of populations. Internal validity for these instruments has been addressed by running reliability tests on the instruments for both the pre-test and post-tests in the study sample. All instruments had a reliability alpha > .85. The reliability for the instruments were reported as follows: SELF pre-test .91 and post-test .95, MOLES-S pre-test .90 and post-test .95, and MONOS pre-test .85 and post-test .89.

The remaining instruments, VNOS-B and TEMK, utilized a scoring rubric in order to determine student outcomes. In order to address the validity of the scores, two other raters were asked to score all of the responses using the rubric. The raters had expertise with

secondary education as well as with educational research. They were instructed on the use of the rubric and then asked to independently score the responses. The inter-rater reliability for the TEMK was 92% and the inter-rater reliability for the VNOS-B was 94%.

## 4. Results

This study sought to find out if a method using self-regulation that prompted students to think metacognitively about the nature of science increased scores in content knowledge, nature of science knowledge, metacognition and self-regulatory efficacy, and explored the ways students used the prompts in their learning. Both qualitative and quantitative responses were analyzed to address the four research questions, 1) What is the effect of 4-Phase EMPNOS on science students' content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy? 2) How are the specific constructs of science content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy related to each other when students complete activities with embedded metacognitive prompts? 3) What characterizes the shared experiences of students who use 4-Phase EMPNOS and students who do not use 4-Phase EMPNOS? 4) In what ways do students approach activities with embedded metacognitive prompts and activities without metacognitive prompts? A pilot study was conducted with eighty-three eighth-grade students and the results were used to inform the design and analysis of the current study. This chapter presents a comparison of the study sample with a national sample, a report of reliability of the instruments for the study sample, an analysis of between group differences, within group differences, correlations among the measures, shared experiences between groups, and approaches to the activities between groups.

*Comparison of Control and Experimental Groups*

Descriptive statistics were calculated, and paired t-tests, independent t-tests and repeated measures were performed to identify differences in metacognition, self-efficacy, content knowledge and nature of science knowledge between the experimental and control groups. Descriptive statistics can be seen in Table 3 below.

Table 3

*Comparison of means for content knowledge, nature of science knowledge, metacognition, and self-efficacy.*

Variables	Group											
	Control						Experimental					
	Pre		Post		Mid		Pre		Post		Mid	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Test of Electricity and Magnetism Knowledge (TEMK)	1.24	.44	2.12	.30			1.08	.43	2.46	.42		
Metacognitive Orientation Scale – Science (MOLES-S)	3.34	.53	3.28	.50			3.16	.57	3.03	.42		
Metacognition of Nature of Science Scale (MONOS)	3.48	.53	3.35	.59			3.12	.57	3.51	.71		
Views of the Nature of Science Version B (VNOS-B)	1.04	.32	1.11	.30			.94	.44	1.71	.37		
Self-Efficacy of Learning Scale (SELF)	6.65	1.34	7.15	1.31	6.83	1.24	6.44	1.52	7.01	1.68	6.77	1.52

Independent *t*-tests were performed for the pre-test comparing the experimental and control groups as follows: content knowledge  $t(1,87) = .51, p = .62$ , metacognitive orientation  $t(1,88) = .09, p = .93$ , metacognition of the nature of science  $t(1,87) = .05, p = .83$ , nature of science knowledge  $t(1,87) = .16, p = .87$ , and self-regulatory efficacy  $t(1, 88) = .73, p = .47$ . As hypothesized no differences were found between the control and experimental group on any of the pre-test measures, all *p*'s > .05. Results for independent-*t* tests on the pre-tests can be seen in Table 4.

Table 4  
*Independent Sample Tests on Pre-Tests*

	<i>t</i>	<i>p</i>
Pre- TEMK	.51	.62
Pre- MOLES-S	.09	.93
Pre- MONOS	.05	.83
Pre- VNOS-B	.16	.87
Pre- SELF	.73	.47

It was also hypothesized that the experimental group will outperform the control group on all five post- measures. When independent *t*-tests were performed, significant differences emerged between the experimental group and the control group in content knowledge  $t(1, 67) = 2.96, p < .01$  and nature of science knowledge  $t(1, 85) = 5.51, p < .01$ . The experimental group demonstrated a greater gain in content knowledge ( $M = 2.46$ ) and

knowledge about the nature of science ( $M = 1.71$ ) than the control group ( $M = 2.12$ ) and ( $M = 1.11$ ) respectively. Neither metacognitive orientation of the classroom,  $t(1,87) = 0.37, p = .73$ , self-regulatory efficacy,  $t(1, 87) = .44, p = .66$ , nor metacognition of the nature of science,  $t(1,78) = .21, p = .84$  showed any significant differences between the experimental and control groups.

It was hypothesized that the experimental group will outperform the control group on the self-efficacy measure and that within each group there will be increases from pre- to mid- to post-test. To summarize self-efficacy data, which was taken before, during and after the intervention, a repeated measures test was performed. Significant differences in self-efficacy were found within the groups, Wilks's  $\lambda = .99, F(2, 82) = 0.53, p = .59$ . No significant differences were found between groups, but steadily numerical increasing gains were made in the control group and the experimental group.

The experimental group was also asked to graph the number of prompts they used in each module. After they completed the module, the students were given a master list of the prompts for all four modules on which they kept a tally of each of the prompts used. The students then graphed their progress after each module. Because of time constraints, the teacher in the study was not able to have the students graph their prompt use after the second module. However, all students from the experimental group were able to graph their use of prompts after module 1, 3, and 4. It was found that students utilized more prompts as the modules progressed. The total number of prompts in this study was twenty. After the first module, the mean number of prompts students used was 13.58. After the second module, students used a mean of 15.25 prompts, and after the third module, students used a mean of

16.18 prompts. Although the prompts were not provided on the following modules, the students seemed to use the prior prompts once they became familiar with them.

The MOLES-S was analyzed for any between group differences in the seven subscales: 1) metacognitive demands, 2) student-student discourse, 3) student-teacher discourse, 4) student voice, 5) distributed control, 6) teacher encouragement and support, and 7) emotional support. It was found that only one of the subscales, student-student discourse, had significant differences between the control and experimental groups. In the student-student discourse, the control group ( $M = 3.05$ ,  $SD = .92$ ) outperformed the experimental group ( $M = 2.44$ ,  $SD = 1.05$ ),  $t(1,87) = 2.93$ ,  $p = .004$ . All other subscales had no significant differences between groups. Table 5 shows a listing of the values found in analyzing the MOLES-S subscales.

Table 5

*Results of MOLES-S Subscale Analysis*

	Control		Experimental		<i>t</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Metacognitive demands	3.34	.83	3.01	.61	1.61	.12
Student-student discourse	3.05	.92	2.44	1.05	2.93	.004
Student-teacher discourse	3.08	.93	2.91	.81	.92	.36
Student voice	3.83	.85	3.94	.67	.72	.47
Distributed control	2.03	.99	1.77	.86	1.28	.20
Teacher encouragement and support	3.80	.88	3.70	.89	.52	.60
Emotional support	4.17	.81	4.07	.81	.61	.54

An analysis of the VNOS-B items was conducted to determine if there were between group differences for the four aspects of the nature of science chosen for the prompts in the four modules. The chosen aspects of the nature of science for the modules are empirical evidence, laws and theories, habits of mind of scientists, and creativity in science. Each aspect was identified in the questions of the VNOS-B as follows: the empirical evidence aspect was needed to answer numbers 1 and 2 sufficiently, the laws and theories aspect was needed to answer numbers 1 and 3 sufficiently, the habits of mind aspect was needed to answer number 6 sufficiently, and the creative aspect was needed to answer numbers 5 and 7 sufficiently. The social aspect of the nature of science was not chosen to be

included in the modules and was needed to answer number 4 on the VNOS-B sufficiently. A between group comparison of the means for each question or questions related to the aspects detailed above was conducted. The experimental group outperformed the control group in all four aspects taught in the modules which were addressed in the VNOS-B: empirical evidence,  $t(1,85) = 2.49, p < .001$ ; laws and theories,  $t(1,85) = 3.14, p < .001$ ; habits of mind of scientists,  $t(1,85) = 5.80, p < .001$ ; and creative nature of science,  $t(1,85) = 5.41, p < .001$ . There were no significant differences between groups on number 4 of the VNOS-B, the social aspect of the nature of science, which was not taught in the modules,  $t(1,85) = 1.85, p = .12$ . The results of this analysis can be found in Table 6.

Table 6

*Comparison of Means for the Aspects of the Nature of Science*

Aspects of NOS	Control		Group Experimental		<i>t</i>	<i>P</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
	Empirical evidence	1.25	.50	1.59		
Laws and theories	1.16	.32	1.51	.68	5.63	.00
Habits of mind of scientists	1.06	.57	2.07	.79	6.58	.00
Creative NOS	1.09	.54	2.04	1.03	2.72	.01
Social	1.11	.74	1.44	1.18	1.54	.13
Durable, yet tentative	1.02	.95	1.06	.65	2.30	.02
Science and technology	.98	.65	1.02	.78	1.18	.07

*Within Group Differences*

Furthermore, it was hypothesized that differences would emerge within the experimental group on all five post-test measures. Paired samples *t*-tests were conducted to compare differences from pre-test means to post-test means. Significant differences were found within the experimental group in metacognition of the nature of science, self-regulatory efficacy, content knowledge, and nature of science knowledge. In the control group, significant differences were found for content knowledge, metacognition of the nature

of science, and self-regulatory efficacy. The largest changes from pre- to post-test was found in the experimental group for content (TEMK)  $t(1,33) = 21.59, p < .01$ , and for nature of science knowledge (VNOS-B),  $t(1,40) = 11.22, p < .01$ . Other significant differences from pre-test to post-test found in the experimental group occurred on the metacognitive orientation of the classroom (MOLES-S)  $t(1, 36) = 2.81, p < .01$ , self-regulatory efficacy (SELF),  $t(1,41) = 3.91, p < .01$ , and on the metacognition of the nature of science scale (MONOS)  $t(1,35) = 4.55, p < .01$ .

Significant differences from the pre-test to the post-test were found in the control group for content knowledge (TEMK),  $t(1,32) = 16.02, p < .01$ , metacognition of the nature of science (MONOS),  $t(1,40) = 2.82, p < .01$ , and self-regulatory efficacy (SELF),  $t(1,44) = 3.97, p < .01$ . Although both groups showed gains from pre-test to post-test in content, a significantly higher gain in content knowledge was demonstrated by the students in the experimental group ( $M = 2.46, SD = .42$ ) over the control group ( $M = 2.12, SD = .30$ ). Students in the experimental group ( $M = 1.71, SD = .37$ ) also demonstrated a higher score on the Views of Nature of Science Version B instrument than the control group ( $M = 1.11, SD = .30$ ).

#### *Comparison of Study Sample with National*

Two questions designed for the National Assessment of Educational Progress or NAEP (National Center for Educational Statistics, 2007) were included on the content instrument because they were aligned to the grade level and content objectives of the study. Performance results for the national sample were available for 2005 and were compared with the study sample as seen in Tables 7 and 8. Before the intervention, the control and experimental groups were slightly above the national average for the

knowledge level question. After the intervention, both the control and experimental groups were well above the national average. For the synthesis level question, the control and experimental groups were slightly below the national average before the intervention. After the intervention the control and experimental groups were considerably above the national average.

Table 7

*Comparison of National Sample and Study Sample for Knowledge Level Question*

Rating Scale	NAEP	Percentages of Students			
		Pre-test		Post-test	
		Control	Experimental	Control	Experimental
3	57	76	68	86	81
2	38	18	11	11	18
1	4	7	21	3	0
0	1	0	0	0	0

Table 8

*Comparison of National Sample and Study Sample for Synthesis Level Question*

Rating Scale	NAEP	Percentages of Students			
		Pre-test		Post-test	
		Control	Experimental	Control	Experimental
3	19	7	4	46	41
2	29	26	28	49	53
1	46	43	38	6	3
0	6	22	32	0	3

*Correlations among the Variables*

In regards to the second hypothesis, as expected, positive correlations among all five variables were found. Specifically, high correlations were found between self-efficacy (SELF) and metacognition of the nature of science (MONOS),  $r = .64, p < .001$  and nature of science knowledge (VNOS-B) and content knowledge (TEMK)  $r = .61, p < .001$ . Other correlations were found to be significant: metacognition of the nature of science (MONOS) and metacognitive classroom orientation (MOLES-S),  $r = .37, p < .001$ ; metacognition of the nature of science (MONOS) and nature of science knowledge (VNOS-B),  $r = .34, p < .001$ ;

self-efficacy (SELF) and metacognitive classroom orientation (MOLES-S),  $r = .23, p < .001$ .

Table 9 presents correlations for study variables.

Table 9

*Intercorrelations between measures of self-efficacy, metacognition, content knowledge, and nature of science knowledge*

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Variables	1	2	3	4	5
1. Test of Electricity and Magnetism Knowledge (TEMK)	1.00				
2. Metacognitive Orientation Scale – Science (MOLES-S)	.10	1.00			
3. Metacognition of Nature of Science Scale (MONOS)	.38**	.37**	1.00		
4. Views of the Nature of Science Version B (VNOS-B)	.61**	.21	.34**	1.00	
5. Self-Efficacy of Learning Scale (SELF)	.13	.23*	.64**	.27	1.00

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\*\* Correlation is significant at the 0.01 level (2-tailed)

\* Correlation is significant at the 0.05 level (1-tailed)

### *Student Meaning of “Thinking Scientifically”*

In studying the question, What characterizes the shared experiences of students who use 4-Phase EMPNOS and students who do not use 4-Phase EMPNOS?, two major themes emerged from the focus groups and think aloud groups, student meaning of thinking scientifically and the strategies students employed to think scientifically. When asked what it was to think scientifically, the experimental group responded that the modules taught them that scientists use their prior understandings to explain new phenomena and that their explanations require a large amount of detail. Gary, a pseudonym, responded, “Thinking like a scientist requires lots of details, seeing things in a lot of different ways. . . the experiments, with the results you get, you can get a lot of different answers.” Carol responded, “When a non-scientist sees a bottle of water, a scientist would see an ordinary object in a scientific way – how much mass, how much volume, how fast the water molecules are moving.” Amina explained, “Now that I think about it, the modules make me think really like a scientist. Asking questions to think beyond what we’ve been doing.” Amina went on to describe that thinking like a scientist “means you pay more attention to specific detail.” The responses of the students in the experimental group converged on the theme that scientists use the details from previous experiences to explain current phenomena.

The experimental group also reported that scientists gain lots of experiences and reflect on these experiences in order to explain their ideas. Students in the focus groups reported being better able to reflect on their experiences because of the guidance of the checklists. Patrick answered, “Scientists think in a different way. They went to school more so they might be able to compare things better. On an experiment they might already know a lot about magnets, so they can make generalizations.” Karen responded, “Scientists go a lot

deeper. Why did this happen? What would happen if you made this happen?” in explaining how scientists probe for knowledge as they begin to understand the world around them. Sam also evoked the use of experience in developing scientists’ ideas, “When you see something happen over and over, you will expect a similar thing to happen again.” Overall, the experimental group believed that thinking like a scientist requires the use of a large amount of experiences, with attention to detail, so that new ideas can be generated.

In contrast, the control group reported that the modules in the intervention did not require them to think like scientists. The students reported that the modules were too fun and creative to be associated with the word “scientific”. They explained that the modules did not have enough strict directions to be scientific. Christine explained, “I don’t consider these to be scientific, my grandfather is a physicist, I don’t think this is science. It is not as uptight.” Roger talked about how the modules might be modified to make them more scientific, “. . . make them more precise, but that would be boring.” Kendra explained that she thought some aspects of the modules were scientific, but she couldn’t pinpoint why she thought that, the modules “were put together by scientific people who know what they are doing. There were labs and stuff that just seems scientific. I don’t really know why but it is about the same amount of science as a step-by-step lab.” When probed for what she meant by scientific, she paused for a long time and then answered, “I guess you gather data and form conclusions of what you saw – I don’t know.” The students in the control group continued to expect science laboratory experiences to have very detailed and directed steps as a foundation.

The control group paralleled the experimental group in their thinking about the extensive knowledge base of scientists and the role of this knowledge in forming new ideas. Sammy talked about the different behaviors of scientists, “A scientist thinks about why does

this happen more than a regular person who doesn't really care. A scientist would think about conclusions. Scientists are more serious about the world. Regular people don't wonder about the world." Mickey explained the difference between scientists' knowledge and non-scientists knowledge, "Ask the people if the universe is expanding, if they talk a lot about it, they are a scientist. A non-scientist wouldn't be able to talk about it much." Fuji agreed that scientists had access to a large personal store of factual information, "As them what is the atomic theory. If they took more than a split second to answer then they aren't a scientist."

#### *Use of Strategies in Scientific Learning*

Another major theme that emerged from the shared experiences of the two groups was the types of strategies students used to learn the material. However, the control group reported using different strategies than the experimental group. The control group talked about metacognition during the labs, although they did not use the terminology, but they could not explicate how they were thinking about their thinking. Jeremy said,

"I remember thinking something, then I reflect upon it. I think about what I got and how I got it. I sometimes think about how it was before I do the experiment and then what I got. I don't really think about how I think."

Christine talked about her thinking strategies in this way, "In step-by-step labs you don't think about why you are doing what you are doing. You think about it more in the modules." The control group also talked about the level of detail of their observations in the modules, "We wrote observations about the same (level of detail) than in step-by-step labs." Mickey goes on to explain, "We write more in the modules than we do in step-by-step labs, but we write about the same amount of detail in our observations."

The experimental group tended to write their observations in more detail, and they attributed this change to the checklists provided. Karen stated, "The checklists helped you

learn more about making your answers more detailed and observing more of what you saw.” Ted discussed how the checklists improved his ability to write observations with more detail, “When I first started the modules, I would go back to change my answer to make it more detailed. At about the third module, I would remember the checklists and you don’t go back to change your answer much.” Patrick talked about his use of the strategies in the checklists,

“The different checklists . . . The first one shows we need to really observe and the first checklist really stayed with me. I looked at the checklist and thought about specific things that showed in the results. I looked at the object, what material it was made of, and if it worked (was a conductor of electricity).”

Karen explained a specific use of one of the checklists, “The checklist idea, big ideas that was backed up by your evidence. When you get a conclusion (in the module), you want to support it with your data.” Patrick explained that the checklists changed the way he communicated observations, “I never would have observed things so detailed. I will do it in the future.” The students also used the strategies from the previous checklists for the latter modules, “I thought about the checklists (from previous modules) and realize that I didn’t do something as well as I could have. I thought about how I might explain it (the phenomena) to other people and I wrote it in more detail.” All of the students in all of the experimental groups spoke about using the checklists to improve the quality of communication of their observations.

The experimental group also discussed how the checklists have changed the way they study for summative assessments. The students explained that they now look for big ideas in the process of completing the modules instead of memorizing content. Sarah explained, “I change the way I study. I used to look at the notes and memorize the content. Now I look at the pictures and look at the data.” Patrick said, “I pay attention to our labs more often to

study for the test.” Karen said, “In step-by-step labs before, big ideas weren’t the bit part. Now it matters to most of us what the big idea was.” The students in the experimental group now see the importance in finding the big ideas in the activities of the unit rather than merely memorizing content.

### *Student Approaches to Conducting Inquiry*

The ways students approached the inquiry units they were given were analyzed through a think aloud protocol, focus groups, student products and teacher memos. Two major themes emerged in the data regarding approaches to problem solving: the methods the two groups resolved conflict of ideas in groups and the source of information the two groups used to change their ideas.

When the experimental group was faced with divergent ideas within a lab group, they would achieve consensus through discussion. The experimental group would not develop a conclusion unless all members of the group were convinced of the evidence that led to the conclusion. Patrick talked about his group’s process in developing consensus regarding results, “We looked for similar results, but sometimes they were not exactly the same. We looked for results that lots of groups had in common. Then we talked about how logical their answers were.” Dylan explained how his group resolved conflict, “We had a conflict about why it was happening this way. We explained it to the one person who didn’t think it was right. But we had to be sure they understood.” Karen’s group also used consensus to find the convergence of ideas, “When we had a disagreement, we kind of figured out what made sense and what didn’t make sense. Eventually we all came to an agreement that we didn’t do something right. Then we went back and changed it.” When faced with conflict, the experimental groups all reported achieving consensus through discussion.

However, the control group differed to authority, even when it conflicted with the evidence presented in the activity. Sarah explained how her group resolved conflicts, “If we couldn’t figure out the big ideas, Ms. White (the teacher) would tell us at the end. That’s how we knew it was right.” A control group member from another class talked about the same type of process, “We waited until the class discussions at the end. Then Ms. White told us what the answer was.” A different lab work group from the control sample had a different process, but they still based their decisions about information on authority, “The group was split about something and we let them think their ideas, and we thought what we did.” In all cases, when the members of the control group were asked how they resolved conflicting ideas, they depended on the teacher to tell them which answer was right.

The experimental and control groups also utilized different sources on which to base their conclusions. The experimental group made changes in their conclusions based on evidence, whereas the control group based their changes on authority. Dylan from the experimental group said, “If I messed up, I would figure them out from my observations and from my group, and went back to change it. That is part of science.” Patrick explained how evidence helped him form ideas, “It is different from reading it than doing it. When I saw what happened to the scissors and the electromagnet, I remembered domains through the whole thing (all four modules).” On the other hand, the control group changed answers when an authority figure would present different ideas, “We would only go back and change the content during the class discussions when Ms. White told us what the right answer was.” Christine explained her frustration with the lack of authority in the modules, “It works better for me if you have directions first. These labs didn’t give much information about what to do. I didn’t know what to do.” Members of the control group also reported that they did not

reflect on the lab when they “got stuck”, rather they approached the teacher for direction. The experimental group tended to base their conclusions on authority, while the control group tended to base their conclusions on authority.

### *Summary of the Findings*

Eighty-eight eighth grade students participated in a quasi-experimental mixed-methods study that examined the effect of developmental, metacognitive prompts based on the nature of science on content knowledge, nature of science knowledge, metacognition and self-regulatory efficacy. The study also explored the common experiences of the experimental and control groups as well as their approaches to problem solving.

The first research question used independent *t*-tests to determine the differences between the pre-test and post-test results of five measures to ascertain the role the intervention played in student learning of content and nature of science knowledge, student development in metacognition, and student self-efficacy of learning. The experimental group significantly outperformed the control group in two of the variables, content knowledge and nature of science knowledge. Within groups, the experimental group had significant growth from pre-test to post-test performance in all five measures, TEMK, VNOS-B, MOLES-S, SELF, and MONOS. Also, the control group had significant within group growth in content knowledge (TEMK), metacognition of the nature of science (MONOS) and self-regulatory efficacy (SELF).

The second research question used correlations between measures to examine any relationship among the instrument constructs. All measures had positive correlations and six out of the nine pairings were highly significant. The measures that had the highest significance are self-regulatory efficacy (SELF) and metacognition of the nature of science

(MONOS), content knowledge (TEMK) and nature of science knowledge (VNOS-B), content knowledge (TEMK) and metacognition of the nature of science (MONOS), metacognition of the nature of science (MONOS) and metacognitive orientation of the classroom (MOLES-S), and nature of science knowledge (VNOS-B) and metacognition of the nature of science (MONOS). One other pairing of measures, self-regulatory efficacy (SELF) and metacognitive orientation of the classroom (MOLES-S) also had significance.

The third research question was explored by conducting focus groups, think aloud protocols, student products and teacher memos to investigate common experiences between the experimental and control groups. Two major themes emerged from the data, student meaning of thinking scientifically, and strategies students applied to think scientifically. It was found that the experimental group equated “thinking scientifically” with attention to detail and reflecting on experiences to develop new knowledge. The control group did not think the modules were scientific, and equated “thinking scientifically” with a large amount of strict direction in the form of step-by-step laboratory experiences. The control group agreed that scientists pay attention to detail and have a great deal of background knowledge, but did not identify themselves in that role. In terms of strategies, the experimental group utilized the checklists in the intervention by making their answers detailed or by going back to change answers in order to make them detailed. The control group reported having to think more to complete the modules than they had in previous laboratory experiences, but they could not explicitly determine their methods for thinking.

The fourth research question also utilized focus groups, think aloud protocols, student products and teacher memos to determine the differences or similarities to problem solving between the groups. When the experimental group was faced with divergent ideas about the

way the phenomena worked, they would achieve consensus through discussion and would base their conclusions on evidence. The control group managed conflict of ideas in their group by seeking the opinion of authority, and would base their conclusions on the declaration of the teacher, rather than on evidence.

## 5. Discussion

This study used a quasi-experimental mixed method design to test an intervention intended to teach students to be metacognitively aware of their scientific thinking, and measured potential changes in content knowledge, nature of science knowledge, metacognition and self-regulatory efficacy as well as exploring the common experiences and problem solving techniques between the groups.

Eighty-eight eighth-grade students in a mid-Atlantic school were chosen to be in either an experimental or control group. The experimental group received a four module inquiry unit teaching electricity and magnetism content that had developmental, metacognitive prompts based on the nature of science embedded throughout the unit. After each module, the experimental group graphed the number of prompts they used in that module. The control group received only the four-module inquiry unit.

The student participated in five pre- and post-tests that measured content knowledge, nature of science knowledge, metacognition of the nature of science, metacognitive orientation of the classroom and self-regulatory efficacy. Independent *t*-tests were performed on the pre-tests and no significant differences were reported. Independent *t*-tests, paired *t*-tests and repeated measures tests were performed on the post-test data. Randomly selected students from the experimental and control groups participated in focus groups and think aloud protocols and the transcripts from these activities were analyzed for emerging themes.

## *Discussion of Results*

*Research Question 1: What is the effect of 4-Phase EMPNOS on science students' content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy?* Independent *t*-tests were performed to determine differences on all pre-tests between groups, and no significant differences were found. This could be attributed to the heterogeneous make-up of the classes chosen for the control and experimental groups. The teachers in the school where the study was held have a system where the students are purposefully placed into heterogeneous groupings for science class. The students' seventh grade teacher rates the student at the end of the seventh grade year as high, middle or low performing in science. Eighth grade teachers then put equal amounts of high, middle and low performing students in each of the science classes. In this way, the teachers maximize the opportunity for collaboration among the students. Since the experimental group consisted of two randomly selected classes and the control group consisted of two randomly selected classes from the same teacher, each group was set up to be heterogeneous, thus reducing the academic differences in the group.

It was hypothesized that students exposed to the intervention would report a higher level of content and nature of science knowledge, metacognition and self-regulatory efficacy. The results support the hypothesis partially, in that there was a significantly higher gain in content knowledge and nature of science knowledge for the experimental group receiving the embedded prompts than in the control group. Students who were instructed in the 4-phase developmental prompts based on the nature of science not only gained in their understanding of the nature of science, but also gained in their understanding in the science content. Students who were exposed to the metacognitive prompts could have understood science to

be more than a collection of facts (Chin & Brown, 2000; Crawford, 2005; Crawford, Kelly & Brown, 2000; Gijlers & deJong, 2005; Hogan, 1999b). Students who had instruction in the nature of science could have been able to construct a broader conceptual framework on which to hang the content learned in the modules, resulting in a gain in both content and nature of science knowledge.

The experimental group could have also outperformed the control group in the content test and the nature of science knowledge test because of their increase in ability to write in detail. The students in the experimental group reported during the focus groups that the metacognitive prompts caused them to go back to change their observations so that they included a large amount of detail. The questions on the content test and the nature of science knowledge test were open-ended, so the students who had an increased ability to describe their thoughts in detail would be able to outperform students who did not have the same communication skills (Beeth, 1998; Beeth & Hewson, 1999; Crawford, 2005; Crawford et. al, 2000; Hogan, 2000; Hogan 1999a; Lemke, 1990).

It was hypothesized that the experimental group would outperform the control group on the self-efficacy measure, which was not supported. There were significant differences within each group on the constructs, but there were not significant differences between the groups. Both groups in the experiment had a steady increase in self-efficacy as they completed the modules. The construction of the activities could have had an influence on student self-efficacy. The students in the focus groups and think alouds reported that the modules were different from the way they normally learned science. Both groups also reported that they enjoyed the structure of the modules because “they (the modules) had simple ideas that kept building” (as the learning progressed). Each module had the basic

pedagogical structure of a “KWL” chart, a group of activities to form the concepts, and a summation activity at the end. Each of the three parts of the modules was designed to involve the student, which was different from the way they learned science in the past. Students from both the experimental and control groups reported that during the classroom discussion of the KWL chart, they realized that they knew more than they originally thought. The summation at the end of the activity asked students to reflect on what they learned in the module and assemble the “big ideas” into a coherent conclusion. Since the summation caused the students in both groups to examine their learning progress, this activity may have led to the increased self-efficacy of learning for both groups.

No significant gains were reported of the experimental group over the control group in metacognition. This result could be due to the teacher’s method of instruction. The teacher in this study was a first-year teacher and she had a good understanding of the nature of science, but her nature of science knowledge may not have translated in to classroom practice (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, & Abd-El-Khalick, 2003; Bell, Lederman, & Abd-El-Khalick, 2000). Students were not directly questioned about the metacognitive prompts; rather they were treated as additional direction to complete the homework. The students in the experimental group may have experienced more self-regulatory efficacy if there were more explicit and active self-regulatory strategies such as discussion of the meaning of the checklists (Zimmerman & Kitsantas, 2005; Weinert, 1987).

A deeper analysis was conducted with the results of the VNOS-B to examine if the particular aspects of the nature of science that were addressed in this experiment produced any patterns in learning. Four of the seven identified aspects of the nature of science were addressed in the intervention. The addressed aspects were empirical evidence, the difference

between laws and theories, habits of mind of scientists, and creativity. The aspects of the nature of science that were not addressed in the intervention include tentativeness, social and historical factors, and the difference between science and technology. The questions on the VNOS-B were analyzed to determine between group differences of the addressed aspects and the aspects that were not addressed. It was found that the experimental group significantly outperformed the control group on the questions that speak to the aspects in the intervention. The questions on the aspects that were not addressed had no between group differences. This supports the idea that the prompts help students form ideas about how the aspects of the nature of science are operationalized in an active inquiry setting. The students who have guidance in monitoring their thoughts and actions about specific nature of science aspects have more success in controlling their thoughts and actions to align with the nature of science.

Within the groups, it was hypothesized that differences would occur within both experimental groups and control groups on all pre- and post-measures. Significant differences were found within the experimental group on content knowledge, nature of science knowledge, metacognition, and self-regulatory efficacy. Significant differences were found within the control group on content knowledge, metacognition of the nature of science, and self-regulatory efficacy.

The gain in content knowledge for both groups could have also occurred because of the design of the inquiry unit. Since students had to construct their explanations for phenomena, they had ownership of the content and were able to make the content fit into current conceptual frameworks (AAAS, 1993; NRC, 1996). The constructivist methods of the inquiry unit were unlike the methods the students experienced in prior labs. Evidence that

supports this idea lies in the results of the questions from the NAEP exam. The average pre-test score for the knowledge level question was slightly below the average national score, but after the intervention, student scores were well above the national average. Students in both groups retained factual knowledge about the phenomena they were constructing ideas about during the modules. Several studies (Beeth, 1998; Beeth & Hewson, 1999; Crawford, 2005; Hogan, 2000; Hogan 1999a; Hogan 1999b) have shown that when students are engaged in activities where they can construct their own knowledge, they retain content knowledge more effectively. In addition, the average pre-test score for the synthesis level question was well below the national average, but after the intervention was markedly above the national average. It seems the intervention was effective in teaching higher level thinking skills to the students. The students reported during the focus groups that they felt they were learning more because of the way the units used prior knowledge to build new ideas. Other studies have demonstrated a deeper student understanding of higher level questions through inquiry methods (Anderson & Fowler, 1978; Marx, Blumenfeld, Krajcik, Fischman, Soloway, Geier, & Tal, 2004; Russell & Chiapetta, 1981). These studies have shown that students develop both factual knowledge and critical thinking skills when they construct understandings in order to proceed in their inquiry. In the same way, the intervention has helped students develop content knowledge in factual realms and in critical thinking realms because students must synthesize their factual knowledge to express big ideas learned in the modules.

The gain within the experimental group in nature of science knowledge could have been due to the extended exposure to the concepts of the nature of science. Because the students had access to checklists and questions regarding the nature of science, they could have interpreted their knowledge in terms of the nature of science, resulting in an increase in

nature of science knowledge. Since the experimental group was the only group exposed to the four phase checklists and questions about the nature of science, their knowledge in this field increased (McComas, 2005; Lederman, 1992).

Gains in both groups in metacognition could have occurred because of the design of the inquiry units. All four of the units had a component of constructivist learning as students were required to observe phenomena, record behavior and speculate on a personal theory of why the phenomena happened. Students were also required to work in groups which results in active discussion of ideas (Kuhn, Amsel, & O'Loughlin, 1988; Hogan, & Maglienti, 2001). Student metacognition could have increased in both groups because they were required to pose and defend their own ideas within their groups (Crawford, 2005; Driver, Newton, & Osborne, 2000). Students were required to think about their thinking in order to express it coherently and logically defend their original ideas.

The gain in self-regulatory efficacy may have occurred also because of the design of the units. All of the units began with an exercise where students were to record what they knew about the content, then what they learned from a partner, then what they learned about the content from the entire class (Kitsantas, & Zimmerman, 2006). Some of the students from both groups reported during the focus groups that they liked the class discussions because they were often reminded of material that they didn't think about originally. Having the experience of being reminded of content that the students already understood could increase their self-efficacy of learning. Also, both groups during the intervention had to reflect on their work in order to summarize the vocabulary and "big ideas" at the end of each module. The students had not been asked to do this task in prior laboratory experiences, and the activity of looking back on one's work to see the ideas that formed from their work could

have an effect of increased self-efficacy of learning. The students may have been surprised about the amount of learning that occurred during the modules, since they were asked to go back and reflect on it.

Another contributor to the increase in self-efficacy within the experimental group could be the developmental nature of the prompts. The prompts were designed to first model the action of thinking scientifically, then ask students to emulate the action with support in the form of checklists, and then answer simple questions on their rationale for collecting and verifying information, and finally ask complex questions to have students reflect on their metacognition of scientific understandings. The experimental group graphed their use of the prompts as they completed each module and the results of this analysis showed a mean increase in the use of the prompts over time. This meant that the students were using the strategies described in the prompts from prior modules, as each module had approximately the same number of prompts. Because there was an increase, the students were using more prompts than were provided in writing on the module. Students had more strategies because of the prompts as they progressed through each module, and therefore could have felt more comfortable with the material as they were given more prompts (Zimmerman & Kitsantas, 2005).

*Research Question 2: How are the specific constructs of science content knowledge, knowledge about the nature of science, metacognition, and self-regulatory efficacy related to each other when students complete activities with embedded metacognitive prompts?* It was hypothesized that there would be a positive correlation among all five variables, which was partially supported by these data. The five highly correlated measures from highest to lowest were the SELF and the MONOS, the TEMK and

the VNOS-B, and the TEMK and the MONOS, the MONOS and the MOLES-S, and the VNOS-B and the MONOS. The SELF and the MONOS have correlations because the MONOS measures context-based metacognition, which is one of the constructs that makes up self-regulation (Zimmerman, 1989). Since self-regulatory processes include checking thought processes, the two constructs should be highly correlated when measured by instruments. In the activity, the experimental group was asked to self-monitor their progress through graphing, which increased their self-efficacy of learning (Kitsantas, & Zimmerman, 2006). The increase in self-efficacy in combination with the task of justifying their ideas to their peers could have also influenced their metacognition.

VNOS-B and TEMK are correlated because the nature of science provides the epistemology which is the framework for scientific content. Knowledge of the nature of science is important in being able to explain theories behind phenomena (Duschl, 1990). In understanding how science operates as a discipline, students become more proficient in discovering and validating personal knowledge in a scientific way. The modules were designed so that students needed to refer to their prior knowledge in order to explain new phenomena. In completing the modules, the students were asked to apply their understanding of how knowledge is verified scientifically in order to gather together the “big ideas” for each module. Students needed to use the nature of science in order to get suitable ideas for the summary of the module.

The MONOS and TEMK are correlated because the MONOS is based on the seven aspects of the nature of science (Lederman, 1992, McComas, 2005) which forms a foundation with which students can understand content regarding physical phenomena. When students understand how knowledge is constructed and validated in the scientific arena, they

are more prepared to understand the theories that connect factual information in the body of scientific knowledge (Duschl, 1990).

The MONOS and MOLES-S were found to correlate highly because they are both instruments that explore metacognition. The MOLES-S measures the metacognitive orientation of the classroom and the MONOS measures students' ability to think metacognitively about the nature of science. This correlation provides evidence that classrooms must be structured to give students the freedom to generate and reflect on their ideas and the ideas of others in order to have metacognition in a context-based setting, such as learning about the nature of science. The structure of the modules allowed for students to collaborate on ideas about new phenomena, which provided a classroom that was highly-oriented toward metacognitive practice. Students were then able to be metacognitive about their rationale in choosing scientific practices during the inquiry unit.

The VNOS-B and the MOLES-S were also found to have high correlations. These data support the idea that the nature of science is correlated with the metacognitive orientation of the classroom. That is, students must learn in a setting where they have the ability to generate ideas and to reflect on their ideas and the ideas of others in order to have an understanding of how science operates as a discipline (Bartholomew & Osborne, 2004; Cotham & Smith, 1981; Duschl, 1990; Duschl & Gitomer, 1991; Duschl, Hamilton, & Grandy, 1992)

*Research Questions 3: What characterizes the shared experiences of students who use 4-Phase EMPNOS and students who do not use 4-Phase EMPNOS?* Two major themes emerged from the data taken in the focus groups, think aloud protocols, student products and teacher memos, student meaning of thinking scientifically and the types of

strategies that students employed to think scientifically during inquiry. The data showed that students who used the 4-phase EMPNOS (the experimental group) talked more about the development of their knowledge in scientific thinking than the control group. The control group tended to focus on listing the content they learned when asked about how they thought in a scientific way during the focus group discussion. The experimental group tended to speak about their explanations about why the phenomena occurred (Bell, Lederman, & Abd-El-Khalick, 2000), whereas the control group could not provide any explanations and instead offered a list of content knowledge instead. The experimental group also had more frequent discussion about the need for empirical evidence that backed up their personal theories. The control group did not talk at all about empirical evidence, even though they expressed concern with getting the “right” answer. During the think aloud protocol, both groups discussed that they felt “freedom” and ownership in the inquiry units, but the experimental group more frequently mentioned their rationale behind their constructed ideas and were more likely to construct their own “scientist” identity.

In discussing perceptions of the thoughts and behaviors of scientists, both the experimental and control groups reported that scientists examine the world differently than non-scientists. Students reported that they thought scientists would look at a common object and be able to analyze different elements from the object, whereas non-scientists would only see the object. In this study it was found that the experimental group was able to reflect on their observations and results and add detail to their descriptions and inferences. However, the control group did not reflect on their observations or conclusions in the modules and depended on authority to gather information. Becker (1989) illustrates the ability of scientists to see more in an ordinary object in his study of Brazilian soil scientists. Becker explains that

to a scientist, a clump of soil can be described by both the material properties and by the abstract meaning the scientists derive from the qualities of the soil, such as the numbered code used to describe the types of microbes found in the sample. In the same way, the experimental students completed the modules as they normally would, and then used the checklists to go back and see more in the phenomena they observed during the activity. The prompts encouraged students to go back and add more detail, leading them to see more in an ordinary object as scientists do.

Giljers and de Jong (2005) conducted an investigation examining the influence of student prior knowledge on knowledge development during collaborative discovery learning, which was a similar learning method to the intervention in this study. They found that a high level of definitional prior knowledge is positively related to the proportion of communication regarding the interpretation of the results. In the same way, the students in the experimental group were given the opportunity to learn more prior knowledge through the prompts. Having more prior knowledge allowed the students in the experimental group to discuss their results in more detail.

The students in the study also talked a great deal about the strategies they used to help them think scientifically. The understanding of scientific knowledge for both groups was to link details from prior experiences to current unknown phenomena, and the experimental group gave more evidence that they employed this strategy as compared to the control group. The experimental group explained that the prompts were used as a guide to go back and write in more detail, which by the student definition is acting like a scientist. However, the control group did not have the prompts to guide their development of ideas, and wrote about the same level of detail in observations and conclusions. The control group also reported that

they wrote about the same level of detail, which illustrates that the control group's actions match their perceptions. Other studies have reported that students engaged with explicit strategies regarding the construction of scientific knowledge have shown students who obtained an intervention communicated results at a higher level of detail (Hogan, 1999a; Hogan, 1999b; White, 1993; White and Frederickson, 1998).

*Research Question 4: In what ways do students approach activities with embedded metacognitive prompts and activities without metacognitive prompts?* In examining the approaches the different groups used to conduct inquiry, two topics continued to surface in the focus groups, think aloud protocols, student products and teacher memos: 1) the methods students used in groups to resolve a conflict in ideas, and 2) the source of information the students used to change their ideas. The experimental group used discussion and consensus to resolve conflicts in ideas, whereas the control group utilized authority in deciding on a satisfactory response. The difference in the methods could be attributed to the strategies detailed in the prompts. One of the aspects the prompts focused on was the use of peer review and constructive criticism as tools to refine ideas in science. The control group was not exposed to this particular strategy and then relied on their prior method of resolving conflicts in ideas, teacher knowledge. The experimental group had developed a respect for listening to other students' ideas in order to resolve conflict from the aspects of the nature of science detailed in the prompts.

The experimental group depended on evidence to develop new ideas; furthermore the control group depended on authority in the form of teacher information to develop new ideas. These phenomena could also be attributed to the prompts. Another aspect addressed in the prompts was the use of empirical evidence to back up new ideas in science. The experimental

group had the use of empirical evidence modeled for them as well as having practice in using empirical evidence to back up their own claims. The control group did not have any modeling or practice in the use of empirical evidence, so did not value the use of evidence in the development of ideas. Since the experimental group had experience using empirical evidence to defend claims, they utilized this strategy instead of seeking authority.

#### *Implications for Instructional Practice*

Often teachers have only a surface understanding of the discipline of science (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Bianchini & Colburn, 2000; Chin & Brown, 2000; Nott & Wellington, 1998) and need additional resources to teach about the nature of science. The information given in the 4-phase EMPNOS prompt can help teachers understand more than just the content of the nature of science. The prompts can also instruct teachers in how the nature of science works as an epistemology by providing examples of how to check inquiry actions against the appropriate scientific actions. The prompts ask the person doing the inquiry to check their methods in establishing observations and conclusions to assure they are aligned with the way science operates as a discipline. Even teachers who have a great deal of knowledge of the nature of science can learn how these inherent guidelines used to establish and verify knowledge can work in an inquiry module.

Teaching science as a series of disconnected facts has been shown to be ineffective (Chin & Brown, 2000; Crawford, 2005; Gijlers & deJong, 2005; Hogan, 1999) and does not help students form ideas about how scientific knowledge is created and verified (Duschl, 1990; Clough, 1997). Four-phase embedded metacognitive prompts based on the nature of science (4-phase EMPNOS) can aid in connecting content knowledge to nature of science

knowledge resulting in an increase in understanding in both areas (Herbert, 2003). When students can understand how scientific knowledge is constructed and verified, they can understand the rationale behind the development of the body of knowledge known as science content.

Four-phase EMPNOS provides a tangible pedagogy that can be easily inserted into previously developed lesson plans. Teachers can choose the aspect of the nature of science that is best illustrated in a particular topic, and locate appropriate places to insert the developmental prompts. Using the 4-phase EMPNOS checklists and questions, teachers can insert phases one through four of the chosen nature of science aspect into their lesson plans. The prompts may also cause some teachers to reflect on their current lesson plans because if the prompts are inserted into lesson plans that do not use inquiry, the students will not have the ability to answer the questions. In this way, the prompts could help some teachers realize that they do not give the students the opportunity to reflect on their thinking. The intervention is cost effective and compliments teachers' current curriculum.

Teachers can use 4-phase EMPNOS to scaffold understanding through a developmental process and enrich student understanding of both content knowledge and knowledge about how the content is developed and verified in the scientific community (DeSautels & Larochelle, 2006). Students gain practice in the ways of knowing in science and have explicit instruction that is connected to the knowledge that they construct. Students do not often have an understanding of the scientific community and the construction and verification of knowledge (Hogan & Maglienti, 2001). Students who use 4-phase EMPNOS gain experience in checking their thinking against scientific thinking which helps them to understand what knowledge is scientific and what knowledge is not scientific. This

intervention also helps students to become more proficient in metacognition, which helps in gaining content knowledge (Costa, Calderia, Gallastegui & Otero, 2000). When students can begin to think about their thinking, they can become independent learners and can conduct inquiries into scientific phenomena on their own.

#### *Recommendations for Future Research*

This final section discusses the limitations of the present study, the lessons learned by conducting this research study, and suggestions for future research.

*Limitations.* Limitations of this study are the small sample size and the convenient sample used because the classes were already formed. The sample also consisted of few minorities, which could have affected results. The instruments used in this study were self-report, which always involves the bias of the participants' perceptions. There is always the possibility of a gap between participant perception and participant action concerning the phenomena. Another limitation may be the use of the instruments that had content validation with high school students. The MOLES-S, the VNOS-B and the SELF were originally intended for high school students. The researcher decided to use these instruments because they illustrated the constructs that were investigated and that the study was done at the end of the eighth grade year and the students were about to graduate to high school.

This study presented several threats to validity. The potential internal, external and measurement threats were identified and addressed.

The issue of researcher bias emerges when qualitative analysis is employed (Maxwell, 2005). Researcher bias refers to the phenomena that occurs when a researcher is examining data for a particular event and unintentionally ignores other important data or overemphasizes the pertinent data. Researcher bias was addressed in this study by

asking two other people to code the qualitative data from the focus groups and the think aloud protocols. One person asked to code the data was a graduate student in education and the other person was a classroom teacher. Only the intersecting codes from the three independent analyses were considered in the results of the study in order to address validity issues.

Other methods to reduce internal validity issues include a two-year involvement in the study, one year for the pilot study and one year for the dissertation study. Having a long-term intensive involvement tends to provide more complete data (Maxwell, 2005). Member-checks were conducted often during the focus groups and the think aloud protocols. The researcher repeated key findings to the focus groups and the think aloud groups in order to clarify and verify that the finding was aligned with the ideas of the participants. The member-checks helped to rule out any misinterpretations of the participants' understandings (Maxwell, 2005).

Since this study examines student outcomes and processes from one school in the mid-Atlantic region of the United States, a threat is posed to the generalizability of the results. This was addressed by placing two questions that were released from the National Assessment for Educational Progress assessment on the Test of Electricity and Magnetism Knowledge. The questions were given to the same grade level students around the country in 2002 and these data are available. The national data was compared to the study sample.

The use of externally validated instruments was one way measurements issues of validity were addressed. Externally validated instruments were the Views of the Nature

of Science – Form B (VNOS-B), the Metacognitive Orientation Science (MOLES-S), and the Self-Regulatory Efficacy of Learning Scale (SELF). In addition to utilizing externally validated instruments, the reliability of the instruments was calculated for this study. Other instruments such as the Test of Electricity and Magnetism (TEMK) and the Metacognition of Nature of Science Scale (MONOS) were not externally validated, but were validated during the pilot test of this study.

The TEMK and VNOS-B were instruments that utilized a scoring rubric to quantify the open-ended answers. Since there is a validity threat to instruments that use rubrics, inter-rater reliability was conducted for both of the measures. Two individuals in addition to the researcher rated the pre-tests and the post-tests for the TEMK and the VNOS-B.

*Lessons learned.* The pilot study of this dissertation and the dissertation study have both shown that it is difficult to separate nature of science instruction from inquiry instruction. Although the experimental group outperformed the control group in content knowledge and nature of science knowledge, these data also show increases in content knowledge and nature of science knowledge within both groups. Evidence in this study and in the pilot study indicated that some of the learning in content and nature of science was due to the inquiry nature of the unit and some of the learning was due to the prompts. If students are taught to do scientific inquiry well, they are inevitably acquiring nature of science knowledge because the nature of science is the rationale behind the skills and knowledge involved in scientific inquiry. Future study may begin to explicate the cognitive connections between inquiry and the nature of science.

Eighth grade students may not be the optimal group from which to study metacognition phenomena. During this study, it was difficult for the students during the think aloud protocol and the focus groups to report their thinking processes. Some of the students reported that it was not possible to think about their thinking, therefore making it very difficult to get students to monitor and control their thinking. Based on the researcher's experience as a ninth grade teacher, future study may be more fruitful if it focuses on slightly older groups of students.

*Future research.* Only four aspects of the nature of science were investigated in the modules due to time constraints. Future research should focus on all seven aspects of the nature of science to determine the appropriateness of the aspects for each grade level. This study could also be extended to other grade levels such as high school and elementary students. Since each aspect of the nature of science is distinct in this study, the process is useful in determining which aspects of the nature of science are appropriate for different grade levels.

The next logical step in this research is to design professional development so that teachers can use this method in their classroom. Training teachers to use developmental metacognitive prompts based on the nature of science could improve the quality of inquiry in classrooms as well as teaching the nature of science explicitly to students. When students and teachers understand how science constructs and validates knowledge, they have the power to conduct compelling scientific inquiry in many different contexts.

## Appendix A1: Metacognitive Orientation Scale

Name \_\_\_\_\_

Gender (M or F) \_\_\_\_\_

### Metacognitive Orientation Scale – S (MOLES-S)

#### What Actually Happens in the Science Classroom?

#### Directions

##### 1. Purpose of the Questionnaire

This questionnaire asks you to describe HOW OFTEN each of the following important practices takes place in this science classroom. There are no right or wrong answers. This is not a test and your answers will not affect your assessment. Your opinion is what is wanted. Your answers will enable us to improve future science classes.

##### 2. How to Answer Each Question

On the next few pages you will find 35 sentences. For each sentence, circle ONLY ONE number corresponding to your answer. For example:

	Almost always	Often	Sometimes	Seldom	Almost Never
Students are asked by the teacher to think about their difficulties in learning science	5	4	3	2	1

- If you think this teacher *almost always* asks you to think about your difficulties in science, circle the 5.
- If you think this teacher *almost never* asks you to think about your difficulties in learning science, circle the 1
- Or you can choose the number 2, 3, or 4 if one of these seems like a more accurate answer

##### 3. How to Change Your Answer

If you want to change your answer, cross it out and circle a new number.

##### 4. Course Information

Please provide information in the box below. Please be assured that your answers to this question will be treated confidentially.

Course/ Year in School	
------------------------	--

**5. Now turn the page and please give an answer for EVERY question.**

Metacognitive demands	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
1. Students are asked by the teacher to think about how they learn science.	5	4	3	2	1
2. Students are asked by the teacher to explain how they solve science problems.	5	4	3	2	1
3. Students are asked by the teacher to think about their difficulties in learning science.	5	4	3	2	1
4. Students are asked by the teacher to think about how they could become better learners of science.	5	4	3	2	1
5. Students are asked by the teacher to try new ways of learning science.	5	4	3	2	1
Student-student discourse	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
6. Students discuss with each other about how they learn science.	5	4	3	2	1
7. Students discuss with each other about how they think when they learn science.	5	4	3	2	1
8. Students discuss with each other about different ways of learning science.	5	4	3	2	1

9. Students discuss with each other about how well they are learning science.	5	4	3	2	1
10. Students discuss with each other about how they can improve their learning about science.	5	4	3	2	1

Student-teacher discourse	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
11. Students discuss with the teacher how they learn science.	5	4	3	2	1
12. Students discuss with the teacher about how they think when they learn science.	5	4	3	2	1
13. Students discuss with the teacher about different ways of learning science.	5	4	3	2	1
14. Students discuss with the teacher about how well they are learning science.	5	4	3	2	1
15. Students discuss with the teacher about how they can improve their learning of science	5	4	3	2	1
Student voice	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
16. It is OK for students to tell the teacher when they don't understand science.	5	4	3	2	1
17. It is OK for students to ask the teacher why they have to do a certain activity.	5	4	3	2	1

18. It is OK for students to suggest alternative science learning activities to those proposed by their teacher.	5	4	3	2	1
19. It is OK for students to speak out about activities that are confusing	5	4	3	2	1
20. It is OK for students to speak out about anything that prevents them from learning.	5	4	3	2	1
Distributed control	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
21. Students help the teacher plan what needs to be learned.	5	4	3	2	1
22. Students help the teacher decide which activities they do.	5	4	3	2	1
23. Students help the teacher to decide which activities are best for them.	5	4	3	2	1
24. Students help the teacher decide how much time they spend on activities.	5	4	3	2	1
25. Students help decide when it is time to begin a new topic.	5	4	3	2	1
Teacher encouragement and support	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
26. The teacher encourages students to try to improve how they learn science.	5	4	3	2	1
27. The teacher encourages students to try different ways to learn science.	5	4	3	2	1

28. The teacher supports students who try to improve their science learning.	5	4	3	2	1
29. The teacher supports students who try new ways of learning science.	5	4	3	2	1
30. The teacher encourages students to talk with each other about how they learn science.	5	4	3	2	1

Emotional Support	Almost Always	Often	Some-times	Seldom	Almost Never
In this science classroom:					
31. Students are treated fairly.	5	4	3	2	1
32. Students' efforts are valued.	5	4	3	2	1
33. Students' ideas are respected.	5	4	3	2	1
34. Students' individual differences are respected.	5	4	3	2	1
35. Students and the teacher trust each other.	5	4	3	2	1

Appendix A2: Metacognition of the Nature of Science Scale

Name \_\_\_\_\_

Gender (M or F) \_\_\_\_\_

**Metacognition of the Nature of Science (MONOS) Survey**

When reading this survey, consider all of the experiences you had in all of your science classes, not just the class you are presently taking.

- Read the statement
- Circle the number that best describes how you feel about the statement.

**1. I enjoy being in science class.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**2. I think about how I learn in science class.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**3. I do well in science class.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**4. When I make an observation, it is clear and understandable to other people.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**5. When I complete a lab in science, I think about how the lab could be improved.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**6. When I classify objects in science, I think about how my classification system compares to other students' classification systems.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**7. When I measure objects in science, I think about possible errors I could make when making measurements**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**8. I like asking questions in science.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**9. When I record data in science, I can understand what I did, even weeks after I gathered the data.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**10. When I make a conclusion for an experiment, I think about what observations might be the most effective to make my point.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**11. When I make observations, I think about all possible perspectives, not just the obvious ones.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**12. When I draw conclusions in an experiment, I think about what scientists have done on this topic.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**13. When given an assignment, I can see how it is a building block to bigger ideas.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**14. I can usually see patterns in my experiment results.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**15. When I organize data, I first think about the best way to explain what I am trying to show.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

**16. I think about how my measurements help me explain an idea in an experiment.**

Disagree with statement		Neutral about statement		Agree with statement
1	2	3	4	5

## Appendix A3: Self-efficacy for Learning Form

### SELF-EFFICACY FOR LEARNING FORM (SELF)

Name \_\_\_\_\_

Gender (M or F) \_\_\_\_\_

Choose a percentage to indicate your answer

**1.** When you miss a class, can you find another student who can explain the lecture notes as clearly as your teacher did?

Definitely Cannot Do it		Probably Cannot		Maybe Can		Probably Can Do It		Definitely		
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**2.** When your teacher\*s lecture is very complex, can you write an effective summary of your original notes before the next class?

Definitely Cannot Do it		Probably Cannot		Maybe Can		Probably Can Do It		Definitely		
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**3.** When a lecture is especially boring, can you motivate yourself to keep good notes?

Definitely Cannot Do it		Probably Cannot		Maybe Can		Probably Can Do It		Definitely		
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**4.** When you had trouble understanding your instructor\*s lecture, can you clarify the confusion before the next class meeting by comparing notes with a classmate?

Definitely Cannot Do it		Probably Cannot		Maybe Can		Probably Can Do It		Definitely		
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**5.** When you have trouble studying your class notes because they are incomplete or confusing, can you revise and rewrite them clearly after every lecture?

Definitely Cannot Do it		Probably Cannot		Maybe Can		Probably Can Do It		Definitely		
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**6.** When you are taking a course covering a huge amount of material, can you condense your notes down to just the essential facts?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**7.** When you are trying to understand a new topic, can you associate new concepts with old ones sufficiently well to remember them?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**8.** When another student asks you to study together for a course in which you are experiencing difficulty, can you be an effective study partner?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**9.** When problems with friends and peers conflict with schoolwork, can you keep up with your assignments?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**10.** When you feel moody or restless during studying, can you focus your attention well enough to finish your assigned work?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**11.** When you find yourself getting increasingly behind in a new course, can you increase your study time sufficiently to catch up?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
----------------------------	--	--	--------------------	--	--------------	--	-----------------------	--	--	------------

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

**12.** When you discover that your homework assignments for the semester are much longer than expected, can you change your other priorities to have enough time for studying?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**13.** When you have trouble recalling an abstract concept, can you think of a good example that will help you remember it on the test?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**14.** When you have to take a test in a school subject you dislike, can you find a way to motivate yourself to earn a good grade?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**15.** When you are feeling depressed about a forthcoming test, can you find a way to motivate yourself to do well?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**16.** When your last test results were poor, can you figure out potential questions before the next test that will improve your score greatly?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**17.** When you are struggling to remember technical details of a concept for a test, can you find a way to associate them together that will ensure recall?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**18.** When you think you did poorly on a test you just finished, can you go back to your notes and locate all the information you had forgotten?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

**19.** When you find that you had to \*cram\* at the last minute for a test, can you begin your test preparation much earlier so you won't need to cram the next time?

Definitely Cannot Do it			Probably Cannot		Maybe Can		Probably Can Do It			Definitely
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Appendix A4: Test of Electricity and Magnetism Knowledge

Name \_\_\_\_\_

Test of Electricity and Magnetism Knowledge

Magnetism

1. Draw a picture showing how two magnets should be placed for maximum attraction between them.
2. Why are some materials magnetic while others are not?
3. How do magnets become magnetic?

Static Electricity

4. What types of materials hold static electric charges more effectively?
5. Why do certain materials hold static electric charges more effectively?

6. How are static electric charges like magnets?
  
7. Describe one situation where two materials that are statically charged attract? What kinds of materials are they and what did you do to get them charged?
  
8. Why do you get a shock on a metal object after you drag your feet on the carpet?

#### Current Electricity

9. Draw a picture of a complete electric circuit with one cell, one bulb and a switch.
  
10. Draw a picture of an electric circuit with one cell, one bulb and a switch that is not complete. That is, it doesn't light the bulb.
  
11. Name the types of materials carry electric current well.

12. Draw a picture of a series circuit with three bulbs. What happens when you take out one of the bulbs?

13. Draw a picture of a parallel circuit with three bulbs. What happens when you take out one of the bulbs?

14. Describe one relationship in an electric circuit where you change one variable and another variable also changes.

#### Electromagnetism

15. Draw a picture showing where a compass needle would point when placed near a coil of wire.

16. Draw the direction of the compass needle in the picture showing where it would point when placed near a coil of wire with an iron nail through it.

17. How does an iron nail become magnetic when placed in a coil of wire with current electricity?

18. Name two ways to make an electromagnet stronger.

19. Look at each item in the list below. Decide if it conducts electricity or does not conduct electricity. Put an X in the box to show what you decided.

Item	Conducts Electricity	Does Not Conduct Electricity
House Key		
Rubber Band		
Coin		
Wooden Toothpick		
Metal Fork		
Plastic Spoon		
Aluminum Foil		

20. Suppose that you have one of the items from the list in Question 19 that you believe conducts electricity, and that you also have a battery, several wires, and a light bulb.

Explain how you could use these things to do a test to find out if the item you chose from the list in Question 19 does conduct electricity. Draw a picture to help explain your answer.

Appendix A5: Views of the Nature of Science Scale – Form B

Name \_\_\_\_\_  
Gender (M or F) \_\_\_\_\_

*VNOS–Form B*

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.
2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
4. How are science and art similar? How are they different?



## Appendix A6: Focus Group Semi-Structured Interview Protocol

### Focus Group Questions

1. What was the topic of your last science class?
2. How did you think like a scientist in that lesson?
3. How did you act like a scientist in that lesson?
4. How do you think science class is different from English, history or math class?
5. How can you think about your thinking?
6. What does it mean to you to think like a scientist?
7. Are there other ways of thinking?
8. Do scientists behave differently than other people?
9. Before the modules, how confident did you feel about learning science?
10. After the modules, how confident did you feel about learning science?
11. If you had a change in confidence, what do you think caused the change?
12. Do you think you learn science differently after you used the modules? Why or why not?
13. Do you need to think scientifically in everyday life? Why or why not?

### Think-Aloud Protocol

1. One of the lessons will be chosen randomly
2. Researcher will model what thinking aloud sounds like for the participants
3. Students will re-do the inquiry lesson while thinking aloud
4. Researcher will ask students to talk about why they made decisions during the inquiry lesson if the students do not talk about it explicitly

Appendix B: 4-Phase Embedded Metacognitive Prompts based on the Nature of Science

**Phase 1: Modeling Scientific Thinking**

<b>Nature of Science</b>  <b>Concept</b>	<b>Examples of Scientific Thinking</b>
Scientific knowledge is durable, yet tentative	William Gilbert in the 1700's noticed that a piece of iron on top of St. Augustine's Chapel was magnetic. Gilbert thought that the metal became magnetic because of the winds. In the 1900's it was found that the piece of metal was magnetic because it was struck by lightning. The lightning magnetized the iron. Ideas in science are usually long-lasting but can sometimes change when new information is introduced.
Empirical evidence is used to support ideas in science	When an inflated balloon rubbed 30 times with wool is brought 1 cm away from paper ripped into 1 cm by 1 cm pieces, the paper is attracted to the balloon.  When the same balloon rubbed 30 times with wool is brought 1 cm away from tin foil ripped into 1 by 1 cm pieces, the tin foil is not attracted to the balloon.  When the same balloon, rubbed 30 times with wool, is brought 1 cm away from 1 cm by 1 cm Styrofoam pieces, the Styrofoam is attracted to the balloon.  Based on these three trials, balloons rubbed with wool attract non-metal objects and do not attract metal objects.

<p>Social and historical factors play a role in the construction of scientific knowledge</p>	<p>All members of the group must help check if observations are complete and truthful because people have different perspectives. Answers are most likely correct if all members of the group agree on an answer.</p> <p>If you think about the ideas that people had in the 1700's compared to the ideas that we have about magnetism, people in the 1700's might make different conclusions than we would.</p>
<p>Laws and theories play a central role in developing scientific knowledge, yet they have different functions</p>	<p>When you make sense of your observations, inferences, and ideas, then you are making your own personal theory about electricity and magnetism. When you make further observations, you make sense of the information using your personal theories.</p> <p>Electric charges have certain characteristics because they attract and repel some substances. When I see a magnet repel another magnet, I think about how static electricity works and try to connect it to magnets.</p>
<p>Accurate record keeping, peer review and replication of experiments help to validate scientific ideas</p>	<p>Other people can agree that your observations, inferences and ideas are accurate if they can redo your investigation and find similar observations, inferences and ideas. Scientific knowledge grows when a new idea can be confirmed by the scientific community.</p>

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	<p>I made a magnet out of an iron nail by rubbing the magnet in one direction 50 times. When I did this, the nail, which was not attached to the magnet, picked up 3 paperclips for one minute. When I rubbed the same nail 100 times in one direction, the nail, which was not attached to the magnet, picked up 5 paper clips. I need to perform more trials to confirm the idea that rubbing a metal object more times makes it more magnetic.</p>
<p>Science is a creative endeavor</p>	<p>In order to understand how a magnet becomes less magnetic, I needed to imagine how domains might look. I made a drawing and saw how dropping a magnet might make each domain become scrambled. When fewer domains are lined up, there is less “pulling” from the magnet on another object.</p>
<p>Science and technology are not the same, but they impact each other</p>	<p>Science and technology are used together when testing different materials to see if they conduct electricity. A circuit is built with a space to insert different materials. If the light bulb in the circuit lights up, then the material conducts electricity. The circuit and materials are technology, but the idea of electricity moving around the circuit and changing from electricity to light is science. Technology helps us to think of scientific ideas and scientific ideas help us to make technology better.</p>

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## Phase 2: Emulation

Nature of Science	Essential Metacognitive Processes Checklist
Concept	
Scientific knowledge is durable, yet tentative	<ul style="list-style-type: none"><li><input type="checkbox"/> I know how scientists throughout history thought about this idea.</li><li><input type="checkbox"/> I can see how this idea has changed when scientists got more information about it.</li><li><input type="checkbox"/> I know that ideas in science change scientists agree the old idea doesn't fit with new information that is reliable.</li><li><input type="checkbox"/> I know that scientists are strict about how they get information, so ideas in science are long-lasting.</li></ul>
Empirical evidence is used to support ideas in science	<ul style="list-style-type: none"><li><input type="checkbox"/> My observations describe what I see, hear or feel.</li><li><input type="checkbox"/> My observations are made up of measurements that other people can agree upon. For example, instead of saying "It is big", I say "The blue car is 20 cm long"</li><li><input type="checkbox"/> My observations are clear to other people who are not performing this lab.</li><li><input type="checkbox"/> My observations come only from my five senses, and are not inferences.</li><li><input type="checkbox"/> My observations can be used later to make conclusions.</li><li><input type="checkbox"/> My observations are not judgments about what I see, hear or</li></ul>

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	feel.
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Social and historical factors play a role in the construction of scientific knowledge	<input type="checkbox"/> I used information discussed in the introduction of the lab to help me make sense of my results. <input type="checkbox"/> I listened to other group members when they suggested different ideas. <input type="checkbox"/> I used information from my class notes or book when I was making conclusions. <input type="checkbox"/> I realize that scientists in the 18 <sup>th</sup> and 19 <sup>th</sup> centuries did not have the same equipment as I do. <input type="checkbox"/> Each member of my group contributed to the learning during this lab. That is, no one dominated the lab or the equipment.
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Laws and theories play a central role in developing scientific knowledge, yet they have different functions	<input type="checkbox"/> I made a conclusion by looking for something similar about the results in the lab. <input type="checkbox"/> My conclusions describe a big idea that can be backed up by my results. <input type="checkbox"/> I thought about what I already knew about the topic before I gathered data. <input type="checkbox"/> My observations are examples of what I am saying in my conclusion. <input type="checkbox"/> I thought about what scientists understand about this topic after I made my conclusion.
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<p>Accurate record keeping, peer review and replication of experiments help to validate scientific ideas</p>	<p><input type="checkbox"/> I would be able to understand my data table weeks or months from now.</p> <p><input type="checkbox"/> I paid attention to all possible observations.</p> <p><input type="checkbox"/> I didn't intentionally ignore any observations because they didn't support my hypothesis.</p> <p><input type="checkbox"/> My data is organized to show my point of my conclusion.</p> <p><input type="checkbox"/> I thought about different ways to organize my data and decided on the one that best emphasizes my conclusion.</p>
<hr/>	
<p>Science is a creative endeavor</p>	<p><input type="checkbox"/> When I was doing this lab, I thought about times when I saw something similar to my results.</p> <p><input type="checkbox"/> I looked for patterns in my results as I gathered data.</p> <p><input type="checkbox"/> I thought about many different conclusions that my results could explain and chose the one that made the most sense to me.</p> <p><input type="checkbox"/> The conclusion I chose makes sense compared to other experiences I have had.</p>
<hr/>	
<p>Science and technology are not the same, but they impact each other</p>	<p><input type="checkbox"/> I made measurements that are based on a standard system like the metric system.</p> <p><input type="checkbox"/> I thought how I could use the measurement tools most accurately in this lab.</p> <p><input type="checkbox"/> I didn't use measurements that were based on non-standards, like my hand or height.</p>

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- I thought about many different tools that could have been used in this lab and chose the most useful one.
  - I thought about how my measuring tool can interrupt what I am trying to measure.
  - I thought about how people in history had different tools to measure and how these different tools could produce different results compared to my results.
-

### Phase 3: Self-Control

Nature of Science Concept	Novice Metacognitive Questions with Short Checklists
Scientific knowledge is durable, yet tentative	<ul style="list-style-type: none"><li>• How has this lab changed the way you think about the phenomena?</li><li>• Was there a point in the lab where you were surprised about what happened?</li><li>• Explain the part of your lab that made you surprised and why you thought it was unusual.<ul style="list-style-type: none"><li><input type="checkbox"/> I know that ideas in science change scientists agree the old idea doesn't fit with new information that is reliable.</li><li><input type="checkbox"/> I know that scientists are strict about how they get information, so ideas in science are long-lasting.</li></ul></li></ul>
Empirical evidence is used to support ideas in science	<ul style="list-style-type: none"><li>• How do you know something is true?</li><li>• Is your observation clear to other people?</li><li>• Check what you think against what you see (feel, hear).</li><li>• What evidence do you have to support your idea?<ul style="list-style-type: none"><li><input type="checkbox"/> My observations are clear to other people who are not performing this lab.</li><li><input type="checkbox"/> My observations come only from my five senses, and are not inferences.</li></ul></li></ul>

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- My observations can be used later to make conclusions.

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|---|--|
| Social and historical factors play a role in the construction of scientific knowledge | <ul style="list-style-type: none"><li>• How did each member of your group contribute to the learning during this lab?</li><li>• Did members of your group give you ideas that you didn't think of?</li><li>• What is the same about the items you are classifying?</li><li>• What is different about the items you are classifying?</li><li>• Would other people agree with your way of classifying?</li></ul> <ul style="list-style-type: none"><li><input type="checkbox"/> I used information discussed in the introduction of the lab to help me make sense of my results.</li><li><input type="checkbox"/> I listened to other group members when they suggested different ideas.</li></ul> |
|---|--|

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- |   |  |
|---|--|
| Laws and theories play a central role in developing scientific knowledge, yet they have different | <ul style="list-style-type: none"><li>• What big ideas could your facts explain?</li><li>• Is there something similar about the facts that you could describe?</li><li>• Have expert scientists reported about the ideas you generated?</li><li>• What big ideas (theory) did you use to make sense of your observations?</li></ul> <ul style="list-style-type: none"><li><input type="checkbox"/> My conclusions describe a big idea that can be backed up by my results.</li><li><input type="checkbox"/> I thought about what I already knew about the topic before I</li></ul> |
|---|--|
-

functions	gathered data.
Accurate record keeping, peer review and replication of experiments help to validate scientific ideas	<ul style="list-style-type: none"> <li>• Could you understand what you did to get your data weeks or months from now?</li> <li>• Did you ignore any data/observations that happened?</li> <li>• Could you understand what you did to obtain your data weeks or months from now?</li> <li>• Is your data organized to clearly illustrate your point? <ul style="list-style-type: none"> <li><input type="checkbox"/> I would be able to understand my data table weeks or months from now.</li> <li><input type="checkbox"/> I paid attention to all possible observations.</li> <li><input type="checkbox"/> I thought about different ways to organize my data and decided on the one that best emphasizes my conclusion.</li> </ul> </li> </ul>
Science is a creative endeavor	<ul style="list-style-type: none"> <li>• What experiences gave you ideas to help you make sense of your data?</li> <li>• What kinds of patterns did you find in your data?</li> <li>• Where else in your life have you seen patterns like the ones you saw in your lab? <ul style="list-style-type: none"> <li><input type="checkbox"/> I looked for patterns in my results as I gathered data.</li> <li><input type="checkbox"/> I thought about many different conclusions that my results could explain and chose the one that made the most sense to</li> </ul> </li> </ul>

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me.

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- Science and technology are not the same, but they impact each other
- Would other people understand your measurement method?
  - Could other tools be used to perform the measurement? How might that tool be more or less useful?
  - Does your measurement method have a standard to compare against?
    - I made measurements that are based on a standard system like the metric system.
    - I thought about many different tools that could have been used in this lab and chose the most useful one.
-

#### Phase 4: Expert Metacognitive Prompts

Nature of Science	Expert Metacognitive Prompts
<b>Concept</b>	
Scientific knowledge is durable, yet tentative	<ul style="list-style-type: none"><li>• What did people long ago think about the phenomena you were studying?</li><li>• How did people's ideas change over time about the topic for your lab?</li><li>• How can scientific knowledge be believed if it keeps changing over time?</li></ul>
Empirical evidence is used to support ideas in science	<ul style="list-style-type: none"><li>• Can other people understand your observation out of context?</li><li>• Is your observation free of any judgment?</li><li>• Are your observations relevant to the purpose of the investigation?</li></ul>
Social and historical factors play a role in the construction of scientific knowledge	<ul style="list-style-type: none"><li>• Was there any information that you learned elsewhere that helped you in the lab? What was the information and where did you learn it?</li><li>• Did other groups point out ideas or processes that needed improvement?</li><li>• How might you consider these areas of improvement in your next lab?</li></ul>
Laws and theories	<ul style="list-style-type: none"><li>• What big ideas (theory) did you use to make sense of your</li></ul>

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play a central role in developing scientific knowledge, yet they have different functions	observations? <ul style="list-style-type: none"> <li>• What generalization did you develop because of your observations?</li> <li>• How do your observations support this generalization?</li> <li>• What do scientists understand about your generalization?</li> <li>• Has your thinking about the observations become more like an expert?</li> </ul>
<hr/>	
Accurate record keeping, peer review and replication of experiments help to validate scientific ideas	<ul style="list-style-type: none"> <li>• What categories make up the system you are using to classify? (For example: classifying by the system of color might result in the categories of red, blue and yellow)</li> <li>• Could other classification systems be more effective?</li> <li>• Does this classification system emphasize important features of the items?</li> <li>• Is your data organized to clearly illustrate your point?</li> <li>• Have you ignored any factors in taking the data?</li> <li>• Are all factors accounted for?</li> </ul>
<hr/>	
Science is a creative endeavor	<ul style="list-style-type: none"> <li>• How did you make sense of your data? What patterns and generalizations did you see in your results?</li> <li>• Do the results from your lab make sense with other experiences you had?</li> <li>• What kinds of thoughts did you need to think so that you</li> </ul>

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could make a conclusion from your data?

- Are there other ways you could explain what you saw in your results?
- What made you choose your conclusions instead of other explanations?

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Science and technology are not the same, but they impact each other

- Does your measurement method have a standard to compare against?
  - How does your measurement interrupt the phenomena you are measuring?
  - What technologies are available to better describe the phenomena?
  - What degree of accuracy can your measurement method offer?
-

## **Magnetism - Module 1**

**Purpose:** In this module, you will study some events involving magnets and record your observations. In your group you will discuss the scientific ideas that help you to make sense of your observations. As a whole class, we will discuss your findings and you will compose notes of the highlights of your findings.

Before beginning the events, explain what you know about magnets by answering the following questions.

Suppose someone gave you two substances and claimed they were both magnets. What evidence would you need to show that both substances were indeed magnets?

What I know myself:

What I found out from my group:

What I found out from the whole class discussion:

### Event 1: Interactions of Ceramic Disk Magnets

How many different ways can 2 magnets interact?

**Orientation #1:** Place two ceramic disk magnets flat on the table, far enough apart so they do not make each other move as in Diagram A.

Diagram A

Without touching magnet #1, slide magnet #2 closer to magnet #1.

Describe what happens to magnet #1 as you bring it closer to magnet #2.

*Example: I would want to explain things in great detail, so other people could understand my exploration. I would measure how far apart the magnets were when the interaction happened. Magnet #1 started to move away from Magnet #2 when I brought Magnet #2 closer. This started to happen when the magnets were 1 cm away from each other, and continued as they got even closer.*

**YOUR DESCRIPTION:**

Explain why this happens to the magnets.

**Orientation #2:** Find a different way to place the two magnets on the table and draw them in the space for Diagram B. Label one of the magnets #1 and the other magnet #2.

Diagram B

Without touching magnet #1, slide magnet #2 closer to magnet #1.

Describe what happens to magnet #1 as you bring it closer to magnet #2.

Explain why this happens to the magnets.

**Checklist:** Use this list to make sure that you made scientific observations during Orientation #2

- My observations describe what I see, hear or feel.*
- My observations are made up of measurements that other people can agree upon. For example, instead of saying "It is big", I say "The blue car is 20 cm long"*
- My observations are clear to other people who are not performing this lab.*
- My observations come only from my five senses, and are not inferences.*
- My observations can be used later to make conclusions.*
- My observations are not judgments about what I see, hear or feel.*

**Orientation #3:** Find a different way to place the two magnets on the table and draw them in the space for Diagram C. Label one of the magnets #1 and the other magnet #2.

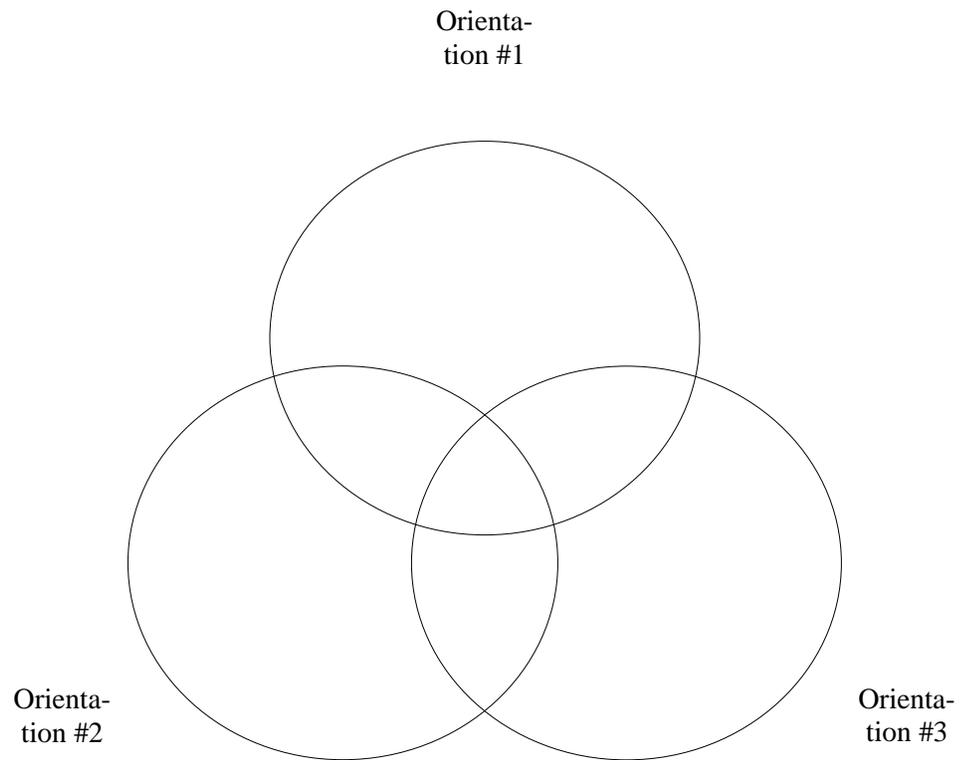
Diagram C

Without touching magnet #1, slide magnet #2 closer to magnet #1.

Describe what happens to magnet #1 as you bring it closer to magnet #2.

Explain why this happens to the magnets.

**Event 1 at a glance:** Fill in the Venn Diagram with statements that both describe and explain what you saw with the magnets.



### **Class Discussion about Event 1**

All of the groups will report what they observed and why they think the events happened as they did. Take notes in the box below about any trials other groups did that may add to your trials on orientation.

Use the checklist below to help you make reasonable conclusions:

Notes on class discussion:

### **Adding Theory to your Observations:**

Domains are parts of magnets that cannot be seen. There are atoms grouped together in the magnet because their electrons spin around in the same way. The number of domains that are lined up in the same way determine how strong a magnet may be. If many domains are lined up, the magnet is strong.

If few domains are lined up, the magnet is weak.

If a magnet is heated or dropped, the domains that were lined up become out of line and the magnet weakens.

**Event 2: Making and Destroying Magnets**

A magnet can be made out of a non-magnetic piece of iron (like a nail) by rubbing it in one direction with a permanent magnet.

Design an investigation that tests the effect of the number of "rubs" on the strength of the magnetism in the piece of iron. You can measure the strength of magnetism by counting how many staples the magnetized piece of iron picks up.

**Procedure:**

1.
2.
3.
4.
5.
6.

Draw your data table here:

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Write a few statements that describe what happened in Event 2 and explain why it happened that way.

Description of investigation	Explanation of investigation

**Scientific Explanations:** Answer the following questions about how you used your evidence to back up your claims and use the checklist to remind yourself of the most important points.

- Are your observations clear to other people? Explain why you think that.

- Check your explanations against your observations. Do they make sense together? Explain with one example.

- My observations are clear to other people who are not performing this lab.*
- My observations come only from my five senses, and are not inferences.*
- My observations can be used later to make conclusions.*

### **Class Discussion about Event 2**

All of the groups will report what they observed and why they think the events happened as they did. Take notes in the box below about any trials other groups did that may add to your trials on orientation.

Notes on class discussion:

### **Making Sense of our Findings**

As a class we will try to find similarities, differences and connections among our findings for Events 1 and 2.

Ground rules for discussions:

1. Claims must be supported with evidence. For example, "I think that \_\_\_\_\_ because \_\_\_\_\_"
2. Comments about claims must also be supported with evidence. For example, "I disagree with what you said about \_\_\_\_\_ because I think we found \_\_\_\_\_"
3. Let everyone contribute to the discussion.
4. Listen to other people while you are waiting to talk about your findings.

### **Event 1 Statements from the discussion . . .**

That make sense with our findings	That don't make sense with our findings
Consensus Ideas from Event 1:	

**Event 2 Statements from the discussion . . .**

That make sense with our findings	That don't make sense with our findings
Consensus Ideas from Event 2:	

**Questions about Observations and Evidence:** Answer the following questions about your evidence.

- Can other people understand your observation out of context? How do you know that?
- Is your observation free of any judgment? Explain.
- Are your observations relevant to the purpose of the investigation? Explain how they are.

- What big ideas (theory) did you use to make sense of your observations?
- What generalization did you develop because of your observations?
- How do your observations support this generalization?
- What do scientists understand about your generalization?
- Has your thinking about the observations become more like an expert?

**Notes about Magnetism Events:**

**Vocabulary needed in understanding magnetism:**

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<b>Defining Characteristics about Magnetism</b>	<b>Evidence from Events</b>

Appendix D: Self-monitoring Strategy Worksheets  
Self-Monitoring Strategies

Name \_\_\_\_\_

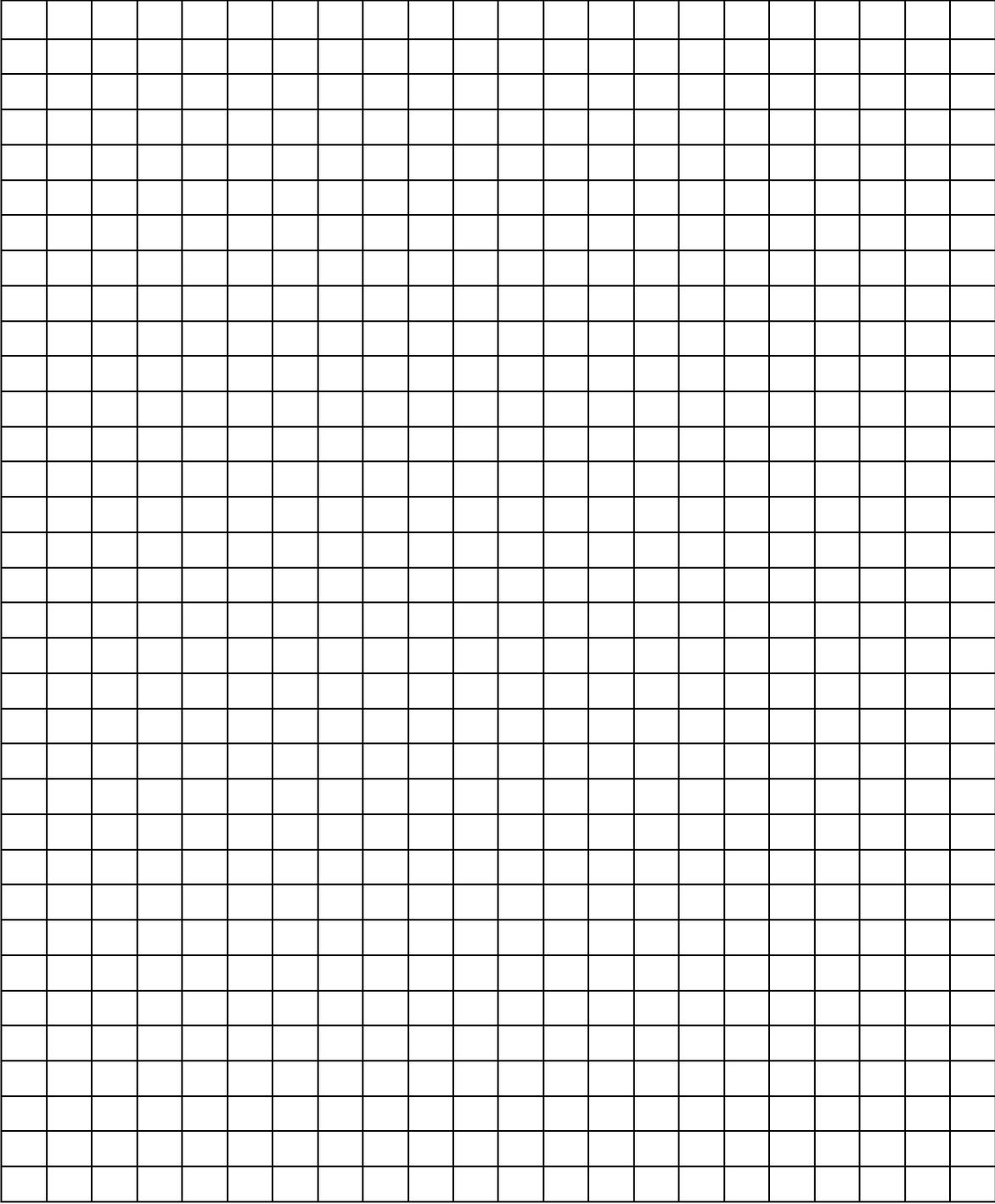
Directions:

1. After completing each module, check off all of the strategies you used during that ONE module. Only check the strategies that you actually used; do not check the strategies that you had wanted to use, but did not actually use.
2. Total the number of strategies you used at the bottom of the table.
3. Graph the total number of strategies on the graph paper provided.

Strategy	Module 1	Module 2	Module 3	Module 4
My observations describe what I see, hear or feel				
My observations are made up of measurements that other people can agree upon. For example, instead of saying "It is big", I say "The blue car is 20 cm long"				
My observations are clear to other people who are not performing this lab.				
My observations come only from my five senses, and are not inferences.				
My observations can be used later to make conclusions.				
My observations are not judgments about what I see, hear or feel.				
I would be able to understand my data table weeks or months from now.				
I paid attention to all possible observations.				
I didn't intentionally ignore any observations because they didn't support my hypothesis.				
My data is organized to show my point of my conclusion.				
I thought about different ways to organize my data and decided on the one that best emphasizes my conclusion.				
I made a conclusion by looking for something similar about the results in the lab.				

My conclusions describe a big idea that can be backed up by my results.				
I thought about what I already knew about the topic before I gathered data.				
My observations are examples of what I am saying in my conclusion.				
I thought about what scientists understand about this topic after I made my conclusion.				
When I was doing this lab, I thought about times when I saw something similar to my results.				
I looked for patterns in my results as I gathered data.				
I thought about many different conclusions that my results could explain and chose the one that made the most sense to me.				
The conclusion I chose makes sense compared to other experiences I have had.				
<b>TOTAL NUMBER OF CHECKS</b>				

Number of Strategies Used in Modules



Module  
1

Module  
2

Module  
3

Module  
4

Appendix E: Human Subject Review Board Consent and Assent Sheets

**Thinking Like Scientists: Using the Nature of Science as a Metacognitive Resource (Looking at How People Think about Science)  
Parental Consent Form**

**RESEARCH PROCEDURES**

The reason for this research is to find out about if a particular approach to thinking about science will help students learn science content. If you agree to allow your child to take part in this study, your child will be asked to spend about fifty-five minutes taking a pencil-paper surveys, participating in an inquiry unit on electricity and magnetism, and retaking the paper-pencil surveys.

**RISKS**

There are no foreseeable risks for participating in this research.

**BENEFITS**

There are no benefits to your child as a participant other than more information about students' thinking habits in science.

**CONFIDENTIALITY**

The data in this study will be confidential. In order to maintain confidentiality, the survey will not ask for any identifying information.

**PARTICIPATION**

Your child's participation is voluntary, and your child may withdraw from the study at any time and for any reason. If your child decides not to participate or if your child withdraws from the study, there is no penalty to your child. There are no costs to your child or any other party.

**CONTACT**

This research is being conducted by Erin Peters at George Mason University. This research has been reviewed according to George Mason University procedures governing your participation in this research. She may be reached at 703-912-7850 for questions or to report a research-related problem. Since the investigator is a student, you may reach her advisor, Anastasia Kitsantas, at 703-993-2688. You may contact the George Mason University Office of Research Subject Protections at 703-993-4121 if you have questions or comments regarding your rights as a participant in the research.

**CONSENT**

- I have read this form and agree to allow my child to participate in this study.
- I agree to have my child videotaped if selected for small group discussions.
- I do not agree to have my child videotaped if selected for small group discussions.

Signature- Parent/Guardian

Approval for the use  
of this document  
EXPIRES

Date of Signature \_\_\_\_\_

FEB 08 2008

Protocol # 4737  
George Mason University

**Thinking Like Scientist: Using the Nature of Science as a Metacognitive Resource  
(Looking at How People Think about Science)**

ASSENT FORM

**RESEARCH PROCEDURES**

The reason for this research is to find out if teaching thinking skills helps people learn science. If you agree to take part in this study, you will be asked to spend about fifty-five minutes taking a pencil-paper survey, participating in a 4-lesson unit about electricity and magnetism, and retaking the paper-pencil surveys. Some students will be chosen to be videotaped in a discussion and some students will be chosen to be videotaped re-doing one of the lessons.

**RISKS AND BENEFITS**

Nothing bad will happen to you if you take part in this study. There are no rewards or money paid for being in this study. But the things I find out may help teachers learn how to teach science better.

**CONFIDENTIALITY**

Your name will not be on the short surveys that you fill out. I will not ask you to fill out any information that may identify you.

**PARTICIPATION**

You don't have to take the surveys or the lessons if you don't want to. If you change your mind after we start and want to stop that is OK. I will not get mad and nothing will happen to you.

**CONTACT**

My name is Erin Peters, and I am studying to get a PhD in Science Education at George Mason University. This research has been reviewed according to George Mason University procedures governing your participation in this research. You can call me at this phone number (703- 912-7850) if you have any questions about this study. You can also call my teacher, Anastasia Kitsantas, a professor at George Mason University, at this phone number 703- 993-2688.

You may contact the George Mason University Office of Research Subject Protections at 703-993-4121 if you have questions or comments regarding your rights as a participant in the research.

**CONSENT**

I have read this form and I agree to be part of this study.

- I agree to be videotaped if chosen.  
 I do not agree to be videotaped if chosen.

Approval for the use  
of this document  
**EXPIRES**

**FEB 08 2008**

Protocol # 4737  
George Mason University

\_\_\_\_\_  
Name

\_\_\_\_\_  
Date

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## Curriculum Vitae

Erin E. Peters was born on December 10, 1965 in Pottstown, Pennsylvania. She received her Bachelor's of Science in Teaching of Physics from the University of Illinois in 1990, and her Master of Education in Educational Psychology and Social Foundations of Education from the University of Virginia in 2004. She has taught secondary science in public schools in Illinois and Virginia for fifteen years. She has served as an Albert Einstein Distinguished Educator Fellow in the Exploration Systems Mission Directorate at the National Aeronautics and Space Administration during the 2006-2007 school year. Currently she is an Assistant Professor of Education at George Mason University.