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Preservice Science Teachers' Experiences with Repeated, Guided Inquiry

Amy B. Slack

ACCEPTANCE

This dissertation, PRESERVICE SCIENCE TEACHERS' EXPERIENCES WITH REPEATED, GUIDED INQUIRY, by AMY B. SLACK, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree Doctor of Philosophy in the College of Education, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chair, as representatives of the faculty, certify that this dissertation has met all the standards of excellence and scholarship as determined by the faculty. The Dean of the College of Education concurs.

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ABSTRACT

PRESERVICE SCIENCE TEACHERS' EXPERIENCES WITH
REPEATED, GUIDED INQUIRY
by
Amy B. Slack

The purpose of this study was to examine preservice science teachers' experiences with repeated scientific inquiry (SI) activities. The *National Science Education Standards* (National Research Council, 1996) stress students should understand and possess the abilities to do SI. For students to meet these standards, science teachers must understand and be able to perform SI; however, previous research demonstrated that many teachers have naïve understandings in this area. Teacher preparation programs provide an opportunity to facilitate the development of inquiry understandings and abilities.

In this study, preservice science teachers had experiences with two inquiry activities that were repeated three times each. The research questions for this study were (a) How do preservice science teachers' describe their experiences with repeated, guided inquiry activities? (b) What are preservice science teachers' understandings and abilities of SI?

This study was conducted at a large, urban university in the southeastern United States. The 5 participants had bachelor's degrees in science and were enrolled in a graduate science education methods course. The researcher was one of the course instructors but did not lead the activities. Case study methodology was used. Data was

collected from a demographic survey, an open-ended questionnaire with follow-up interviews, the researcher’s observations, participants’ lab notes, personal interviews, and participants’ journals. Data were coded and analyzed through chronological data matrices to identify patterns in participants’ experiences.

The five domains identified in this study were understandings of SI, abilities to conduct SI, personal feelings about the experience, science content knowledge, and classroom implications. Through analysis of themes identified within each domain, the four conclusions made about these preservice teachers’ experiences with SI were that the experience increased their abilities to conduct inquiry, increased their understanding of how they might use SI in their classroom, increased their understanding of why variables are used in experiments, and did not increase their physics content knowledge. These conclusions suggest that preservice science teachers having repeated, guided experiences with inquiry increase their abilities to conduct SI and consider how inquiry could be used in their future science classrooms.

PRESERVICE SCIENCE TEACHERS' EXPERIENCES WITH
REPEATED, GUIDED INQUIRY

by
Amy B. Slack

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ABBREVIATIONS

AAAS	American Association for the Advancement of Science
NOS	Nature of Science
NRC	National Research Council
NSES	National Science Education Standards
SI	Scientific Inquiry
VNOS	Views of Nature of Science
VOSI	Views of Science Inquiry
VOSI-M	Views of Science Inquiry—Modified

CHAPTER 1

INTRODUCTION

Statement of the Problem

Scientific inquiry is one aspect of the current reform effort in science education (American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council [NRC], 1996). The *National Science Education Standards* (NRC, 1996) stress that science students of all ages should be able to understand inquiry and possess the abilities needed to do scientific inquiry (SI). For students to meet these standards, they must have valid experiences in the science classroom. Factors such as an open curriculum, caring and prepared teachers, and adequate time for inquiry-based lessons must occur in the classroom to facilitate these experiences. However, one important factor is that science teachers are able to understand SI and possess the abilities to conduct SI in the same manner as is expected of the students. Because teachers first need to comprehend what comprises inquiry abilities and understanding, one of the goals of teacher preparation programs should be to facilitate this development.

In this study, I examined a teacher preparation program that uses SI with its preservice teachers. The guiding research questions were as follows:

1. How do preservice science teachers' describe their experience with repeated, guided inquiry activities in their coursework?
2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?

These questions were explored by research with a group of preservice science teachers who were graduate students studying science education and earning teaching certificates for broad-field science in grades 6-12. Participants were interviewed, completed a questionnaire, kept experimental notes, and reflected about their experiences with provided post-activity questions. Analysis of this data and my observations are used to describe preservice teachers' experiences with inquiry and their understandings and abilities of SI.

The National Research Council (1996) stressed in the *National Science Education Standards* (*NSES*) that teaching science through inquiry promotes scientific literacy, an opinion that is maintained in this research project. Scientific inquiry and its associated terminology can be a tenuous concept. It often has different terms, such as inquiry, scientific inquiry, and inquiry learning, associated with its use. Multiple definitions exist for the same concepts and semantics play a part in defining inquiry; therefore, it is necessary to define the terms to be used throughout this paper.

In the *NSES*, (NRC, 1996), SI is defined as the way scientists explore the natural world and propose explanations based on evidence from their work. SI also refers to students' activities as they gain knowledge of scientific ideas and understand how scientists study the natural world. SI is found in Content Standard A of the *NSES* for grades K-12, which states: "As a result of activities in grades K-4 (or 5-8 or 9-12), all students should develop: abilities necessary to do scientific inquiry and understandings about scientific inquiry" (NRC, pp. 121, 143, 173). Thus, the *NSES* stress that SI includes both understanding and abilities. Therefore, in this study SI is defined as students having an *understanding* of scientific knowledge and how scientists conduct their research.

Additionally, SI involves students having the *abilities* to conduct SI, these abilities involve the work done by students, of any age or ability, as they try to understand the natural world through open-ended activities that mimic the work done by scientists. This use of the term SI recognizes that students conduct investigations in different ways from scientists, yet acknowledges that for students, the investigations are novel.

Although Gunstone, Loughran, Berry, and Mulhall (1999) claim that scientific inquiry is a restrictive term used along the lines of “the scientific method,” for the purpose of this study, SI is considered to be different from the “scientific method” that is often taught to students. The scientific method suggests a rigid, step-by-step approach to doing science (NRC, 1996) and is usually described as a fixed set of steps that all scientists follow in a specific sequence when conducting research (Schwartz, Lederman, & Thompson, 2001). Students are often expected to memorize the scientific method and asked to repeat it in cookbook-like lab procedures. Although engaging in SI consists of abilities that are performed logically and often in sequence, it also requires students to take part in “high-level reasoning [and] applying their existing understanding of scientific ideas,” thus leading to a more open, less rigid experience than the step-by-step methods of the scientific method (NRC, p. 145). Reform efforts that advocate SI emphasize there is no one scientific method; instead, approaches to answering scientific questions vary within and across scientific fields (Schwartz et al.).

Because SI is an important topic in the field of science education (AAAS, 1990, 1993, NRC, 1996), the purpose of this research study was to examine preservice science teachers’ experiences with inquiry activities and describe their SI understandings and abilities. For this study, the understandings of SI are those described by Schwartz et al.

(2001) and are based upon the descriptions of SI found in both the *NSES* (NRC, 1996) and the AAAS's *Benchmarks for Science Literacy* (1993). These understandings are

- Knowledge of methods used to conduct investigations instead of one "scientific method";
- Understanding the role of investigations within research agendas;
- Recognition of assumptions involved in designing and conducting scientific inquiries;
- Recognition of limitations of data collection and analysis;
- Recognition and analysis of alternative explanations and models;
- Understanding the reasons for using controls and variables in experiments;
- Understanding the distinction between data and evidence;
- Understanding the relationship between evidence and explanations;
- Understanding the role of communication in the development and acceptance of scientific information.

The six abilities of SI described in the *NSES* Content Standard A for grades K-12 are used in this study. Because the participants in this research study are preservice science teachers earning certification for grades 6-12, the 9-12 standards form the basis of the abilities that were assessed in participants. The six abilities of SI as described in the *NSES* for grades 9-12 as established by the NRC (1996) are

- Identify questions and concepts that guide scientific investigations;
- Design and conduct scientific investigations;
- Use technology and mathematics to improve investigations and communications;

- Formulate and revise scientific explanations and models using logic and evidence;
- Recognize and analyze alternative explanations and models;
- Communicate and defend a scientific argument.

Much educational research has occurred in the field of scientific inquiry. Research has been conducted about both students' and teachers' views of scientific inquiry (Schwartz et al., 2001; Wallace & Kang, 2004), how to teach inquiry (Schwartz & Crawford, 2003), and why inquiry is not being implemented in the classroom (Costenson & Lawson, 1986; Welch, Klopfer, Aikenhead, & Robinson, 1981). The results of these studies have contributed valuable information about SI in education, such as what constitutes valuable experiences of inquiry for students and how to prepare teachers, both pre- and in-service, to use SI in their classrooms. One troubling outcome of much of this research is that practicing teachers do not have adequate understandings of SI and do not implement SI in the classroom (Costenson & Lawson; Muscovici, 2000; Wallace & Kang). Even those who understand SI often do not implement it into the classroom (Marlow & Stevens, 1999; Wallace & Kang). Providing preservice science teachers with SI activities might allow them to develop the abilities needed to do inquiry and deepen their understandings of the concepts associated with inquiry.

Some preservice teacher programs teach SI through the use of authentic science experiences by having students conduct scientific research (Brown & Melear, 2006; Melear, Goodlaxson, Warne, & Hickok, 2000; Wilson, 2003). These studies demonstrate authentic science experiences facilitate understanding of SI and help preservice teachers value SI. However, it may not be possible for every student to take a science class that

offers an authentic research experience. It seems contradictory for educators of science teachers, the group who stresses the importance of inquiry in the classroom, to leave the teaching of science inquiry to scientists alone. Therefore, exposing preservice teachers to SI in their methods courses provides teacher educators an opportunity to facilitate a development of the understandings and abilities of SI. Having inquiry experiences that are similar to those conducted by K-12 students in a science classroom might be adequate exposure to increase preservice teachers' understandings and abilities of inquiry, as well as demonstrate how SI might appear in a classroom. Although much of the research into teachers practicing SI is with students conducting research with a scientist or in a science classroom (Brown & Melear; Melear et al., 2000; Schwartz & Crawford, 2003; Schwartz, Lederman, & Crawford, 2000; Wilson), I studied the outcomes of preservice teachers engaging in inquiry-based activities such as those found in a K-12 science classroom.

Students entering a science teacher preparation program come to the program with different skills, abilities, experiences, and understandings. The way preservice science teachers' understandings and abilities of SI change and are shaped by experiences with inquiry is not well understood. Therefore, in this research project, a group of preservice science teachers experienced repeated, guided scientific inquiry activities in a methods course, and their descriptions of their experience with inquiry are examined. Guided SI involves supplying the students with materials or a problem but allows the students to ask further questions and design the procedures they will use to answer their questions.

In addition to the experiences with inquiry, preservice teachers made explicit connections between their activities and SI through reflection about their experiences in a

journal. Explicit connections involve purposeful and planned linkage of their activities with the characteristics of SI through the use of questions that evoke these connections (Gess-Newsome, 2002). Their journal entries are used to describe their experiences with inquiry and their understandings and abilities of SI.

Significance of the Problem

Currently in most K-12 science classrooms, science is treated as a large body of knowledge that students must possess in order to pass a standardized test. While the tests vary from state to state, much classroom time is often devoted to test preparation, and rote memorization of science "facts" and content is often characteristic of science education throughout the country. Too often science teaching emphasizes recall of factual content with little focus on knowledge generation (McComas, Clough, & Almazroa, 1998). Most of the adults in U.S. society "learned" science in a classroom that used memorization, with the result that they have a very poor understanding of science, especially as it relates to their lives in the everyday world. As a result, much of our current population could be termed "scientifically illiterate," having little or no understanding of the ways in which science affects the world. The American Association for the Advancement of Science (1990, 1993) and the NRC (1996) advocate a movement towards a scientifically literate population. Examples of science literacy in individuals include understanding there are consequences to throwing away a glass jar instead of recycling it; consciously pondering news items dealing with supposed science and questioning their claims; and holding oneself and his or her political representatives responsible for issues dealing with scientific issues, such as stem cell research, drilling for oil in Arctic National Wildlife Refuge, or ratifying the Kyoto protocol. For U.S.

society to be scientifically literate, its citizens must start with their young students, relating science to them not as a body of facts, but as an enterprise that is tentative, creative, inquiring, empirical, and subjective in its search for an understanding of natural phenomena (AAAS, 1990, 1993; NRC).

Although the vast majority of K-12 students will be in science classrooms that stress fact over action, process, or critical thinking, since the 1950s there has been a movement away from regurgitation of facts, and many teachers attempt to break away from this model. Organizations such as AAAS, NRC, and the National Science Teachers Association (NSTA) have put forth statements and documents emphasizing the importance of scientific literacy. These groups consist of scientists, science teachers, psychologists, teacher educators, and other representatives of the science and education communities who are interested in the learning and teaching of science. Thus, the documents they published are well researched and representative of the current knowledge of the best practices in science teaching. Although there are many scientists and organizations that emphasize the importance of scientific literacy, there is a debate about it among some social scientists (Nisbet, 2003). This group argues there is too much emphasis placed on scientific literacy by the scientific community. Even though there is a small movement that questions the importance of scientific literacy, the position taken in this paper is that it is an important component of educating students in the sciences.

To increase science literacy in the United States, AAAS created Project 2061 with funding from the National Science Foundation. Under Project 2061, AAAS published several documents that describe their stance, such as S*cience for all Americans* (1990), *Benchmarks of Science Literacy* (1993), and the *Atlas of Science Literacy* (2001). These

documents contain guidelines and standards for science educators. The *NSES*, published by the NRC (1996), encourage increased scientific literacy in the classroom and define scientific literacy as

> the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity . . . [as well as] specific types of abilities. (p. 22)

Science for All Americans puts forth similar assertions and states there are three areas of knowledge involved in scientific literacy: scientific worldview, scientific inquiry, and the scientific enterprise (AAAS, 1990). Scientific worldview encompasses the basic beliefs and attitudes that scientists share about their work. Scientific inquiry involves understanding the tools, processes, and methods used by scientists. Scientific enterprise recognizes the individual, social, cultural, and institutional aspects involved in doing science. SI is thus an important aspect of scientific literacy, can be used in science classrooms, and may be emphasized in preparing science teachers. This study contributes to the field of scientific literacy research by examining the area of scientific inquiry, specifically, preservice teachers' descriptions of their experiences with SI and their understandings and abilities of SI.

Philosophical Framework

This study is guided by a constructivist paradigm. Guba and Lincoln (1994) describe constructivism as one of the four research paradigms that guide qualitative inquiry. Each of the four paradigms represents the researcher's worldview for a particular study. Constructivist thinking suggests that "realities are apprehendable in the form of multiple, intangible mental constructions [and] socially and experientially based" (Guba & Lincoln, p. 110). Furthermore there is no absolute truth and the real world remains

unknowable; rather, constructions are held by the individual and fall along a continuum of less to more informed**.** Some scientists and science educators embrace constructivist thinking and its idea that truth and reality do not necessarily correspond (Yager, 1991). For example, the discipline of science offers best possible explanations of the workings of the natural world, but it does not and cannot offer absolute truths about the universe.

In the field of science there is no absolute form of inquiry. Rather, scientists, educators, and others hold understandings, or constructions, of inquiry based upon their experiences with inquiry. Some people hold naïve understandings and abilities of SI while others hold more advanced understandings and abilities. Thus, constructions of SI can be viewed as occurring along a continuum of less to more advanced. In this study, preservice teachers had preexisting beliefs of SI – possibly established through previous methods and science courses. One expectation of this study was that preservice teachers experiencing SI activities would move along the continuum of understanding SI.

The theory of constructivism has its roots in the work of developmental psychology, especially the psychologist Jean Piaget. Herbert Spencer viewed development as the product of tension between "the organism's tendencies to consume the environment it inhabits" and "environmental pressures [to] resist consumption" (Green, 1989). Spencer coined the terms assimilation and accommodation to describe these tensions. Piaget used this concept for the field of psychology and believed the processes of assimilation and accommodation are the cause of all cognitive development in humans. According to Piaget (1952), assimilation is the way by which an individual incorporates an environmental stimulus into his or her already existing schema. It is the way an individual interprets the world around him according to what he already knows.

Accommodation requires the individual to make adjustments and modifications of what he or she believes (Green, 1989; Piaget, 1952). It is the way previous experiences influence and determine learning. Every action taken requires some degree of both assimilation and accommodation. These two balance out in a process Piaget termed equilibration, where previously acquired knowledge (assimilation) and new information (accommodation) equilibrate (Flavell, 1998; Green, 1989). As people undergo developmental change and construct new knowledge, they progress from periods of equilibrium, through transitions of disequilibrium caused by discrepant events or phenomena not previously noticed, to equilibrium at a higher stage (Flavell, 1998). Thus new understandings grow out of previously held knowledge. In this study, preservice teachers' constructions of SI result from the integration of their previously held knowledge with the meaningful aspects of their experiences with inquiry activities.

Conceptual Framework

Nature of Science

One view held by many science educators is that understanding nature of science (NOS) is a key aspect of developing scientific literacy (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Bianchini, Johnston, Oram, & Cavazos, 2003; McComas et al., 1998). Additionally, they believe that to create a scientifically literate population, science should be taught in the classroom for the development of conceptual understanding of science content and an understanding of NOS and SI (Schwartz & Crawford, 2003). Most researchers and practitioners of science education recognize that NOS and SI are intricately linked; however, the extent of this link varies depending upon the source.

Defining nature of science is not easy as there is no consensus view of what it entails. It is termed NOS, not *the* NOS because there is no agreed upon definition of NOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The literature suggests the existence of a continuum of concepts that constitutes NOS. At one extreme there appears to be a more philosophical view in which NOS cannot be defined because even science philosophers can not agree about NOS (Abd-El-Khalick et al., 1998; Bell et al., 2000). However, proponents of this view believe NOS can be generalized for teaching in the classroom and maintain the components of NOS include the recognition that scientific knowledge is tentative, empirically based, subjective, the product of human inference and creativity, and socially and culturally embedded (Abd-El-Khalick et al.; Bell et al.; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Researchers who work from this viewpoint often do not include SI in their studies. For example, Abd-El-Khalick et al. stated, “although there is overlap and interaction between science processes and NOS, it is nevertheless important to distinguish the two.” Scientific processes are defined here as activities related to the collection and interpretation of data and the derivation of conclusions (Abd-El-Khalick et al.; Bell et al.). This definition of scientific processes is in line with aspects of scientific inquiry as discussed in Project 2061’s *Science for All Americans* (AAAS, 1990). This group places inquiry into the field of NOS to a lesser degree.

At the other end of the continuum is a group of science educators who include the process skills of SI in their research of NOS. For example, one group of researchers claim that not only must teachers have an understanding of NOS to teach NOS effectively, they “must also have an understanding of the processes by which scientific knowledge is

created to effectively incorporate inquiry-based activities or projects as pedagogical approaches to teaching NOS" (Schwartz & Crawford, 2003, p. 8). In a review of international science standards from eight countries, McComas et al. (1998) created a consensus view of NOS, identifying 14 components of NOS, some of which are inquiry abilities:

1. Scientific knowledge is tentative.
2. Scientific knowledge relies heavily on observation, experimental evidence, rational arguments, and skepticism.
3. There is not one way to do science and therefore no scientific method.
4. Science is an attempt to explain natural phenomena.
5. Laws and theories are different in science.
6. People from all cultures contribute to science.
7. New knowledge must be reported clearly and openly.
8. Scientists keep accurate records, and are subject to peer review and replicability.
9. Observations are theory-laden.
10. Science is creative.
11. The history of science has both an evolutionary and revolutionary character.
12. Science is part of social and cultural traditions.
13. Science and technology are related.
14. Scientific ideas are affected by their social and historical milieu.

Numbers 2, 3, 7, and 8 are related to the enterprise of SI. These opinions demonstrate that, although there is no consensus about the relationship of inquiry and NOS, there is a place for inquiry within the realm of NOS, and the two topics can be viewed as intertwined. To demonstrate this, research about NOS often includes or is related to SI. For the purpose of this study, I viewed SI as an important component of NOS.

Many studies have been conducted that examine the way pre- and in-service teachers, K-12 students, college undergraduates, and scientists understand NOS (Abd-El-Khalick & Lederman, 2000; Brickhouse, 1990; Chun, 2000; Gess-Newsome, 2002; Lederman, 1992; Lederman et al., 2001, 2002; Lederman, Wade, & Bell, 1998;

Palmquist & Finley, 1997; Schwartz et al., 2001). Although the assessment methods vary and the terminology changes between studies, these studies measure views of NOS by determining how closely a subject's views align with views of NOS found in the literature and standards documents. For example, the list above that was put forth by McComas et al. (1998) presents 14 understandings of NOS. If an individual understands a component of NOS as it is put forth in the literature, than his or her understanding is termed advanced, informed, or contemporary (Lederman et al., 2002). Subjects whose views do not align with understandings put forth in the literatures are termed naïve, traditional, or uninformed. The term used varies based upon the researchers. In this research study, I used the word "naïve" to describe understandings that do not align with established views of NOS and the word "advanced" to describe understandings that align with established views of NOS.

Science teachers must have advanced understandings of NOS and SI and be able to use SI activities in the classroom to foster science literacy in their classrooms. In order to change students' views of NOS, teachers must understand NOS and be able and willing to incorporate it into their classrooms (Abd-El-Khalick et al., 1998; Lederman et al., 2001). This holds true for SI as well. For teachers to understand inquiry and be able to practice it, they must be adequately exposed to the concept as preservice teachers. Thus, teacher educators have a responsibility to help foster the understandings and abilities of SI in their students. There has been much research into the best methods to teach NOS to preservice teachers (Abd-El-Khalick et al.; Lederman & Abd-El-Kahlick, 1998; Lederman et al., 2001). Because I take the stance that NOS is closely linked to SI, I

assumed that the results of studies providing insights to teaching NOS would apply to teaching SI as well.

Scientific Inquiry

Regardless of the nature of the relationship between NOS and SI, SI is a necessary component to doing science. It is argued in *Science for All Americans* that "there are certain features of science that give it a distinctive character as a mode of inquiry" (AAAS, 1990, p. 4). These features of inquiry include the following:

1. Science demands evidence.
2. Science is a blend of logic and imagination.
3. Science explains and predicts.
4. Scientists try to identify and avoid bias.
5. Science is not authoritarian.

As discussed previously, the NSES (NRC, 1996) also addressed inquiry, stating, "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p. 23). Inquiry also refers to the "activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (p. 23).

Although both Project 2061 (AAAS, 1996) and the NRC (1996) stress the importance of SI, the ideas that comprise SI found within the documents published by each group are somewhat different. Project 2061 stresses understanding the components of SI and how scientists engage in SI. The NRC stresses understanding the processes and concepts of SI as well as having the abilities to conduct SI. The position I have taken in

this paper is that understanding SI requires understanding how and why scientists engage in SI as well as having the abilities to use some of the processes of inquiry, a position aligned with the NRC**.**

In addition to the views of Project 2061 and the NRC, other discussions of SI state that SI refers to the systematic approaches used by scientists in attempting to answer their questions of interest (Schwartz et al., 2001). In the classroom, SI is a more “authentic” way of “doing science” than traditional cookbook labs (Chinn & Malhotra, 2002). It allows students the opportunity to generate their own questions, design research, gather data, and communicate their findings. Although SI involves process skills such as observing, inferring, classifying, interpreting, and analyzing data, it extends beyond the development of these abilities by involving the combination of these processes with knowledge, reasoning, and critical thinking (Schwartz et al., 2001). Because of the emphasis on SI in science education, especially as it entails both understanding and abilities, it is crucial that teachers understand these nuances of inquiry in order to use SI adequately and link SI to NOS, thus fostering scientific literacy.

Currently, few science teachers have their students conduct inquiry explorations in the classroom. Welch et al. (1981) determined several reasons for the lack of SI use. Among the reasons teachers did not conduct inquiry were (a) confusion about the meaning of inquiry, (b) an allegiance to teaching facts, (c) teachers’ feeling inadequately prepared for inquiry-based instruction, (d) inquiry’s being viewed as difficult to manage, (e) the belief that inquiry instruction only works well with high ability students, and (f) the belief that the purpose of a course is preparing students for the next level of study. Furthermore, naïve views of NOS have been attributed to learners’ lack of experience

with conducting science investigations, therefore having preservice teachers engage in SI should help their understandings of NOS (Schwartz, Lederman, & Crawford, 2004).

Matson and Parsons (1998) discussed the issue of previous experiences in undergraduate science courses and pointed out that in their experiences with teachers, many practicing teachers are not prepared to teach science through SI methods because they learned science in classrooms that were dominated by teacher activity rather than student-centered activities. Additionally, most undergraduate preservice science teachers are exposed to confirmatory lab experiences that are similar to those found in high schools instead of open inquiry (Windschitl, 2002). Thus, an important aspect of training science teachers is providing them with a strong science content background and the ability to conduct SI activities in the classroom. If this occurs, these preservice teachers are prepared to teach science in a way that promotes science literacy by using teaching methods that encourage conceptually oriented, hands-on/minds-on, problem solving, and critical thinking activities (Matson & Parsons, 1998). Because of the history of inadequate SI instruction and the need to move teachers to advanced views of NOS and SI, teacher preparation programs that address SI may be able to alleviate some of the problems mentioned above.

The Explicit Approach to Scientific Inquiry through Reflection

An explicit, rather than implicit, pedagogical approach to SI is used in this research study (Lederman et al., 2001). The implicit pedagogical approach implies students will learn NOS and SI concepts merely through engaging in inquiry activities (Abd-El-Khalick et al., 1998). The explicit approach to learning SI concepts requires that students are made aware of the aspects of inquiry they are performing through direct

instruction or methods (Gess-Newsome, 2002; Lederman et al., 2001). It does not assume students passively absorb the concepts of SI merely through doing inquiry activities. Research shows in teaching NOS and SI, students of all ages do best when the material is explicitly related through activities such as classroom discussion, peer sharing, and reflective journaling (Abd-El-Khalick et al., 1998; Gess-Newsome, 2002; Lederman et al., 2001; Schwartz & Crawford, 2003).

Reflective journaling is the explicit method used in this research study because NOS and SI research and microgenetic research use reflection, journaling, and/or notebook keeping to prompt participants successfully to make connections between their actions and bigger concepts such as NOS and SI (Gess-Newsome, 2002; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Kuhn, Schauble, & Garcia-Mila, 1992). While open-ended journaling is not an explicit approach, providing participants with specific reflection questions related to SI encourages them to make connections between their activities and SI (Gess-Newsome). Thus, in this study, at the conclusion of each inquiry activity, participants were provided with several questions to prompt their reflection about SI. They were also encouraged to write additional comments not related to the provided reflection questions.

Boud, Keogh, and Walker (1985) stated linking experience to reflection is one way to strengthen learning. Creating this link is facilitated by scheduling a debriefing period or by setting time aside to journal. Reflection also makes individuals ready for their next experiences with outcomes including new methods of doing something or the development of a skill (Boud et al., 1985). Therefore in this study, time for reflection

directly followed the experience both to facilitate the formation of links and to prepare participants for their next experience with the problem the following week.

Microgenetic Method

The microgenetic method is a research paradigm used in cognitive developmental psychology, and I used certain aspects of this method in this study as a way for preservice teachers to experience inquiry. The microgenetic method is concerned with determining how learning occurs (Siegler, 2006; Siegler & Crowley, 1991). The microgenetic method "offers an opportunity to study people in the process of acquiring new knowledge, a process some regard as synonymous with learning" (Kuhn, 2002, p. 111). Because I studied preservice teachers' experiences with SI and how these experiences contribute to learning, I integrated the microgenetic method.

In developmental psychology research, there are multiple ways the microgenetic method is used. Microgenetic studies have been done with many age groups; with topics varying from math and science reasoning to memory to perception; in laboratory and classroom settings; and using differing theories of cognitive development (Siegler, 2006). Despite the differences in implementation, Siegler and Siegler and Crowley (1991) described three properties of all microgenetic studies:

1. Observations of participants span the period of changing competence.
2. The density of observations is high relative to the rate of change
3. Observations are thoroughly analyzed in an attempt to infer the process that gave rise to the action.

In addition to the three properties of this method, there are also three typical experimental designs used in most microgenetic studies (Siegler, 2006). The first method

uses a single subject design and may or may not involve direct instruction of the subject. The second design focuses on the learning of a small number of participants over a long period with no experimental intervention occurring. A third design involves

> presenting children with an unusually high density of an experience, with the goal of speeding up the typical developmental process, thus allowing more detailed analysis of change than would otherwise be possible. (Siegler, p. 484)

There is a subset of researchers within the developmental psychology field who use this third design to study scientific reasoning processes (Kuhn et al., 1992, 1995; Schauble, 1996). This group defines microgenetic studies as those that attempt to increase the processes of developmental change by having subjects experience investigative opportunities many times over a short period of time, usually weeks or months (Kuhn, 1995, 2002; Schauble, 1996). Their goal is to speed up the natural process of change in individuals through repeated experiences with the same problem. Subjects receive feedback from their actions and use this feedback to inform their next decisions of how to approach the problem. Many of the microgenetic methods used with pre- and adolescent children resemble the types of SI activities science education reformists advocate using in a science classroom (Kuhn et al., 1995; Kuhn et al., 1992; Opfer & Siegler, 2004; Schauble; Schauble, Glaser, Duschl, Schulze, & John, 1995). Thus, these studies bear a striking similarity to science education studies involving SI, and the results have implications for the field of science education. Pieces of the third microgenetic method design are used as part of the inquiry activities in this study.

The microgenetic studies that influenced this study use similar activities with participants and follow a similar methodology (Kuhn et al., 1992, 1995; Schauble, 1996). Participants in these studies are presented a problem or task to solve. The problem has

multiple variables that influence the outcome of the problem. Each of these variables has a specific and constant relationship to the outcome. For example, in a boat activity, using a boat that is of a small size advances the boat two zones, a boat placed in deep water advances one zone, and sail color has no effect on the movement of the boat (Kuhn et al., 1995). In doing the activities, subjects work individually for a set period of time on a problem. During this time, the researcher makes observations and asks questions about participants' choices and methods. Sessions typically last for 30 to 45 minutes and occur twice per week.

Typically, the researchers gather data using three procedures (Kuhn et al., 1992, 1995). The first procedure requires the researcher to elicit participants' theories of what they expect to occur before they conduct the activity. The second procedure involves reassessing participants' theories briefly at the end of each session and more thoroughly at the final session. Theories are assessed through questioning and conversation as well as through written accounts participants keep in notebooks. Finally, participants are asked to consider the causal structures they had discovered in their work and to use that knowledge to predict outcomes. For this study, the first two aspects of these procedures are used.

Pieces of the microgenetic method are used to provide SI experiences for preservice teachers. It is believed that change (preferably advancement) of their understandings and abilities of SI occur with experience. The borrowed pieces of the microgenetic method are the instrument to bring about change rather than the method through which the process of change is studied. Four areas taken from the microgenetic method are repetition of the inquiry problem, maintaining reflective notes, identifying

initial thoughts and conceptions about the scientific task, and the relationship of the variables in the inquiry problem.

Repetition of the experience is the primary characteristic of the microgenetic method found in this study. The repetition and refining of investigations provides preservice teachers the opportunity to understand what is involved in performing inquiry and the chance to hone their SI abilities. Kuhn (1995, 2002) argues that it appears the density of the experience is responsible for the changes in learning observed in her microgenetic studies, although how this occurs is not understood. She (1995) states

> Possibly frequent experience focuses a subject's attention on strategies in a way that would not happen in normal experience and this heightened . . . awareness is what produced change. (p. 138)

Because the repetition of activities brings about learning in subjects, repetition of the inquiry activities is used with participants in this study.

Another characteristic of microgenetic research in this study is reflection. Kuhn et al. (1992) use journals and reflective questions in order for participants to reflect about their investigations. One advantage of using reflection is it increases participants awareness of their actions in doing the activities (Kuhn et al., 1992). Also, reflection causes participants to gain insights and ideas to be used in their subsequent inquiries. In this study, students were provided reflective questions after conducting their experiments to mimic the pre- and post-activity theory assessment done by Kuhn et al. (1992, 1995) and Schauble (1996). The reflective questions are also an explicit approach to presenting SI.

Before participants in microgenetic studies begin their experiments, their theories about what would solve the problem are assessed. Participants' theories are assessed by showing them problems and asking which features would affect the outcome of the

problem (Kuhn et al., 1992). In this study, participants were shown a pendulum and circuit and asked to predict what would affect the swing of a pendulum and the lighting of a bulb. The use of reflective journaling and theory assessment in this study is slightly different than that of microgenetic studies described previously. In microgenetic studies, reflection and theory assessment is written and oral because participants were asked questions and wrote about their experiments in a lab notebook. In my study, reflective journaling and theory assessment were written only.

Finally, several of the investigations found in microgenetic studies involve variables that have cause and effect relationships. Although there is more to conducing SI than controlling variables (e.g., asking good questions and making accurate measurements; Kuhn & Dean, 2005), many microgenetic studies have participants' controlling variables as part of their inquiry activities (Kuhn et al., 1992, 1995; Schauble, 1996). The reason to have participants control variables in this activity is that it is a characteristic of conducting SI (Kuhn, 2002). The cause and effect nature of the variable relationships is mirrored in this study through the use of activities that have at least one cause and effect variable. However, the relationships between variables are not controlled by the researcher the way microgenetic researchers did. For example, in microgenetic studies, choosing a specific sail color always has the same effect on the boat. In this study, the outcomes occur naturally.

Microgenetic studies are viable to use in science education because several of their features resemble the way scientists conduct authentic research (Chinn & Malhotra, 2002). Chinn and Malhotra analyzed several research studies for aspects of SI, including microgenetic studies by Kuhn et al. (1995), Schauble (1996), and Schauble et al. (1995).

Their findings suggest these microgenetic studies contain aspects of authentic SI. Thus, activities modeled after these microgenetic studies may be examples of SI activities that preservice science teachers could use in their future science classrooms.

Other studies conclude students conducting microgenetic experiments with scientific concepts changed in two planes: They increased their understanding of scientific concepts, and they gained better skills with investigative strategies by which that knowledge is acquired (Kuhn et al., 1995). An activity capable of teaching both content and inquiry abilities is a valuable addition to a science teacher's methods.

It has been well established in developmental psychology research that the microgenetic method does work to bring about change (Kuhn et al., 1992, 1995; Siegler, 2006). Typically psychologists are concerned with the process. In this study, I used characteristics of the microgenetic method to create an experience that serves as the instrument of change. I did not use it to *accelerate* change but to *expose* change. Thus, it allows for a description and a better understanding of the emergence of the abilities and concepts associated with SI.

Theoretical Framework

The theoretical framework that guides this research study is influenced by Piaget's (1952) theory of development, specifically the idea that learners reach equilibrium through assimilation and accommodation of new information. Kuhn's theory of knowledge acquisition, which is associated with studies using the microgenetic method, also guides this study (Kuhn et al., 1992, 1995). Piaget proposed the idea that as people learn, periods of stability alternate with transitional periods, and microgenetic studies have provided extensive support for this idea (Siegler, 2006). For this study, I

believed the process of performing repeated inquiry activities in conjunction with reflective journaling would move participants through stages of equilibrium and disequilibrium, ending with each student's constructing understandings and abilities of SI.

Theories of knowledge acquisition from microgenetic studies provide support for this framework (Kuhn, 2002; Kuhn et al., 1995; Siegler & Crowley, 1991). Kuhn claims all individuals have variations in the skills and strategies they use to solve a problem. The repetition in her microgenetic studies allows students to "shift the distribution of usage to one in which the optimal strategy is dominant" (p. 115). Thus, students begin to use more advanced strategies over time. In terms of this study, that shift corresponds to participants developing more advanced abilities of doing SI. Additionally, repeated learning experiences allow a person the opportunity

> to activate his existing schemes and to increase the opportunity for interaction between these schemes and the emergent schemes which result from interaction with the problem environment. (Inhelder et al. as cited in in Siegler & Crowley, 1991, p. 608)

Thus, as new ideas emerge through participants' repeated use of inquiry activities, participants assimilate these ideas into their existing framework or accommodate the ideas into a new framework and formulate more advanced understandings and abilities of inquiry.

Kuhn et al. (1995) stress that the ability to reflect about strategic knowledge is a critical component of cognitive development. Therefore, keeping reflective journals was likely to help participants achieve cognitive growth in the area of SI. For this study, one purpose of the reflective journal was to encourage movement through the states of disequilibrium and equilibrium. I expected that each experience with the inquiry activities

throws participants into disequilibrium as they attempt to incorporate new ideas and discoveries into their current beliefs. Use of the reflective journal would provide participants an opportunity to assimilate and accommodate their new ideas, leading to equilibrium further along the continuum of understanding. Additionally, the time between repetition of activities provides participants with another chance to equilibrate their understandings and abilities of SI.

Ultimately, the experience of repeated inquiry activities and reflection serves as a means to put students through disequilibrium and equilibrium. I believed the repetition would bring about disequilibrium, while the reflection would encourage equilibrium. As participants moved through these stages, I believed they would move farther along a continuum of understanding and abilities of inquiry, completing the final activities at a higher level on this continuum.

Rationale

One rationale for conducting this study was to add to the literature regarding preparation of science teachers to use SI. There are multiple studies demonstrating that practicing teachers do not use inquiry methods in their classroom (Anderson, 2002; Costenson & Lawson, 1986; Wallace & Kang, 2004; Welch et al., 1981). For example, Wallace and Kang demonstrated that teachers found several constraints to bringing inquiry into the curriculum. The results of my study contribute to the literature by analyzing preservice science teachers' descriptions of experiences with SI and their understandings and abilities of SI.

Another reason to conduct this study was that the topic of inquiry is particularly relevant to science education in the state of Georgia, as new content standards were

implemented beginning in the 2005-2006 school year. The Georgia Performance Standards (GPS) emphasize SI and demonstrate the need for teachers to understand SI. Because teachers often do not understand or do SI (Costenson & Lawson, 1986; Wallace & Kang, 2004; Welch et al., 1981) and because it is stressed in the GPS, the *Benchmarks of Science Literacy*, and the *NSES*, it is a relevant topic to be studied in preservice teachers.

My interest in this project stems from earning a Master's degree in science education and a broad-field science teaching certificate through an alternative certification program. This program is still in existence and emphasizes constructivist, reflective teaching methods. In the past, the program introduced students to SI yet did not provide the opportunity for students to conduct SI the way it could be done in a classroom of students. As a graduate of this program, I did not completely understand SI in the classroom until I began work on my Ph.D. This lack of understanding was not due to inadequate experiences with scientific research because I previously had earned a Master's degree in biology and conducted authentic scientific research. It was my experiences as a practicing teacher and doctoral student that demonstrated the value of SI and how it was a better reflection of the scientific enterprise than the traditionally taught scientific method. Because of my experience in the program, I believed students in this alternative certification program need to conduct SI to prepare them to use it in the classroom. I believe having in-depth experiences with SI that are similar to those found in middle or secondary science classrooms might assist preservice teachers enrolled in this program to construct understandings of SI.

Overview of the Methodology

This research study is a qualitative case study of the experiences of preservice science teachers with SI. Case study research involves “how” or “why” questions being posed about a contemporary phenomenon within a real-life context (Yin, 2003). Furthermore, case study research is valuable when there is a research question or a need for general understanding about a program or case (Stake, 1995). Yin describes a “case” as an individual, a group of individuals, or an event, program, or entity that is less well defined than an individual. The case in this study is the inquiry experience that occurred within the context of a methods course. Within a case are individual units of analysis that provide data for the study (Yin). The individual participants in this study, who were students in the class, are the units of study.

In designing a case study, there are five components that should be considered (Yin, 2003). They are the research questions, the study’s propositions, the units of analysis, the logic linking the data to the propositions, and the criteria for interpreting the findings. For this study, the research questions ask how experiences with inquiry are described by preservice science teachers and what effect these experiences have on their understandings and abilities of SI. The proposition came from the theoretical framework: Having repeated, guided inquiry experiences followed by reflection would move participants along the continuum of understanding and abilities associated with SI. The units of analysis were the individual participants. Yin states that the logic linking the data to the propositions and the criteria for interpreting findings often are not well developed in case studies. In this study, analysis of qualitative data using a code based upon

understandings and abilities of SI provides the logic to link the data to the propositions and the criteria for interpreting findings.

The data in this study were qualitative and emerged from open-ended questionnaires with follow-up interviews, reflective journals, participant lab notes, personal interviews, a demographic survey, and my observations. The participants were five preservice teachers in a science education program. They were enrolled in a graduate science education program in order to earn an initial teaching certificate in broad-field science and a Master's degree in education. The study was conducted during a summer semester class required of all students enrolled in this program. All students in the class conducted repeated, guided inquiry activities, completed an inquiry questionnaire, and kept lab notes and a reflective journal about their experiences as part of their course work. Participants in this research study shared their journals, notes, and questionnaires with me and were interviewed about their experiences. Five students in the class volunteered to participate. I acted as one of the class instructors, attending the class, participating in class discussions, and teaching several lessons. However, I did not lead the inquiry experiences. Instead, I observed the participants while conducting SI and maintained a written account of my observations. The data gathered in this study sources were analyzed for patterns of changes in participants' understandings of SI, their abilities to conduct a scientific inquiry investigation, and their descriptions of the overall experience of conducting SI activities.

Summary

Schools today are expected to produce students who are scientifically literate and who understand the enterprise of science. Scientific inquiry is one of the key concepts in

understanding the scientific enterprise. In order to have students grasp the ideas and abilities of SI, it is necessary that teachers both understand SI and have the abilities to engage in inquiry. One way to increase preservice teachers' abilities and understandings of SI is to have them experience and practice SI before they are placed into the classroom.

The goal of this research study was to examine preservice teachers' experiences with SI activities. The purpose was to determine how they describe the inquiry activities and what their understandings and abilities of SI are. This was accomplished by using repeated inquiry problems and reflection about the problem. After reflection, students returned to the problem with their new insights and attempted to solve it again. Through these repeated exercises, I believed an understanding of both science concepts and inquiry as well as more sophisticated abilities of performing inquiry would emerge in these preservice teachers. Deepening their understanding of inquiry would help prepare them to teach science in K-12 schools.

CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

The purpose of this research study was to examine preservice teachers' descriptions of their experiences with scientific inquiry activities and how their experiences affected their understandings and abilities of SI. The inquiry experiences were modeled after the microgenetic method used in developmental psychology research, and participants reflected through journaling about these experiences. It is necessary to understand current research about learning through experience, SI, the microgenetic method, and reflection to understand the experiences of the participants. This chapter begins with an overview of experiential learning. SI is covered in two sections, one of which deals with science education standards and the other with results of current research into SI. The importance of reflection in learning is discussed in the fourth section. The final section is an overview of the microgenetic method.

Learning through Experience

Many educators recognize that experience lies at the heart of education. Thus, it is valuable to understand how experience is linked to learning. Experience is "direct observation of or participation in events as a basis of knowledge [and] the fact or state of having been affected by or gained knowledge through direct observation or participation" (Merriam-Webster online dictionary, 2005). This definition acknowledges the value of events and knowledge to an individual's experience. Much of the value accorded to

experience in education can be attributed to the thoughts and writings of John Dewey, who (1938) claimed, “there is an intimate and necessary relations between the processes of . . . experience and education” (p. 20). Dewey characterized educational experiences in the following manner: experiences in education can be good or bad, it is the quality of the experience that matters; experiences lead to growth and development intellectually and morally; experiences influence attitude; experiences do not occur in a vacuum; rather, sources outside the individual also influence the experience; and experiences consist of a transaction between an individual and his or her environment. Thus, an experience can be defined as an event or transaction, either good or bad, which occurs within and outside of an individual and typically leads to growth or development of that individual.

One distinction Dewey made about experience is between ordinary experiences and “*an* experience” (Wong, Pugh, & Dewey Ideas Group at Michigan State University, 2001). In *an* experience the “material experienced runs its course to fulfillment” (Dewey, 1934, p. 35). Ultimately, students finish a conversation, solve a problem, or complete an activity. To create an experience for preservice teachers requires that they finish the activity and are satisfied with its completion. Repeated opportunities with an inquiry activity, modeled after the microgenetic method used in developmental psychology research, allowed participants to complete the experience until they were satisfied with the outcome. Another quality of *an* experience is anticipation. Anticipation involves both the intellect and emotions and is what drives an experience (Wong et al.). Science labs that are a mere series of activities with little true inquiry or questioning are missing this sense of anticipation (AAAS, 1990; Wong et al.). Additionally, Dewey believed an important aspect of experience is satisfactorily solving a problem in such a way that can

lead to an enriched future inquiry, ultimately leaving students anticipating the future inquiry (Glassman, 2001). Students who are aware they will be given an opportunity to repeat an activity at a different time, after reflection about the activity, might feel this sense of anticipation, thereby deepening their total experience with and resulting understanding of the problem.

Dewey stressed the importance of “vital experiences” in education (Glassman, 2001). Vital experiences are not routine, instead, these experiences are deeper, and they link actions and consequences with previous and future, related activities. Dewey distinguished vital experiences, which he termed secondary experiences, from routine primary experiences, which require little thought or reflection. The reflection involved in a secondary experience is one difference between these two experiences (Glassman). Acquiring new knowledge involves moving primary experiences to a deeper level and integrating the previous experiences with new ideas and thoughts through reflection. Other researchers stress that the act of reflection is what makes an experience educative (Joplin, 1981). The reflection process is what turns an experience into experiential education (Joplin; National Research Council, 2000). Thus, reflection is a key component of a worthwhile experience.

In the classroom, the teacher has a role in facilitating and creating the experience of the students (Dewey, 1938; National Research Council, 1996). Dewey stated

> The educator has the ability to influence directly the experience of others and thereby the education they obtain . . . this places upon him the duty of determining that environment which will interact with the existing capacities and needs of those taught to create a worth-while experience. (p. 45)

It is up to the educator to shape the students’ experience and to give it the quality that makes it valuable and makes future, similar experiences desired (Dewey, 1938). Because

Dewey believed teachers are the agents through which knowledge and skills are communicated, it is essential that preservice teachers have adequate experiences with a topic in order to teach that topic.

Several educational applications of experience for pre- or in-service teachers are found in the literature. One study involved the development of cultural understandings, the second dealt with special education, and the third with astronomy. Each of these demonstrated the value of experience in the learning process and that experiential learning can be used to prepare students for a career in teaching.

Spalding, Savage, and Garcia (2003) stressed the importance of experiential learning for preservice teachers' developing an understanding of multiculturalism. G. Pritchy Smith (as cited in Spalding et al.) stressed the importance of experience for students who have lived monocultural lifestyles and believed a good teacher education program should include a strong experiential component to prepare these preservice teachers. Thus, Spalding et al. used an experience to teach preservice teachers about multiculturalism. Participants experienced an aspect of the Holocaust through an activity called The March of Remembrance and Hope. This experience included extensive travel, a curriculum of reading and videos, and journaling by preservice teachers. The results of the study suggested effective learning took place when content knowledge was connected with physical experiences, demonstrating the ability of an experience to facilitate learning.

Ensign (1999) worked with preservice teachers to have them experience how it feels to try to learn with a learning disability. Students experienced learning a new, complicated skill and maintained reflective journals of their experiences. As a result,

these student developed empathy and learned skills involved in teaching special education students (Ensign). This study demonstrated the learning of skills and expression of emotions through experience.

Finally, Wilson's (2003) study involved preservice teachers' conducting SI in astronomy. Wilson created an inquiry experience for pre- and in-service teachers in which they conducted research into binary star systems. Wilson explained the concept of binary stars, and the teachers worked in teams to research the existence of these paired systems. Wilson's inquiry experiences were open and authentic, unlike the guided SI used in this research study. Furthermore, Wilson's students were solving problems about binary stars whose answers were not known by the scientific community. In order to make the experience involve explicit learning and reflection, concept mapping was used to encourage the students to think metacognitively about their experience. Additionally, he examined their views of NOS as related to the binary star research. As an outcome, all students showed in increase in content knowledge of astronomy and some showed improvement in their understanding of NOS (Wilson). This experience facilitated learning of content and an understanding of the nature of science.

Each of these three studies demonstrated the ability of an experience to be educative and prepare preservice teachers. Although the knowledge and skills learned in each of the studies were incredibly different, each study showed participants gained skills and knowledge that could be used in his or her future classrooms. Thus, this literature supports my study's goal of understanding the role of experiences with SI on preservice teachers' understandings and abilities of SI.

Scientific Inquiry: Definitions and Standards

Scientific inquiry is one component of scientific literacy (AAAS, 1990), yet there is confusion as to what comprises SI. This confusion arises from different uses of the term “inquiry.” One use refers to what scientists do through their research practices, while another refers to what students do in the classroom (Anderson, 2002; Colburn, 2000; Gunstone et al., 1999; Martin-Hansen, 2002). While the term “inquiry” typically refers to any search for knowledge (Gunstone et al.), in science education research it is often used in reference to the practice of scientists studying the natural world or to students’ conducting experiments and asking questions in the science classroom (Martin-Hansen). A learning or teaching approach used in classrooms that allows students to search for knowledge regardless of the content area or method used is often dubbed “inquiry learning” (Anderson; Gunstone et al.). The term “scientific inquiry” was used by Gunstone et al. to describe the subset of inquiry that refers to the development of new scientific knowledge by scientists. Welch et al. (1981) defined scientific inquiry as being concerned with the natural world and guided by specific beliefs and assumptions. Many others use this term to describe inquiry learning in a science classroom.

The confusion in terminology may arise in part from a disagreement between researchers as to what constitutes “authentic inquiry.” Some argue that authentic inquiry is done only by scientists who seek new knowledge (Schwartz et al., 2001). The type of inquiry done by students in the science classroom is not authentic because it does not contribute to the knowledge base of scientists nor does it involve the complex reasoning or negotiating of meaning that is associated with the scientific community (Schwartz & Crawford, 2003). Although the information studied by students in science classrooms

may be novel to them, it is not new to the scientific research community. A second group defines authentic inquiry as investigation of scientific events in which “the learner observes the phenomena, manipulates/‘tinkers with’ materials, asks questions, designs investigations, conducts experiments, analyzes data, and reports results” (Brown & Melear, 2006, p. 939). In my study, the participants’ SI experiences did not generate new scientific evidence, however the experience itself can be termed scientific inquiry because the students had not experienced it before.

As discussed in Chapter 1, one difference between the NRC (1996) and Project 2061 (AAAS, 1990) with respect to SI is found in expected student outcomes. Although Project 2061 encourages having students actively engaged in conducting SI, its *Benchmarks for Science Literacy* (AAAS, 1993) emphasize SI as a topic to be understood and as a concept embedded within NOS, with little emphasis in the standards on conducting SI. For example, the *Benchmarks* state that by the end of the 12th grade, students should know that investigations are conducted for different reasons; that hypotheses are used in science; that sometimes scientists can control conditions in obtaining evidence, sometimes not; that the different science traditions have in common certain basic beliefs about the value of evidence, logic, and good arguments; that scientists in any one research group tend to see things alike, therefore they must look for bias in their work; that new ideas in science often encounter criticism; and that new ideas in science are limited by the context in which they are conceived. These standards are concept oriented rather than action or process oriented; they embody NOS in the form of understanding SI without discussing the importance of students conducting scientific investigations.

The *NSES* (NRC, 1996), vary in their approach to SI in that students are expected to understand the concepts related to scientific inquiry and possess the abilities necessary to conduct SI. NRC created content standards that elaborate what students should know about SI. Content Standard A states, “As a result of activities in grades K-4 (or 5-8 or 9-12), all students should develop: *abilities* necessary *to do* scientific inquiry and *understandings about* scientific inquiry” (NRC, 1996, p. 121, 143, 173, emphasis added). In grades 5–12 the abilities associated with doing scientific inquiry include identifying questions that can be answered through investigations; designing and conducting a scientific investigation; using tools and techniques to gather, analyze, and interpret data; developing descriptions, explanations, predictions and models using evidence; thinking critically and logically in linking evidence with explanations; using technology and mathematics to improve investigations and communications; formulating and revising scientific explanations; recognizing and analyzing alternative explanations and models; and communicating and defending a scientific argument (NRC). Several of the understandings about inquiry to be communicated in these grades include that scientists conduct investigations for a variety of reasons; that scientists rely on technology; that mathematics is part of inquiry; that scientists inquire into natural systems; and that science advances through skepticism (NRC).

From a teacher’s standpoint, the *NSES* (NRC, 1996) put forth that SI is basic to science education and should be a controlling factor that teachers consider in planning and selecting activities for their students. This vision maintains that SI is more than scientific processes; instead, it combines science processes with scientific knowledge, reasoning, and critical thinking. This engagement in SI should help students develop an

understanding of concepts, an understanding of NOS, skills to become independent inquirers, and the dispositions to conduct SI. Because SI comprises such an important aspect of the scientific classroom, it is imperative that teachers understand SI in order to implement it into their teaching.

In addition to the inquiry content standards, the *NSES* (NRC, 1996) has teaching standards and professional development standards associated with SI. The NRC's emphasis on inquiry demonstrates its commitment to SI in the classroom and acknowledges the importance of SI as a concept to be incorporated in the science classroom. Teaching Standard A states that science teachers should "plan an inquiry-based science program for their students" (p. 30). Professional Development Standard A proposes that science teachers learn science content "through the perspectives and methods of inquiry" (p. 59). The *NSES* demonstrate the need for science teachers to teach, model, and facilitate understandings and abilities of conducting SI inquiry, thus teachers need to be exposed to these concepts in their training in order to be adequately prepared for this role.

It is necessary to look beyond the NRC and AAAS to other organizations' and researchers' definitions to understand SI. For example, the term "process skill" is often used to mean the same thing as SI abilities. This is seen in the similarity between The College Board's (TCB, 1990) process skills and the abilities of SI described in the *NSES.* TCB published a set of learning outcomes that students in science classes should have. These processes are the ability to ask appropriate scientific questions; the skills to gather scientific information; the ability to organize and communicate results gathered in observation and experimentation; the ability to draw conclusions or make inferences; and

the ability to recognize the role of observation and experimentation in the development of scientific theories.

Some researchers argue there are three components of “science as inquiry” (Bybee, 2000; Welch et al., 1981). Bybee defines these three components as the skills of scientific inquiry (what students should be able to do), knowledge about scientific inquiry (what students should understand about scientific inquiry), and a teacher’s pedagogical method of teaching science subject matter. Welch et al. outline these components as science process skills (the doing of inquiry); the nature of scientific inquiry (an epistemological understanding); and general inquiry processes (thinking strategies of rational inquiry). Although these views vary, science education researchers, The College Board (1990), and the NRC (1996) emphasize the importance of process skills and understanding SI in science classrooms. Therefore, my position in this study was the same as the *NSES* view that SI can be used to create classroom experiences that are likely to bring about science literacy in students.

Scientific Inquiry in the Classroom

As previously demonstrated, SI is an important component of a science classroom. There are various ways to use inquiry in the science classroom for teachers who choose to implement SI in the classroom. These range from open inquiry, where students design and conduct all aspects of the investigation, to the more traditional “cookbook” method, where the teacher, textbook, or worksheet provides the questions, the procedure, and materials (Bonnstetter, 1998; Colburn, 2000; Martin-Hansen, 2002). Classroom implementation of SI occurs along a continuum from teacher controlled to student-controlled activities, as shown in Table 1.

Table 1

Inquiry as an Evolutionary Process

	Type of Inquiry				
Process Step	Traditional Hands-on	Structured	Guided	Student Directed	Student Research
Topic	Teacher	Teacher	Teacher	Teacher	Teacher/ Student
Question	Teacher	Teacher	Teacher	Teacher/ Student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedures/ Design	Teacher	Teacher	Teacher/ Student	Student	Student
Results/ Analysis	Teacher	Teacher/ Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student

Note. From Bonstetter (1998).

In Table 1, terms such as structured and guided describe points along this continuum. None of the terms are empirically derived; instead, they have been created through a common understanding. Because of this, the terms used for various points often vary depending upon the source. At the teacher-centered end are traditional, closed, or cookbook lab situations that have students focusing on completion of a task and searching for the “right” answer (Gunstone et al., 1999). Mixing student and teacher oriented activities are structured, guided, or student-directed inquiries in which the teacher provides the question but the students work out the relationships between variables on their own, allowing for a more authentic experience than traditional, cookbook labs (Colburn, 2000; Martin-Hansen, 2002). The term “guided inquiry” is used in this study to refer to this level on the continuum. Student research, or open inquiry,

involves the students' determining the question to be investigated, the methods to use, and how to analyze the data to determine relationships. Student research will be referred to as open inquiry. Open inquiry is often seen only in science fair or open-ended projects and is most representative of how scientists conduct research, thus allowing students to understand this aspect of inquiry. Bonnstetter (1998) argues that open inquiry activities focus on learning instead of teaching and promote internal reconstruction of information by students.

Preservice teachers in this research study were engaged in guided inquiry because I provided them with materials and guiding questions. Students designed their own procedures, chose how to collect and analyze data, and drew their own conclusions. Windschitl (2002) stated this form of inquiry is a valuable learning experience because students come to understand through their experiences how evidence and argument must be coordinated in order to support their knowledge claims. Although guided inquiry is not the most open form of inquiry, it was used in this study because it guaranteed all participants began with the same materials and problem. Thus the interpretations each participant made and the knowledge she constructed depended upon the experience that she created for herself from a common set of materials and instructions.

Much research exists that demonstrates science teachers do not use inquiry on a regular basis in the classroom (Anderson, 2002; Costenson & Lawson, 1986; Marlow & Stevens, 1999; Muscovici, 2000; Wallace & Kang, 2004; Welch et al., 1981; Windschitl, 2002). Forty-one percent of science teachers with emergency permits surveyed by Muscovici self-reported that they teach primarily from the textbook. However, 36% of those surveyed stated a preference to teach with SI, demonstrating that teachers wanted to

know how to use SI in the classroom. Several studies examined the reasons teachers do not conduct SI in the classroom (Costenson & Lawson; Martin, 2001; Welch et al.). These studies revealed that teachers feel that SI is time and energy intensive, that teachers possess confusion about the meaning of inquiry; that teachers exhibit an allegiance to teaching facts; that teachers feel students are not mature enough to handle inquiry; that teachers feel inadequately prepared for inquiry-based instruction; and that teachers experience discomfort with managing inquiry activities. These perceived roadblocks often prevented teachers from using SI in their classrooms.

Palmquist and Finley (1997) examined preservice teachers' views of NOS, which included several elements of SI. They learned that preservice teachers' views of NOS moved from naïve to advanced in the course of two methods classes. More importantly, the advanced views of NOS were carried out in lesson plans as many of the preservice teachers' plans corresponded with a contemporary or advanced view of NOS. However, this did not hold for the SI portion. Instead, only half the preservice teachers moved from naïve to advanced views and none of the teachers used advanced methods in their student teaching in terms of the scientific method (Palmquist & Finley). This study demonstrated SI should be included and addressed explicitly as separate from NOS in methods courses in order for teachers to understand and teach it.

Anderson (2002) suggested many of the difficulties in teaching SI in science classrooms lie with the teachers. A teacher needs to understand SI and be able to conduct SI on his or her own terms before he or she will be comfortable bringing SI into the classroom. Even teachers who do have an advanced understanding of SI often do not use it in the classroom. For example, Marlow and Stevens (1999) interviewed a group of

practicing teachers. The majority believed SI involves student choices, open-ended questions, and is based on problems. Although they defined SI in an open manner, classroom observations of these teachers revealed few of them actually implemented SI into their teaching. Wallace and Kang (2004) studied in-service teachers who participated in a 1-week inquiry workshop. The workshop involved reading and discussing SI, participating in SI activities, and designing SI lessons. The teachers' understanding of SI increased as a result (Wallace & Kang). However, not all of the teachers brought SI into their classrooms following the workshop. Their results suggested SI should be approached as an application and problem-solving strategy, which involves mastering the skills of SI. A study of preservice teachers learning about SI demonstrated they all did not use SI once they reached a classroom (Windschitl, 2002). Only three of the six students used SI on a regular basis during their student teaching. In another study, student teachers who understood SI and were placed with teachers who did not use SI showed a loss in their SI abilities (Martin, 2001).

Many researchers suggest having preservice science teachers engage in authentic science research is one way to increase their understandings of SI and have them learn how to practice SI (Brown & Melear, 2006; Melear, 2000; Melear et al., 2000; Wilson, 2003; Windschitl, 2002). For example, Melear et al. argued "providing preservice teachers with opportunities to design their own experiments may promote a deeper understanding of the processes of science" (p. 78). In an attempt to mirror how scientists approach questions, Melear et al. provided preservice teachers with multiple opportunities to design, implement, and analyze experiments with a fast-growing fern.

These students ultimately learned to design open-ended experiments, interpret data, and formulate results—all important skills needed to engage in scientific inquiry.

Wilson (2003) studied preservice and in-service science teachers conducting authentic inquiry into binary stars in an astronomy course. He coupled explicit teaching of NOS and SI with authentic SI research in the field of astronomy. As a result, the students increased their content knowledge of astronomy and understanding of NOS. These studies demonstrated doing authentic inquiry increases students' skills of SI (Melear et al., 2000; Wilson; Windschitl, 2002). Although these authentic experiences have been demonstrated to be valuable methods of teaching SI, they may not be feasible for all science preservice teachers who may not take science courses that involve conducting research. Therefore, a method that allows preservice teachers to engage in SI in their teaching methods courses, and increases their understandings of SI and their abilities to conduct SI would be a valuable addition to research about preservice teachers' learning about SI.

Assessing Views of Scientific Inquiry

Researchers have developed assessment instruments for measuring pre- and in-service teachers' understandings of NOS and SI (Lederman et al., 2002; Lederman et al., 1998). There is a long history of assessing views of NOS and SI; for example, Lederman et al. (1998) report over 20 standardized instruments have been used to assess NOS over the past 40 years. Many of these instruments used multiple choice, Likert-scale, or agree/disagree formats. Criticisms have been aimed at the standardized answer format of these instruments, including that the statements were ambiguous; that the instruments typically reflected their developers' views of NOS; and that limited choices existed for

each statement. Even instruments that yielded an accurate view of participants' conceptions of NOS did not tell the researchers everything they wanted to know about participants' views (Lederman et al., 1998).

A set of instruments was developed to assess students and teachers views of NOS through open-ended questions followed by interviews because of the problems associated with standardized instruments. The open-ended nature of the questions and interviews allowed participants' views to be elaborated and explored more thoroughly. The original instrument developed was the Views of Nature of Science (VNOS) questionnaire (Lederman et al., 2002). VNOS assesses the following characteristics of the nature of science: the empirical nature of scientific knowledge; differences between theories and laws; the creative nature of science; science as theory-laden; science as embedded within social and cultural foundations; the multiple methods used in scientific investigations; and the tentative nature of scientific knowledge (Lederman et al.). Over time, questions were added and removed by several of Lederman's doctoral students, resulting in three versions of VNOS: VNOS-A, VNOS-B, and VNOS-C. Construct validity was established for VNOS-B and VNOS-C through discussions between science educators, science historians, and scientists. The VNOS forms have been used in multiple studies involving science students and pre- and in-service science teachers (Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman et al., 2001; Schwartz et al., 2002). The most current form of VNOS is VNOS-C.

One group of researchers interested in assessing high school students' understandings of SI created the Views of Scientific Inquiry (VOSI) questionnaire by modifying VNOS-C and adding additional questions (Schwartz et al., 2001). VOSI

assesses the following characteristics of scientific inquiry: the multiple methods of scientific investigations; the importance of coordinating evidence with conclusions; the difference between data and evidence; the acceptable nature of multiple interpretations of data; and the direction of data analysis by the original questions of interest (Schwartz et al., 2001, 2002). VOSI was validated by three science educators and modified after suggestions from high school students who completed the questionnaire (Schwartz et al., 2001). It has not been used as extensively as VNOS, but it has been shown to be a valuable instrument for assessing scientific inquiry in high school science students (Schwartz et al., 2001, 2002) and in in-service teachers (Schwartz et al., 2002). Questions from VOSI and VNOS-C were used in this study to assess understandings of SI.

An Explicit Approach to Scientific Inquiry

There are two ways NOS and SI can be learned in preparing science teachers and teaching science students: an implicit approach and an explicit approach. The implicit approach involves no direct teaching of the subject; instead, the teacher assumes that merely through the act of "doing science" students will develop an understanding of NOS and SI (Abd-El-Khalick et al., 1998). This approach contends that the construction of an understanding of NOS and SI is a natural consequence of students' engaging in inquiry activities (Schwartz et al., 2004). In doing inquiry activities, the implicit approach does not offer a clear discussion or direct instruction relating the inquiry activities to elements of NOS or SI (Schwartz & Crawford, 2003). Schwartz and Crawford reviewed previous research studies about open-ended inquiry teaching approaches that used the implicit method. The outcomes of each study demonstrated that the inquiry-approach alone,

without discussion or instruction relating the activity to NOS, did not increase students' conceptions and understandings of NOS.

Explicit instruction of NOS or SI uses directly planned instruction to improve students understandings (Lederman et al., 2001). Explicit instruction occurs when the goal of improving learners' conceptions is clearly stated and planned for (Schwartz et al., 2002). In terms of explicit teaching of SI, guided reflection that is used to draw learners' attention to relevant aspects of SI in the context of inquiry-based activities may facilitate learning about SI (Schwartz et al.).

Students are more likely to understand NOS when they learn NOS through explicit instruction. One study of preservice teachers demonstrated implicit teaching of NOS through the use of inquiry did not increase preservice teachers' understanding of NOS, but explicit teaching through discussion and reflection did increase their NOS understanding (Schwartz & Crawford, 2003). Another study involved preservice science teachers' learning about NOS through implicit and explicit means (Palmquist & Finley, 1997). Although participants' views of NOS moved from naïve to advanced, views of the scientific method remained relatively naïve. This may be because the inquiry aspects of the scientific method were taught implicitly. Schwartz et al. (2004) used reflection and seminars to teach explicitly NOS and SI and demonstrated that understandings of NOS and SI advanced through the use of an explicit approach. The authors concluded, "The guided reflections and peer sharing appeared to enable the interns to first, personalize their understandings of NOS, and second, to explore deeper issues of NOS than had been previously recognized" (p. 634). The explicit teaching methods used in these studies and others included discussion, reflection, questioning in the context of activities,

investigations, and historical examples (Gess-Newsome, 2002; Lederman et al., 2001; Schwartz & Crawford, 2003; Schwartz et al.).

Explicit teaching is valuable in teaching the concepts and skills of SI as well as NOS. If purposeful planning, integration, and discussion of the interplay of the NOS and SI with scientific knowledge occurs, then students are likely to understand SI better (Gess-Newsome, 2002). Furthermore, explicit instruction

> models, discusses, and distinguishes between the skills of SI (the "how" of doing science), the cognitive outcomes of SI (the "why" of doing science), and the pedagogical applications of SI (the how's and why of inquiry-based science instruction). (p. 56).

If preservice teachers understand these variations of SI, they may incorporate SI in their classrooms.

Participants in this study reflected about their SI experiences because one form of explicit teaching is reflection. Boud et al. (1985) stated reflection is one response of a learner to experience. They claim there are two components of reflection: the experience and the reflective activity created from the experience. Reflection occurs when the experience is evaluated and analyzed, and it is necessary for the experience to be integrated into a person's current conceptions. Dewey (1938) believed quiet time for reflection should follow an educative experience. He stressed that these times

> are periods of genuine reflection only when they follow after times of more overt action and are used to organize what has been gained in periods of activity in which the hands are used. (p. 63)

Participants in this study were provided time to reflect following an inquiry experience to encourage this "genuine reflection." Reflection occurs when individuals explore their experiences and create new understandings (Boud et al.). For example, Bonnstetter (1998) emphasized the importance of reflection in having in-service teachers use and

integrate new methods into their existing repertoire of teaching ideas. He argued that without reflection, teachers often “learn” a new method but never use it in their classrooms. Joplin (1981) stated the process of reflecting about the past often leads to decisions about what needs to be done in the future or how something should have been done in the past. This outcome of the reflection process encourages students to repeat that action, adding the modifications they thought about during their reflective period.

Studies of explicit instruction of SI have successfully used the explicit method through reflection in having students answer journal questions and/or participate in planned discussion about SI (Gess-Newsome, 2002; Schwartz et al., 2001. 2002). In the study by Gess-Newsome, the explicit teaching methods facilitated a shift in students’ definitions of science. Their views changed from defining science as a body of knowledge, or product, to a definition recognizing science as a conception that blends scientific products and processes, one goal of the *NSES* (Gess-Newsome, 2002). Schwartz et al. (2002) used explicit teaching through reflection to facilitate in-service science teachers development of understandings of NOS and SI. These teachers initially held naïve views of SI. Teachers views shifted to more advanced views of SI through their reflective activities.

Many educational classrooms use journaling to encourage reflection by students (Corley, 2000; Gess-Newsome, 2002; Hughes, Kanevsky, & Kooy, 1997; Shin, 2003; Windschitl, 2002). Corley argued that journaling is a useful tool for promoting critical reflection in preservice teachers. Other researchers demonstrated keeping journals encourages students to interact with the material they are studying and to construct personal meanings of their experiences with the material (Hughes et al.). Furthermore,

they argue that reflection can bring a sense of closure to activities. Because of these qualities, journaling has been successfully used in several teacher-training programs (Corley; Gess-Newsome; Shin; Windschitl).

Reflective journaling has been used with preservice science teachers to increase their understandings of NOS and SI (Gess-Newsome, 2002; Windschitl, 2002). Gess-Newsome used journaling with preservice teachers by having them write about concepts such as their ideas about science teaching and the definition, nature, and organization of science. Students' journal responses included descriptions of science, the use of science in problem solving and critical thinking, and changes in their conceptions of science. This study demonstrated that explicit teaching through reflective journaling facilitated students' advancing their understandings of what comprises science.

Windschitl (2002) used a two-part journal to have preservice teachers reflect about an inquiry experience. In the first part, students reflected on their experience with an open inquiry experiment, and in the second part, students reflected about inquiry instruction in their future classrooms. Unfortunately, participants used the journal more as a lab notebook than as a reflective experience, although some reflection did occur. Thus, Windschitl suggested journaling should be structured to prompt reflection, such as through instructor-given questions, in order to make the experience truly reflective. In the parts of the journal where participants did reflect about their experience, analysis suggested the students were self-reflective and self-aware about some of their actions in doing inquiry (Windschitl). This demonstrated that journals encourage reflection about conducting SI.

Research conducted in non-science areas of education also demonstrates the efficacy of reflection through journaling as a teaching tool. Shin (2003) used reflective journaling with a group of preservice ESOL students. She stated that reflection through journal writing can serve as evidence of preservice teachers' development as learners. The ESOL preservice teachers wrote about their experiences teaching writing. One finding was that maintaining a journal increased preservice teachers' awareness of their own writing style and habits (Shin). This self-reflection spurred these students to recognize the thoughts and actions they took in writing. This sort of self-reflection leads to recognition of thoughts and actions and may increase preservice science teachers' understandings of SI and encourage them to consider their next actions in conducting SI.

Corley (2000) used electronic journaling to foster continuous reflection by preservice teachers. He believed journaling might help students develop a more realistic view of the practice of teaching. The students' attitudes about journaling were measured, rather than their views of teaching. Ultimately, students perceived e-journaling as a valuable experience in their growth as teachers (Corley). For example, one student stated, "'Journaling has given me more responsibility to look at my information more thoroughly than I usually do'" (Corley, p. 12). Additionally, these students reported they liked being provided reflective questions as well as being encouraged and allowed to answer freely. This type of critical reflection is invaluable for preservice teachers' learning about topics relevant to their teaching.

Because the literature demonstrates reflection is a valuable component of an experience, and journaling is a good reflection tool for preservice teachers, it was the means of reflection for the participants in this study. Both guiding questions provided by

me and open-ended reflection were used to encourage participants to reflect about their experiences with SI.

Microgenetic Method

The microgenetic method derives from Lev Vygotsky's theory of development and is used to study development while it occurs. Vygotsky differentiated ontogenetic development, changes over the lifetime of an individual, with microgenetic development, changes in an individual that occur over brief periods of time (Bjorklund, 1999). The history of the microgenetic method stretches back to the early 20th century and includes Heinz Werner as well as Vygotsky (Siegler & Crowley, 1991). Werner performed "genetic" experiments in which he studied the unfolding of successive representations that made up psychological events (Siegler & Crowley). Vygotsky also studied changes as they occurred in subjects within experimental sessions (Siegler & Crowley). Their experiments formed the framework of the microgenetic method.

Siegler and Crowley (1991) stated studies that examine changes while they occur suggest mechanisms that produce the changes and provide data that can be used to evaluate the plausibility of these potential mechanisms. They described three features of the microgenetic method: (a) observations of individuals occur throughout the period of change; (b) a high density of observations relative to the rate of change period are taken; and (c) analysis of behavior occurring in each trial should be intensive. Use of this method allows that

> increased density of exercise of existing cognitive strategies over an extended period may accelerate . . . development, enabling the researcher to observe the change process at a greater level of detail. (Kuhn et al., 1992, p. 286)

Although this method is used primarily in studying developmental changes in children, it may work as a method for facilitating learning in adults.

Deanna Kuhn, Leona Schauble, and other developmental psychologists have used the microgenetic method extensively in studying developmental change in children's abilities to reason and think scientifically. It is this body of research that inspired me to use the microgenetic method in this study. One characteristic of their work that influenced this study is these researchers allowed children repeated exposures to the same problem to encourage them to revise their reasoning, investigative strategies, and theory development (Kuhn, 1995; Kuhn et al., 1992, 1995; Schauble, 1996; Schauble et al., 1995). Kuhn argued that the success associated with repetition of the activity may be due to the idea that "practice makes perfect" – that is, practice allowed students to perfect their execution of investigative strategies. Furthermore, repeated investigations may have fostered within the students a greater metastrategic awareness of the methods they used in their investigations (Kuhn). Finally, the results of a study conducted by Schauble et al. suggested "students best learn about the nature of experimentation through sustained periods of real investigation." Therefore, the idea of repetition of experiments and problems was borrowed to create the inquiry experience for participants in this study.

The findings of microgenetic studies are also important to science education. Researchers demonstrated change in participants occurs in two areas: in knowledge of scientific concepts and the investigative strategies by which that knowledge is acquired (Kuhn, 1995). This knowledge about conducting investigations relates to students' gaining abilities to conduct SI. As students in the microgenetic studies repeated their investigations, they came to understand the relationships between the variables and how

to conduct investigations. Actively engaging students in experimentation taught them both about scientific reasoning and experimentation itself (Schauble et al., 1995). These students designed boats to carry fictional construction materials up a river, “sailing” each boat between trials. In carrying out their experiments, students made inferences about boat features, such as height and carrying capacity, looked for patterns in data, and reasoned abstractly to design their next boats. Because understanding experimentation and inquiry can be complicated, the microgenetic method is a valuable tool because it helps students realize what is involved in “doing” science through repeated experiences with inquiry.

One characteristic of microgenetic experiments is the cause and effect nature of the tasks given to participants (Kuhn et al, 1992; Schauble, 1996). A study of fourth-grade children who performed a set of experiments nine times over a series of weeks used this cause-effect relationship in the tasks (Kuhn et al.). There were two tasks, the first of which examined the relationship between boat speed and variables such as boat size, water depth, sail size, and sail color. The second task was a computer simulation involving car speed and had variables similar to the boat task. The students manipulated the variables in any way they chose and generated theories about what variables made boats or cars move faster. One student, Beth, demonstrated a common trend among students, that of not “controlling” the variables in the experiment. Initially, Beth tested at random and did not take into account the number of variables involved. During her fifth session, she recognized the need to control variables to determine which factor was affecting the movement of the boat. These results were similar with other children; only after repeated experiments did students comprehend that inferences about one variable

could not be made if the other variables were not controlled. These studies demonstrated the children's experimental strategies improved over time with use of the microgenetic method.

Another characteristic of the microgenetic method that is appropriate for this research project is found in students' strategies of experimental design. Kuhn et al. (1992) conducted research with preadolescent students' repeating self-directed investigations. The researchers concluded people have more and less advanced experimental and reasoning strategies coexisting in their repertoire of abilities. In initial experimentation, participants used both the less and more advanced strategies in testing their theories. However, over time and with repetition, the more advanced strategies overcame the less advanced. Because teachers want students to move toward more advanced competencies of investigative skills, I predicted that use of the microgenetic method to repeat experiments might cause the preservice teachers in my study to gain advanced competencies in their abilities to conduct SI.

Many science educators value allowing students to design their investigations and reach their own conclusions. However, educators often assume the actual use of open-ended experimentation is enough, believing one exposure to the content and methods is sufficient to impart an understanding of both scientific knowledge and the experiment. The experiments by Kuhn et al. (1992), Schauble (1996), and Schauble et al. (1995) demonstrated there is more involved to experimenting than the generation of an answer. Several studies have shown that children who were given the opportunity to repeat work on a problem improved in their understanding of the science content and in their methods of performing experiments (Kuhn, 1995; Kuhn et al.; Schauble; Schauble et al.). This has

implications for the use of SI in science education: There is much discussion about having students conduct scientific investigation occurring in science education, but rarely in the form of letting students repeat experiments until concepts become clear. This aspect of the microgenetic method contributes an idea to the way inquiry is done in the science classroom. Therefore, using a method modeled upon the microgenetic method with a group of preservice teachers has the potential to both change their understandings and abilities about SI and provide a possible instructional method for them to use in their own classrooms in the future.

Typically research using the microgenetic method has been done with children; however, some research has occurred with adults. Schauble (1996) conducted a study comparing the experimentation strategies of fifth and sixth grade children and noncollege adults. Participants worked with a spring and a boat and canal to study scientific concepts such as weight and density. The results demonstrated that both adults and children underwent developmental changes in their experimentation methods and their ability to make valid inferences. Both groups increased their understanding of the science content and improved their strategies for generating and interpreting evidence. Other researchers examined community college adults' and preadolescents' strategies of knowledge acquisition and changes in understanding of content using the microgenetic method (Kuhn et al., 1995). Both groups developed more advanced strategies over the course of the study. The microgenetic method can be used with adults as demonstrated by these studies.

The developmental psychology literature supports the microgenetic method as a research method valuable for bringing about and studying change within individuals. One

of the goals of this research study was to examine change in individuals' understandings and abilities of SI, and research using the microgenetic method suggests it is a way to stimulate this change**.** Because this method has helped students improve their conceptual understandings of science and increase their abilities in performing experiments, asking questions, and consolidating theories and evidence, it was the method that guided the creation of SI activities for preservice teachers.

Summary

One goal of science education is scientific literacy for all students. Scientific inquiry is one component of scientific literacy and is emphasized in standards documents (AAAS, 1990; NRC, 1996). The abilities of SI include identifying questions for inquiry; designing and conducting scientific investigations; gathering, analyzing, and interpreting data; developing explanations and predictions using evidence; thinking critically; and communicating scientific arguments. Understandings of SI include that there are many reasons to conduct investigations; that scientists use technology and mathematics; that scientists inquire into the natural world; and that science is skeptical. Research into pre- and in-service teachers' understandings of SI demonstrated many teachers' have naïve and undeveloped ideas about SI. Teachers who have naïve understandings of SI rarely incorporate it into their classrooms. Thus, it is necessary that preservice teachers understand SI and have the abilities to conduct SI to facilitate properly SI in their classrooms.

Dewey and others argued that experiences are intricately linked with education. Experiential learning involves linking actions and consequences with activities. Reflection is a key aspect of learning through experience. Research demonstrated that

experiences linked with reflective-type activities help students learn skills, deepen understandings, and develop emotions. Because of this nature of experiences, if preservice teachers are allowed to experience SI, they may develop deeper understandings and abilities of SI.

The microgenetic method is used in developmental psychology for studying the processes of developmental change. Outcomes of microgenetic studies are that students develop deeper understandings of scientific concepts and better abilities at conducting scientific investigations. These are two goals of science education and the microgenetic method may be a valuable method to try in science education research.

CHAPTER 3

METHODOLOGY

Introduction

The purpose of this study was to examine preservice science teachers' experiences with repeated, guided inquiry activities modeled after the microgenetic method. The following questions guided this research:

1. How do preservice science teachers describe the experience of repeated, guided inquiry activities in their coursework?
2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?

This research combined the following: scientific inquiry experiences, explicit connections about SI made through reflective journaling, and the microgenetic method. The research project was conducted during summer semester of 2006. Participants had 1-hour SI experiences that were repeated during the 6-week course, with approximately 45 minutes devoted to the activity and the remaining 15 minutes spent in reflective writing. Reflection occurred directly after the SI experience to facilitate higher-order thinking about the problem, the methods which solved the problem, and how the problem might be approached the next class.

In this research, I employed qualitative research methodology. Data initially were coded using a static start code of three codes, as suggested by Miles and Huberman (1994). The start code grew to five codes as data coding continued. The data were

analyzed and organized through the use of a chronological data matrix to establish patterns across and within each of the participant's experience (Miles & Huberman).

Qualitative Research

In this study, I used qualitative methodology to examine preservice science teachers' descriptions of their experiences with SI and their understandings and abilities of SI. Because this research problem is based upon a constructivist framework, qualitative methodology, with its natural context and multiple data sources, was suited to answer the research questions. Case study methodology shaped this study (Bogdan & Biklen, 2003; Guba & Lincoln, 1994; Yin, 2003). As discussed in Chapter 1, case study research involves "how" questions that study events within real-life settings (Yin). The how questions in this study were how do preservice teachers describe inquiry experiences in their science teaching methods class, and how do their experiences influence their understandings and abilities of SI. The case in this study was the inquiry experience that occurred during the methods course. The individual units of analysis within the case were the participants in the study. This study collected descriptive data in the form of personal interview transcripts, answers to an open-ended questionnaire (VOSI-M) and follow-up interviews to clarify answers, journal entries, participants' lab notes and reflections, and my observations. Data were analyzed to find meaning in participants' experiences with inquiry and to describe participants' experiences. Thus, the goal was to describe how preservice teachers' experiences with inquiry influenced their constructions of inquiry.

Participants

Purposeful sampling of participants was used in this study, for as Miles and Huberman (1994) said, "You cannot study everyone everywhere doing everything,"

(p. 27). In typical qualitative studies, a researcher employs purposeful selection of participants in order to find a group that will best help the researcher understand his or her research problem (Creswell, 2003; Glesne, 1999). A large, urban university in the southeastern United States was chosen as the site of this study because the researcher was a graduate student and instructor there, allowing access to a group of preservice science teachers.

Graduate students enrolled in EDSC 6550 and EDCI 6600, courses in science teaching methods, were the source of participants for this study. These two courses were taught simultaneously. This course-sequence was chosen as a source for participants because it was the students' first science methods courses and they were unlikely to have learned much about the process of SI. These students were working toward a teaching certificate in grades 6-12 broad field science, a Master's degree in education, and initial licensure. Two professors from the science education faculty and four doctoral candidates in science education taught EDSC 6550, Principles of Science Instruction, and EDCI 6600, Introduction to Secondary Teaching. The courses met for 7 hours, twice a week, for 6 weeks. Four to six participants were needed for this study in order to yield sufficient but not overwhelming data. Additionally, participants who were novice learners who knew little about SI or physics were desired. Selection criteria were used to narrow the possible participants from the 17 students enrolled in this class to the four to six novice learners desired for this study.

The first selection criterion was that the students had no teaching experience because it was likely that a practicing teacher would have encountered the subject of SI before. Nine of the 17 students were teaching science in public or private schools with a

provisional certificate and did not meet the first criterion. One student was not teaching currently but had taught in the past. Seven students had no teaching experience and were possible participants.

The second selection criterion was that students had little physics content in their educational background because content weakness in physics was more likely to make the inquiry activities novel for them. Novelty of the activities was important because the participants were doing these activities on 3 successive days. The time between activities allowed participants to process the problems outside of class. If a participant were to solve the problem on the first day, it would prevent their need to process the activity outside of class. Processing each activity outside of class was of interest to me; therefore, it was best that students solved each problem through reasoning and experimenting. Six of the seven students fit this criterion.

The third criterion was that participants volunteer to be in this study. Of the six students who matched criteria one and two, only five volunteered to participate. Therefore, these five students became the participants in this research study. The five participants were female. Participants chose the pseudonyms of Noemie, Tracy, Pearl, Mischa, and Anna to be used instead of their actual names.

Noemie had a B.S. in physiology. She was employed as a physical therapist's aide. She had no prior teaching experience but wanted to enter the teaching field because she enjoys working with students and is interested in coaching sports. She had little lab experience, although she assisted in the preparation of materials for one experiment at her undergraduate institute. She did not turn in her final VOSI-M form; therefore, this was missing from her data.

Tracy had a B.S. in biology. She was a substitute teacher for 2 years. She had some undergraduate research experience but most of it was procedural lab work. She had a very busy schedule, and it was difficult to find interview time. She was also absent from class one day. Therefore, her data was missing one day of the pendulum work and one personal interview.

Pearl had a B.S. in animal science and spent 1.5 years in veterinary medicine school. She had experience with research that was directed by others. She had no experience teaching. However, she had taught Bible study classes and had some idea about planning lessons and time management. She was absent on the first day of the circuit tasks; therefore her data were missing one day of the circuit tasks.

Mischa had a B.S. in animal science. She had worked at an animal hospital, in a microbiology laboratory, and as a substitute teacher for one semester. Additionally, she taught science to fifth graders during one semester of her college career. Mischa was studying teaching to show other students how interesting and important science can be. Although she had some teaching experience, she had no formal research experience and stated that most of her labs in college were procedural.

Anna had both a B.S. and M.S. in chemistry. She had significant experience doing authentic research and had some of her Master's research published. While working on her Master's she taught 10 hours a week in a local, urban high school for one year. Anna enjoyed this experience and enjoyed helping undergraduates in her lab more than she enjoyed doing research. Thus, she decided to become a teacher.

Description of the Inquiry Experience

The inquiry experiences lasted 5 of the 6 weeks that EDSC 6550 students were in the classroom. The experience consisted of answering an inquiry questionnaire (VOSI-M) with follow-up interviews at the beginning and end of the course, performing two inquiry activities modeled after the microgenetic method, and reflecting on these activities. Additionally, participants were interviewed about their personal experiences and shared their class reflective journals with me.

The microgenetic method was used to create the inquiry activities in this study. In previous microgenetic studies, students were presented with a problem and a variety of materials that were used to solve that problem. Pre- and adolescent students were usually the subjects of microgenetic studies and they worked on one inquiry problem. In this study two inquiry problems were provided because these participants are adults and it was likely they would understand the inquiry problems much faster than children. A second reason for two problems was this study focused upon SI rather than the acquisition of science content, therefore more exposure to different SI problems was beneficial for this focus. Finally, it was crucial that the participants remained stimulated by the inquiry activities, for as Dewey (1938) stated, “the most important attitude that can be formed is that of a desire to go on learning" (p. 48).

I believed there was some overlap between SI experienced by the participants and the methods used to collect data. For example, the VOSI-M questionnaire and follow-up interviews were both a method and an experience. VOSI-M was intended as a method to collect data about participants’ understandings of inquiry. However, I thought that completing the questionnaire and follow-up interviews would become part of the

participants' SI experience because both might cause them to think more about SI than they would have without completing VOSI-M.

An overview of when and what the participants experienced is found in Table 2. This overview is not a timeline of data collection.

The inquiry problems in this study were physics problems about pendulums and electrical circuits**.** Because reflections, VOSI-M, and follow-up and personal interviews were done on an individual basis and because microgenetic studies involve students working individually, students worked individually for each of these activities. The pendulum problem was selected for its simplicity in design and materials and because previous research studies which used pendulums as part of their teaching methods have successfully taught pre- and in-service teachers about NOS (Connor, 2005; Gess-Newsome, 2002). As described in Chapters 1 and 2, I created inquiry problems similar to those that middle or secondary students might encounter in a science classroom. Additionally, the activity had to be repeatable and have several variables that students would expect to affect the outcome. For example, the students might expect that the mass of the weight, the mass of the string, the type of string, the size and/or mass of the bob, or the position where the swing is started would affect the pendulum. In reality, the length of the string was the only possible variable affecting the motion of the pendulum.

The students were shown a simple pendulum, and the pendulum period was defined. They were asked to write down how they believed the pendulum operated. Next, they were presented a variety of materials, which included various types of string (heavy clothesline, hemp string, yarn, and fishing line), multiple types of weights (washers and

Table 2

Schedule of Participants' Inquiry Experiences

Class Meeting	Description of Activity	Interviews
1	VOSI-M Demographic survey	
2	Pendulum inquiry problem Reflection one	
3		Completion of VOSI-M follow-up interviews (Outside of class)
4	Pendulum inquiry problem Reflection two	
5	Pendulum inquiry problem Communication of results Reflection three	
6	Circuit inquiry problem Reflection four	
7	Circuit inquiry problem Reflection five	Completion of pendulum experience interviews (Outside of class)
8	Circuit inquiry problem Communication of results Reflection six	
9	Fill out VOSI-M forms	
10	Discussion of inquiry	
11		Completion of VOSI-M follow up interviews and circuit experience interviews (Outside of class)

nuts of various sizes and masses), scissors, metric rulers, a balance, protractors, and stopwatches. There were three separate pendulum tasks with which students worked (see Appendix A). The first task had two parts: to create a pendulum with the fastest possible period and to create a second pendulum with the slowest possible period. This task was given on the first day of the inquiry experience. Students worked at their pace to complete the task and once they were satisfied that it was completed, they were given the

second task. The second task was to determine experimentally the mathematical relationship between the variables that affect pendulum period. When they finished the second task, they moved to the third task. The third task was to design an inquiry lesson using the materials and information gathered during tasks one and two. Students were given 45 minutes each day to work on the tasks. At the end of the 45 minutes, they were given 15 minutes to complete a set of reflection questions (Appendix A).

The second inquiry problem involved electrical circuits because, as with the pendulum problems, the problem requires simple supplies and has multiple variables. Furthermore, circuit problems are likely to be found in secondary and middle school science classrooms. The idea was copied from the *Minds of Our Own* video series produced by the Harvard-Smithsonian Center for Astrophysics (1997) project and from The UCI Summer Science Institute’s website about electric circuits (Simpson, 1999). In the *Minds of Our Own* video, science students and random adults were surveyed and asked to light a light bulb using only one wire, a battery, and a bulb. Although the materials are simple, the task is difficult because the circuit must be closed and lined up in a very specific way. The UCI website about circuits contained multiple examples of simple, parallel, and series circuits and provided the idea that led to the creation of the specific inquiry tasks that will be presented to the preservice teachers.

For the circuit problem, there were four tasks that could be completed (see Appendix B). The materials provided were flashlight bulbs (typically 1.5 – 3 volt), AA, C, and D batteries, rolls of insulated conducting wire of various sizes, wire stripper/cutters, and electric tape. In the first task, the participants were instructed to light the bulb using one battery. Once the bulb was lit, the second and third tasks required the

use more than one battery to light the bulb at the same brightness as they saw previously and to light the bulb at twice the brightness as they saw previously. If time allowed, the fourth task had students design an inquiry lesson for the classroom using these materials. As with the pendulum problem, students worked individually to complete the tasks and moved through the series of tasks at their own pace. The variables that affected the lighting of the bulb were the location of the bulb in relation to the battery, where the bulb and wire are connected, where the bulb and battery are connected, and how the batteries are connected (in series or in parallel). Because this problem is more complex and has more variables than the pendulum problem, it was the second inquiry activity with which participants engaged.

These inquiry tasks were designed by modeling the structure of microgenetic studies. Previous microgenetic studies of adults used uneducated adults (no college or community college) and made the assumption that they and the preadolescents started out at fairly similar points in their abilities (Kuhn, 1995; Schauble, 1996). In this study, the participants have a college diploma in a science field. It is likely they have more advanced abilities than the adults studied in Kuhn et al. (1995) and Schauble (1996). There is little evidence of how adults having a college education might respond to the microgenetic method; thus, these participants might not have shown the gains in understanding and abilities demonstrated in previous studies.

Data Collection

Multiple types of data were used in this research study. These data came from a demographic survey, VOSI-M questionnaires with follow-up interviews, students' notes of their experiments, personal interviews of students about their experience, reflective

journals of students, and my observations. Multiple methods of data collection were preferable because it made the data more trustworthy (Glesne, 1999). Multiple sources provided opportunity for triangulation and allowed each set of data to confirm, deny, or corroborate the other sets (LeCompte & Schensul, 1999). Further, triangulation meant each research question was answered by more than one data source.

Data was collected over the 6-week period corresponding to the time the preservice teachers were enrolled in class. The demographic survey, reflection questions, time for reflection, and VOSI-M questionnaires were given to all 17 students during class time. All interviews with participating students were conducted outside of class in my office on campus. All interviews were audiotaped and transcribed. The timeline of data collection is found in Table 3.

Table 3

Data Collection

Class Meeting	Data Collection
1	Participants answer VOSI-M and demographic survey
2	Reflection 1
3	VOSI-M follow up interviews
4	Reflection 2
5	Reflection 3
6	Reflection 4
7	Reflection 5; completion of pendulum problem personal interviews
8	Reflection 6
9	VOSI-M
10	No collection
11	Completion of VOSI-M follow up interviews; completion of circuit problem personal interviews

Demographic Survey

Participants completed a short survey to provide information about their educational backgrounds; previous science courses; research experience; and prior teaching experience. The demographic survey is found in Appendix C. The survey was completed on the first meeting of class.

VOSI-M Questionnaire and Follow-up Interviews

An open-ended questionnaire was given to participants to assess their understandings of SI. The open-ended nature allowed participants to answer freely rather than choose a researcher-designed answer. After completing the questionnaire, participants were interviewed to clarify and elaborate their answers. This was a structured interview in which participants explained their answers to the questionnaire.

This questionnaire was created using questions from two previously developed questionnaires: Views of Nature of Science, form C (VNOS-C) and Views of Scientific Inquiry (VOSI). VNOS-C had 10 questions (Lederman et al., 2002) and VOSI had 9 questions (Schwartz et al., 2001). Questions from VNOS-C and VOSI were used to create a modified version of VOSI called Views of Scientific Inquiry – Modified (VOSI-M). VOSI-M contained 7 questions to ensure the number of questions would not overwhelm participants. Additionally, this allowed participants more time to answer each of the questions, encouraging deeper, richer responses. Question 1 was from VNOS-C and was chosen because it was the only question in VNOS-C related to experimentation that did not also appear on VOSI. The remaining 6 questions were taken from VOSI. They were chosen because they emphasized the following features of scientific inquiry: that there is no one scientific method, that there are multiple ways to conduct scientific research, that

the nature of observations and experiments, that the nature of data and evidence in experimentation, and what comprises scientific experiments. These features of SI are aligned with the understandings and abilities of SI discussed in Chapter 1. A copy of VOSI-M is found in Appendix D.

All students enrolled in EDSC 6550 and EDCI 6600 completed VOSI-M at the beginning and end of the inquiry experience. Because of the open-ended nature of VOSI-M, students were given as much time to answer as necessary. Each item was placed on a single sheet of paper to allow respondents enough space to write their answers, as recommended by Lederman et al. (2002). The instructor of the methods course (not me) administered VOSI-M to remove pressure participants may have felt from my doing so.

Follow-up interviews were conducted within 2 weeks following administration of the VOSI-M questionnaire. The follow-up interviews were structured and modeled upon previous research with VNOS-C and VOSI (Lederman et al., 2002; Schwartz et al., 2004). These interviews were a way of member checking to ensure that participants' written statements were aligned with their understandings of SI. Following the first administration of VNOS-C, researchers presented participants with their answers and asked them to read, explain, and elaborate their responses. They asked participants if their beliefs were different from what was represented in their written answers. Lederman et al. (2002) asked respondents questions to clarify ambiguities, explore participants' lines of thinking, and assess the meaning that respondents ascribed to terms and phrases. Through these techniques, each set of researchers clarified responses and identified any misinterpretation of questionnaire items to represent faithfully participants' understandings of NOS (Schwartz et al., 2004). These established methods of conducting

follow-up interviews to VNOS-C and VOSI were used as a model in this study after administration of VOSI-M. Each participant in this study was interviewed about her answers to VOSI-M and each interview was tailored to the answers that were given on each participant's questionnaire.

Follow-up interviews were conducted after the second administration of VOSI-M to elaborate upon participants' changes in their understandings. The first follow-up interview lasted approximately 30 minutes and was only about VOSI-M. The second follow-up interview lasted approximately 60 minutes and occurred concurrently with the second personal interview. Schwartz et al. (2004) asked participants to describe or elaborate any changes they believed had occurred in their understandings of scientific inquiry and to provide examples to which they attributed these changes in understanding. This method of follow-up interviews described above, taken from Schwartz et al. (2004), was used in this research study as the method of interviewing participants after answering the VOSI-M questionnaire.

I expected that the VOSI-M questionnaire and follow-up interviews would contribute to this research study in another way. I expected that answering the questions and elaborating during follow-up interviews would comprise part of the participants' experience. I believed answering questions and discussing concepts associated with SI would make participants more aware of certain characteristics of SI

Student Notes

Another data source was the notes participants took while experimenting and trying to complete each task. For each task, all students received a packet of paper. At the top of the first page was the task. At the bottom of the first page were two questions

asking participants how they thought they could solve each problem. The first question asked participants what they believed they would need to create the appropriate pendulum or circuit. The second question asked participants to draw or explain their first experimental design. The following pages had much space to record data and prompting questions such as, “What did you find out from your first experiment?” “Did the data correspond to your initial ideas?” and “What will you try next?” Postactivity questions were on the last page of the packet. These were different than the reflection questions because they focused on the experiments participants conducted. Examples of the postactivity questions include: “What have you found out today by experimenting?” “What did you collect as data?” “How did you modify your activity?” These participant notes were a valuable source of data.

Asking participants pre- and postactivity questions followed Kuhn’s (1995) microgenetic method. In this study, the first two questions assessed participants’ knowledge before they began experimenting. Additionally, before students began working with the pendulums or circuits on the first day, they were shown a pendulum and circuit and asked what variables they believed made each work. This is similar to Kuhn et al. (1992), who asked their subjects to articulate their theories of why or how something will work and to indicate which features of the problem would affect the outcome and which would not. Although this was done verbally with Kuhn’s participants, that was not feasible in this study. Therefore participants were asked to write down their theories of what variables affected the task before they began the task. Postactivity questions were provided in this study to assess what participants had learned. Again, this was modeled

on Kuhn’s work because her participants had to interpret the outcome of their experiments and explain their conclusions.

There were two additional reasons to provide participants with structured worksheets. The first was to prompt participants to keep notes because it was possible if they did not have questions to answer they would not take many lab notes and provide little data. The second reason was that all students worked at their own pace on the tasks. Because students work at different paces, they needed to be able to begin the next task without waiting for those who were not finished. In this way, students who finished would turn in one task packet and pick up the packet for the next task.

Personal Interviews

Another method of data collection was personal, open-ended interviewing because it provided access to the context of behavior and allowed me to understand the meaning of behavior (Seidman, 1991). Furthermore, conducting interviews helped me understand the experience of participants and the meanings they construct from that experience. Because this research problem involved understanding participants’ descriptions of their experiences with SI and how these experiences affected their understandings and abilities of inquiry, personal interviews were a valuable source of data.

In addition to the follow-up interviews that occurred with the VOSI-M questionnaire, participants were interviewed twice to discuss their inquiry experiences and to assess their understandings of SI. These are referred to as personal interviews. The first personal interview was conducted following the conclusion of their first inquiry problem, and the second personal interview followed the conclusion of the second

inquiry problem. The personal interviews provided insight into the ways the SI activities influenced or changed participants' understandings and abilities of inquiry. Finally, the personal interviews provided information about the ways these preservice teachers might use inquiry activities in their future classrooms.

Although there were some structured interview questions, some questions were generated from my observations of and participation with the participants' inquiry activities. Other questions arose spontaneously during the course of the interview. The structured personal interview questions are found in Table 4 and are related to this study's two research questions. Participants also answered questions that emerged in the course of the personal interview such as, "why did you find that activity to be so frustrating?"

Participant Journals

Gess-Newsome (2002) found journaling was an effective tool in explicitly teaching NOS and SI; therefore, it was used in this study to make participants' aware of their experiences with inquiry and to help me understand participants' experiences with inquiry. Three elements of the reflection process, returning to the experience, attending to feelings, and re-evaluating the experience, were guidelines used to create reflective questions for the participants (Boud et al., 1985). All students in the class were provided reflection questions at the end of each inquiry activity. Given the personal nature of journaling, participants did not have to answer all reflection questions, they could have been resistant to the reflection process, or they may not have reflected deeply about their experiences. Thus, quality of answers varied between participants. This study yielded six

Table 4

Post-activity Interview Questions

Interview Question	Related Research Question
1. How do you think the activities we did in class were similar to scientific inquiry? How were they different?	1. How do preservice science teachers' describe the experience of repeated, guided inquiry activities in their coursework?
2. Do you believe the activities we did in class changed your understanding of inquiry? If so, how?	
3. Do you believe the activities we did in class changed your abilities with inquiry? If so, how?	
4. If you think your abilities and understandings of inquiry changed over the course of this class, to what factors do you attribute these changes?	
5. Did you learn anything from the inquiry activities that you might use in your classroom?	
6. How did your ideas about the pendulum/circuit change over time? Why did they change?	
7. How did you change your design or approach to each activity as you encountered it repeatedly?	
8. What was your overall opinion of the pendulum/circuit inquiry task?	
9. What did you think about having to work with the pendulum/circuit on 3 different occasions?	
10. How did having to write down your ideas about your experiments affect you?	
11. Do you think your skills at running an experiment got better over time when you worked with the pendulum?	
12. What do you think comprises the enterprise of scientific inquiry?	2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?
13. Do you think there are skills or abilities required to conduct scientific experiments? If so, what are they?	
14. Do you think you have the abilities needed to conduct scientific inquiries?	
15. Did you learn anything from the inquiry activities that you might use in your classroom?	
16. What is your overall opinion of science inquiry?	

reflective journal entries from Noemie, Mischa, and Anna and five reflective journal entries from Pearl and Tracy, who each missed one day of class.

In a study involving students who kept journals, students liked having assigned questions to answer but also wanted to be able to write in an open-ended manner (Corley, 2000). Students appreciated having some guidance to their reflections but also liked the opportunity to respond freely. Thus participants answered a set of prompting reflection questions but were encouraged to reflect openly at the end of each set of questions. The reflection questions were given on a handout at the end of each inquiry activity. Participants had approximately 15 minutes in class to answer the questions. Reflection questions and their associated research question are found in Table 5. Additionally, the day(s) each reflection question was asked is provided.

Observation and Field Notes

In this study, I used field notes as a recording tool (Glesne 1999). Field notes include descriptions of people, objects, events, activities and conversations as well as my ideas, reflections, and noted patterns (Bogdan & Biklen, 2003; Glesne). They are a written account of what the researcher experiences, observes, and thinks as he or she collects data in the study (Bogdan & Biklen). Microgenetic researchers keep field notes by making close observations with explicit details of students' actions as they engage in activities (Kuhn et al., 1992; Schauble, 1996). Thus in this study, I kept field notes based upon observations of the participants' inquiry activities.

Abilities of SI were difficult to assess in written forms such as the VOSI-M questionnaire and the reflective journal, thus field notes corroborated written data. Observations were made of the ways in which students approached the inquiry tasks,

Table 5

Reflection Questions for the SI Activities

Reflection Question	Day Asked
Research Question 1. How do preservice science teachers' describe the experience of repeated, guided inquiry activities in their coursework?	
1. Would you say your approach to today's activity was successful or not? Why or why not?	Pendulum Day 1 Circuit Day 1
2. Did having time away from the problem help you in doing today's experiments? If so, how? If not, why not?	Pendulum Day 2 Circuit Day 2
3. How has having to think through your theories about the pendulum/circuit affected the way you worked on the pendulum tasks?	Pendulum Day 3 Circuit Day 3
4. What is your opinion about having experience with the pendulum/circuit on 3 separate occasions?	Pendulum Day 3 Circuit Day 3
5. Did you think about the tasks between class meetings? If so, what did you think about?	Pendulum Day 2 Circuit Day 3
Research Question 2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?	
6. If you were to try this activity again, what might you try next time?	Pendulum Day 1 Pendulum Day 2 Circuit Day 1
7. What conclusions did you draw from your experiences with today's activity?	Pendulum Day 1 Circuit Day 1
8. What ideas have you taken from the pendulum/circuit tasks that you might use in your science classroom?	Pendulum Day 3 Circuit Day 2
9. Did you learn anything about how to conduct an inquiry today?	Pendulum Day 1 Pendulum Day 3 Circuit Day 1 Circuit Day 2
10. What did you learn today about inquiry?	Pendulum Day 2

changes in their understandings of inquiry, and their abilities at doing inquiry. Four participants worked at one table and I could observe these four simultaneously. However, Tracy sat at a table with nonparticipants and, to observe her, I had to move away and

miss what the other four were doing at that time. The observations lasted for the entire 45-minute inquiry activity.

Jotted notes were taken in class to keep track of observations. These notes were key words and phrases written down at the time of observation to help remember a description or thought when the notes were later written (Glesne, 1999). Jotted notes were kept to allow me to walk around during activities, interact with students, and make thorough observations of each student without being distracted by keeping detailed notes. Immediately after conclusion of the activity, I went to an empty corner of the classroom to type the field notes in as much detail as could be remembered, using the jotted notes as a reference and guide.

Data Analysis

Collected data were coded and analyzed using a start code and chronological data matrices (Miles & Huberman, 1994). Miles and Huberman recommended that when using codes, the researcher should begin with a “start list” of codes before beginning the research (p. 58). Furthermore, the start code should be dynamic and only a suggestion of codes for the data. As new ideas and themes emerge, they should be added to the start code, or the initial codes should be modified. Data should not be made to fit the start code; rather, the start code should guide data analysis.

Based on this recommendation, a detailed list of start codes was generated from the understandings and abilities of SI described by NSES and by NOS and SI research. This elaborate start code was used to code data collected in a preliminary study with undergraduate preservice teachers doing SI activities. However, some of these codes were not used at all, and others emerged throughout the analysis process. Essentially, the

code was too restrictive and was modified to three broad areas: understandings of inquiry, abilities of inquiry, and implications of inquiry in the classroom. This broader start code was used in a second preliminary study where one preservice science teacher completed SI activities, and the data collected was coded successfully with the three codes. Based upon these preliminary studies, in this research study I used the three broad codes discussed earlier.

Although initial coding involved a start code of three codes, as coding began, it became clear two more codes were needed. Although science content knowledge was not a focus of this study, participants demonstrated knowledge, or lack of knowledge, throughout their experiments. Participants also expressed feelings, such as anger and joy, as they conducted their SI experiments. Thus participants' personal feelings about the SI experiences and science content knowledge were added as codes. These five codes were used to code all data collected.

After coding with the five codes was completed, the codes were organized into a chronological data matrix. Miles and Huberman (1994) described a chronological data matrix as a data organizer that crosses two lists. In this study, it was a list of the five codes and a list of the activities ordered in a time sequence. Summaries from participants' written statements, interview transcripts, and researcher's notes that were associated with each of the five codes were placed in the matrix. For example, Noemie's initial VOSI-M indicated she believed scientists are creative. This represented an understanding of SI and was thus placed in the box that intersected the area of VOSI-M with understandings of SI. A data matrix was constructed for each of the five participants, and these matrices are presented in Chapter 4.

Lincoln and Guba (1985) stressed that during data analysis, categories should be identified and units or incidences should be assigned to each category. In this study, the categories were the five codes and were referred to as domains (Lincoln & Guba). Thus the five domains were understandings of SI, abilities of SI, personal reflections, classroom application, and science content knowledge. Within each of the domains were individual units of data that were organized in the data matrices, allowing the researcher to look for patterns and themes across the individual units. Individual units that were repeated across participants were termed themes. The identified themes were used to paint a picture of the inquiry experience for the preservice teachers and to identify their understandings and abilities of SI based upon their experiences with SI.

Final analysis occurred within the domain of understandings of SI. I linked the individual units with understandings of SI as reported in the literature and described in Chapter 1. If a unit corresponded with an understanding found in the literature, it was labeled advanced. If it did not correspond, it was labeled naïve. For example, two participants did not distinguish between data and evidence at the end of the study. This was labeled as a naïve understanding because Schwartz et al., (2001) claimed there is a distinction between data and evidence.

Trustworthiness of Qualitative Research

In this study, four criteria were followed to ensure the trustworthiness of this qualitative research (Guba & Lincoln, 1994). These four criteria were credibility, dependability, confirmability, and transferability. Credibility ensured that the descriptions put forth by the researcher on the part of the participants were accurate, or credible, with the constructions the participants held (Guba & Lincoln). In this study, methods of

insuring credibility were triangulation of data, member checks, and clarifying and making explicit researcher bias (Creswell, 1998; Glesne, 1999). Taking data and data analyses back to the participants so they could determine if the analyses were accurate was member checking (Creswell). This was done in the VOSI-M follow-up interviews. Participants also reviewed and corrected the typed transcriptions of their interviews. Triangulation involved the use of multiple forms of data in order to increase confidence in research findings (Glesne). It was used in this study through the use of questionnaires, participants' experimental notes, follow-up and personal interviews, reflective journals, and researcher's observations. Additionally, triangulation of data occurred through the use of data matrices, which were used to analyze data across all participants.

Lincoln and Guba (1985) likened dependability to consistency and replicability in quantitative research. Although qualitative research cannot be replicated because of the nature of humans and human interactions, dependability can be ensured if the researcher looks for consistent themes across multiple sources of data. In this study, triangulation of data in the form of questionnaires, participants' experimental notes, follow-up and personal interviews, reflective journals, and researcher's observations was a measure of dependability.

Ensuring confirmability in qualitative research is similar to maintaining objectivity in quantitative research (Guba & Lincoln, 1994). Essentially, confirmability involves examination of the data to be certain that the data presented is accurate. Member checking, triangulation, and audio-taping of all interview sessions were methods that ensured the confirmability of the data collected in this study.

Guba and Lincoln (1994) described transferability as similar to generalizability in quantitative research; however, unlike quantitative studies, clear generalizations cannot be made in qualitative research. Although the results of this study were not generalizable to all preservice science teachers taking methods courses, the results of this study may be transferable to studies with similar methodology. Transferability in this study was demonstrated by thorough descriptions of each participant's background and their individual experiences with SI.

Prolonged engagement with participants is another method that contributes to the trustworthiness of qualitative inquiry (Guba & Lincoln, 1994). Prolonged engagement involves the investment of sufficient time to gain an understanding of a culture or group. This can build trust and rapport with the participants and helps to ensure the accuracy of the data. The duration of this study was 6 weeks, and although it yielded sufficient data, I did not follow these students into their middle or high school internships. Thus, a limitation of this research study is that I was not engaged with participants for the duration of their graduate program. As such, the participants did not develop as deep a rapport with me as they might have in a 15-week semester course. That sort of prolonged engagement would build more trust into the data collected, but it was not feasible for the purpose of this study.

Human as Instrument

One of the characteristics of conducting qualitative research is that humans serve as the instruments of data collection. The quality of interactions of the researcher with the participants influences the nature of the relationships built between the researcher and participants (Glesne, 1999). The building of this relationship is termed "rapport," and it

serves as a trust-building mechanism that can result in rich data (Glesne). I interacted with students in this class to build rapport that might encourage participants to share and be honest about their descriptions of their experiences with SI. For example, Noemie came to my office on several occasions to discuss a class project and difficulties in another class. This demonstrated that she trusted me, and her doing so may have led to her being more open in answering personal interview questions.

My role in this research study was as a researcher and instructor in the methods class and as an observer of the inquiry activities. I was an instructor in EDSC 6550 and EDCI 6600, but I was not the instructor who facilitated and taught the inquiry activities. All students in the class were expected to participate in the inquiry activities as part of their class work. However, participation in this study did not affect the participants' grades because I was not responsible for assessing the inquiry portion of the class.

Being a human instrument required that my role and bias be elaborated. Recognition of bias demonstrates the researcher is aware of beliefs that might influence analysis of data and keeps the resulting narrative open and honest (Creswell, 1998). As Glesne (1999) stated, "every time you decide to omit a data bit as unworthy or locate it somewhere, you are making a judgment" (p. 134). Because these judgments are dependent upon the researcher and will influence how the data is analyzed and interpreted, the researcher must understand his or her bias when considering how to interpret the data (Bogdan & Biklen, 2003). One area of bias in this study is in regards to SI. Before beginning this study, the researcher believed engaging in inquiry makes a person's understandings of inquiry increase and that having experiences with SI would help preservice teachers recognize the benefits of using SI in their classrooms. Because of

these beliefs, the researcher was aware of this bias when analyzing data to prevent attribution of understandings or abilities of SI to participants when no such understanding existed.

Finally, because of bias and time between data analysis, it is possible the researcher's coding scheme did not remain consistent throughout data collection. A colleague in science education coded a portion of the data with the five start codes to be certain the researcher's coding scheme stayed constant. Overall, her coding was consistent with the researcher's coding, suggesting the researcher maintained the coding scheme throughout data analysis..

Summary

This research study was a qualitative exploration of preservice science teachers' experiences with scientific inquiry activities. The study examined preservice science teachers' descriptions of their experiences with SI and the understandings and abilities of SI that were demonstrated by the participants. Specifically, it was a case study in which the case was the overall inquiry experience and the individual units of analysis were preservice science teachers.

There were five female participants in this study who were graduate students enrolled in a science methods course. Participants experimented with two sets of physics problem in their methods class. In one set of problems, they determined the period of a pendulum, and in the second problem, they created electric circuits from light bulbs and batteries. Data were collected from an open-ended questionnaire, participants' lab notes, interviews, journals, and researcher observations. The data were categorized with a start code and organized into chronological data matrices. Data were analyzed to describe

participants’ understandings and abilities of inquiry and how participants described their experiences with SI.

CHAPTER 4

RESULTS

Introduction

The results of a research study of preservice science teachers' experiences with repeated scientific inquiry problems are presented in this chapter. Five preservice teachers worked with two SI problems while enrolled in a 6-week science teaching methods class. The focus of this study was their experiences with SI. This study was guided by the following research questions:

1. How do preservice science teachers describe the experience of repeated, guided inquiry activities in their coursework?
2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?

The results are presented in three sections. The first section examines the understandings and abilities of SI identified in the study. The second section summarizes each participant's experiences with SI during the 6-week course. The final section introduces other themes about SI that emerged in the study.

The study's participants experienced SI through a set of tasks and guided reflection that were described in Chapter 3. However, they were also exposed to SI through nature of science conversations, an article about the forms of SI in the classroom, a video program, *A Private Universe* (Harvard-Smithsonian Center for Astrophysics, 1987); and an article about converting cookbook labs into inquiry labs. Additionally,

participants may have learned about SI in other classes that were outside the control of this research project. Therefore, it is possible that factors besides the SI tasks and reflections may have influenced participants' views of SI. Although I attempted to gather information related to students' tasks with SI and use that as the frame of reference, I cannot claim that the outcomes presented here are only the result of the participants' experiences with SI tasks and reflections done in the course of this study.

Five domains were identified in this study based upon analysis of the collected data and start code. Chapter 3 discussed the coding of the data that led to these five domains, which are understandings of SI; abilities of SI; personal feelings about the SI experiences; SI in the classroom; and science content knowledge. Within each of the domains, themes were identified and are discussed in this chapter and Chapter 5.

Understandings and Abilities of Scientific Inquiry

This section addresses the second research question about the participants' understandings and abilities of SI throughout their experiences with SI. The understandings and abilities of SI discussed in Chapter 1 represent advanced views of SI and were compared to the participants' understandings and abilities of SI. The understandings are that there is not one scientific method; that investigations are part of research; knowing what is involved in designing and conducting SI; that data collection and analysis have limitations; recognizing alternate explanations; understanding controls and variables; knowing the difference between data and evidence; understanding evidence and explanations are related; and that communication is necessary in science (Schwartz et al., 2001). The abilities of SI are identifying questions to investigate, designing and conducting SI, using technology and mathematics in SI, formulating and

revising scientific explanations, recognizing alternative explanations; and communicating scientific knowledge (NRC, 1996). The following is a discussion of the themes that emerged within the domains of understanding and abilities of SI.

Understandings of SI

VOSI-M was the instrument used to assess participants' understandings of SI. While it was a useful assessment instrument, the understandings of SI found in it were embedded within the framework of NOS. Essentially, VOSI-M is about the way scientists do SI rather than understanding the way SI might look in the classroom. However, the understandings shown by participants dealt with the classroom. This is not surprising because the activities done in class were modeled after activities that might be done in a classroom, not after what scientists do in labs. The understandings that dealt with classroom applications of SI were placed under the domain of classroom application, which is discussed later in this chapter.

At the beginning of the study, participants showed primarily naïve understandings of SI as it is conducted by scientists. For example, all participants wrote in VOSI-M and stated in the follow-up interview there is one scientific method. By the end of the study, the participants demonstrated a mixture of advanced and naïve understandings of SI. Only one participant consistently demonstrated advanced understandings. Because of the general lack of understanding, only three advanced themes of understanding were identified in the participants by the end of the study.

The first theme is that scientists are creative in conducting SI. All participants demonstrated this advanced understanding of SI before they had experiences with SI; thus, participants' experiences with SI did not advance this understanding. For example,

Anna wrote, “[Scientists] need to think outside the box and get creative” (VOSI-M Pre-survey). Noemie wrote, “Imagination and creativity are key to finding new information, phenomenons and ideas” (VOSI-M Pre-survey). At the end of the study participants wrote that scientists are creative; thus, although they demonstrated an advanced understanding of SI, their understandings did not change over time.

The second theme is understanding that controlling variables leads to more accurate experiments. As participants began working on their SI tasks, they did not control variables. However, over time they began controlling variables and all wrote or stated they understood the importance of controlling their variables. For example, Pearl wrote

> I would next time have the same mass on two separate weights, which would test one variable in the experiment, the length of the string. I had so many variables that could have affected period of the pendulum. (Pendulum Reflection Two)

Thus, this understanding changed from naïve to advanced in all participants over time. For all participants, this understanding was related to their experiences conducting SI.

The third theme is understanding that the scientific method is not a rigorous set of steps all scientists follow. Based on their answers to VOSI-M survey before their SI experiences, all participants believed there is a general set of steps scientists use to conduct SI. This is a naïve understanding of SI. For example, Pearl wrote, “There is a basic format that is followed” (VOSI-M Pre-survey). Even Anna, with her experience conducting research, wrote

> Yes, there is one general set of steps, but not all steps are used all the time. 1. Form hypothesis. 2. Design experiment. 3. Carry out experiment. 4. Record observations. 5. Draw a conclusion (VOSI-M Pre-survey).

In addition to Anna, Tracy, and Noemie answered this question with a step-by-step method.

In VOSI-M Post-survey, three of the five participants changed their understanding to a more advanced view, with one participant not assessed on this view. Anna, Tracy, and Mischa believed scientists do not follow a rigid step-by-step procedure always. For example, Tracy wrote

> Some scientific methods follow rigid steps. . . . Other experiments involve more observation than procedure and other experiments mix up the steps. (VOSI-M Post-survey)

Thus, she began to demonstrate an understanding that not all experiments are conducted with one specific scientific method. Pearl did not change her understanding of the scientific method. Noemie did not answer the VOSI-M Post-survey, so any change in her understanding of the scientific method was not assessed. Table 6 presents the understandings demonstrated by participants in this study. These are the understandings demonstrated by participants at the end of the study and found in the second VOSI-M questionnaire and their second interview. Each understanding was compared to the understandings put forth by Schwartz, Lederman, and Thompson (2001). Understandings that were not aligned with these understandings were labeled as naïve (N), and understandings that were aligned were labeled advanced (A). The understandings found in this table were not demonstrated by all participants, but were shown by at least two.

Abilities of SI

As participants worked with the SI tasks, they demonstrated varying abilities of conducting SI, and several participants' abilities changed over time. These abilities emerged from my observations and through participants' written lab procedures, reflective journals, and course journals. Several abilities were in place in all participants

Table 6

Understandings of SI Demonstrated by Participants

Participants' Understandings of SI
Scientists follow specific procedural steps (N).
Scientists might not use these steps always (A).
Scientists are proving things (N).
Scientists change their experimental designs based upon evidence that emerges (A).
Scientists have beliefs and opinions that may influence their data (A).
Scientists need analyzed data to draw conclusions (A).
Variables must be controlled (A).
There is a difference between data and evidence (A).
There is not a difference between data and evidence (N).
Scientists do not work alone; they share their work with others (A).
Scientists use creativity in SI (A).
Scientists need to keep accurate records (A).
SI is subject to human errors (A).
Scientists repeat their experiments (N).

at the beginning of the tasks and were maintained throughout their experiences. These included the abilities to identify personal theories of why or how the tasks work, to manipulate variables, to collect data, and to draw conclusions based upon data. However, three abilities emerged or improved over time in all participants. These themes were the abilities to control variables, to keep accurate records, and to modify experiments based upon the results of previous experiments.

The first theme was the ability to control variables. For example, Anna mentioned that when she started the pendulum task,

> I first started out trying to just hold the pendulum in the air and just swing it. And then I saw my arm moving all over the place, and I was, like, this is not going to work. Then I taped it to the side of the table, but I put the tape farther back from the edge of the table, so then the string was just moving all over the place. So then I put the tape right at the edge of the table so my length would be accurate. (Pendulum Interview)

This demonstrated her ability to control variables. Mischa began to control her variables on the second day working with the pendulum. She wrote,

> After thinking about my technique, I have realized I need to be measuring where I am holding each string and regulating the length of each period by timing the swing to the length of the ruler. (Pendulum Task One, Day Two)

Like Mischa and Anna, the other three participants began controlling their variables in similar ways during their pendulum tasks.

The second theme was the ability to keep accurate records. Noemie did not keep any records of her pendulum data for the first two days beyond a simple drawing of a bob at the end of a string. By the third day, she began keeping records of the mass of each bob, the length of the strings, and the number of seconds in each period (Pendulum Task Two, Day Three). In her initial SI tasks, Pearl also kept simple drawings of a pendulum with no records of how long the string was, the mass of the bob, or the time of each period (Pendulum Tasks One & Two, Days One & Two). By Day Three, she began to keep an account of how long the string was, although she did not keep a record of the time of the period. However, when she began working on the circuit tasks, she began to keep better records. Her drawings of her circuit set-ups were detailed, and she constructed simple data tables that told her which methods were successful and which were not (Circuit Task One, Day Two & Circuit Task Two, Day Three).

The third theme was the ability to modify experiments based upon the results of previous experiments. Initially in the pendulum tasks, several of the participants would test variables and their effects on the pendulum’s period but did not integrate their findings into their next experiments. For example, on pendulum day one, Pearl wrote, “when trying to maintain the same force on the pendulum the amount of time it took the

period time was the same" (Pendulum Task One, Day One). Even though she recognized that the force applied to the pendulum had no effect on time, she still tested the force variable on pendulum day two (Pendulum Tasks One and Two, Day Two). However, by the third day and task, she recognized that force did not play a role in the period (Pendulum Task Three, Day Three). Additionally, as she continued on to the circuit tasks, she modified variables based on her experimental results. When she found her first set-up did not work, she modified it in the next experiment. For example, in her first experiment with the circuit, she tried AA batteries and could not get the bulb to light, thus she modified her experiment by changing to size D batteries (Circuit Task One, Day One).

The SI abilities demonstrated by the participants at the conclusion of the course were (a) identified personal theories of why something worked and tested those theories, (b) manipulated variables, (c) controlled variables, (d) collected data, (e) kept accurate records, (f) drew conclusions from analyzed data, (g) used mathematics in experimental design and data analysis, and (h) modified experimental design through practice and data collection. While not all participants demonstrated these abilities, each was demonstrated by at least two participants. Further discussion of each participant's abilities with SI is found in the following summaries of each individual's experiences.

Participants' Experiences with Scientific Inquiry

In this section, data that were used to answer both the first and second research questions are presented through descriptions of each participant's experience. A chronological data matrix, as described by Miles and Huberman (1994), was used to organize and present each participant's data. The matrices also allowed for triangulation of data.

The five domains (understanding SI, abilities of SI, scientific knowledge, classroom applications of SI, personal reflections) identified in this study were placed along the top of the matrix. The sources of data collection and the inquiry experiences were placed along the left side of the matrix. These consisted of the VOSI-M Pre-survey; participants' notes and reflections from pendulum tasks for days one, two and three; the pendulum interview and class journal entries; participants' notes and reflections from circuit tasks for days one, two, and three; circuit interview, class journal entries, circuit interview, and VOSI-M Post-survey. The two research questions, with the study's working hypothesis that repeated exposure to SI activities would lead participants to a better understanding of and abilities to conduct SI provided a lens for analysis. Using these matrices, a story was constructed for each participant that told of her experiences with SI, her understandings and abilities of SI, and what she believed about SI after taking this methods course. A summary of each participant's background was found in Chapter 3.

Noemie's Experience

Noemie's experiences with SI were initially filled with frustration, but by the end of the 6 weeks, she valued inquiry and had hopes for using it in her classroom. The data matrix for Noemie is found in Figure 1. On her first attempt with the pendulum, she wrote, "I was doubting myself at first" because inquiry was new to her (Pendulum Reflection One). This doubt was reflected in the way she worked on the first task. She created two different pendulums (one with a nut and heavy string, the other with a washer and lighter string), trying to compare each of them at the same time, with little control of variables between the two. She believed pendulum period to be affected by the mass of

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-PRE & INTER-VIEW	-Identified her thoughts about what makes an experiment work.	-Scientists are creative. -One scientific method. -SI proves things. -Scientists get same results from the same tests. -Scientists get different results from diff. hypo. -Data & evidence are different. -Analysis is finding trends and patterns in data. - SI is systematic -Math is part of science.			
PEND 1 (Task 1)	-Identified variables. -No record keeping. -Some variable control -Changed experimental setup -Drew conclusions from data.	-Variables must be controlled	-Felt doubt because inquiry was new. -Felt curious -Inquiry makes her think -Enjoyed task.	-Believes this type of activity might be good in a classroom.	-Period affected by: Weight of bob String diameter String length
PEND2 (Task 1)	-Identified variables -Identified her theories of why something works. -No record keeping - Drew conclusions from data -Changed experimental setup.	-Human error occurs in SI. - Variables must be controlled. -Record keeping is necessary in SI.	-Thought about task outside of class. -Activity beginning to be repetitive.		-Period affected by: String diameter
PEND3 (Task 2)	-Identified variables -Controlled variables -Began record keeping -Changed experimental design	- SI is systematic process. -Variables must be controlled.	-Initially unsure of her procedures for task 2. -Task is frustrating by times 2 & 3. -Working in groups would be helpful.	-Repetition gets students to reflect and know what they understand. -Students should work in groups to share thoughts	-Mass does not affect period -Length does affect period.

Figure 1. Data matrix for Noemie.

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
INTER-VIEW 1 & JOURNAL	-Did not always control variables -Modified experiment based on data.	-Creativity is important in science. -Scientists start out with just questions.	-Initially interested. -Frustrated over time. -Too much repetition - would rather do all at once. -Thinking out ideas before task was helpful. -Liked the openness	-Would use guided inquiry. -Would use groups -SI is a way to introduce concepts.	
CIRCUIT 1 (Task 1)	-Identified her theories of how circuit works. -Drew conclusions from data. -Modified experiment	-Modify non-working designs -Variable position matters. -SI needs accuracy & precision	-Fun activity -Felt curious -Thought about safety as battery got hot.		-Understands circuit must be complete.
CIRCUIT 2 (Task 1, 2)	-Very specific order to circuit. -Identified theories of working in series. -Changed design to see if a different way will also work. -Little record keeping	-Observations as data.	-Appreciates SI -Reflection outside of class. -Time away gave fresh perspective	-SI will work well in classroom -SI gets students thinking -Group work may be helpful.	-Contact necessary to close circuit. -Series circuit will make 2X as bright
CIRCUIT 3 (Task 3)	-Identified theories of parallel -Drew conclusions		-Reflected outside of class -Thinking about ideas helped with tasks. -Class discussion of bulb decreased frustration		-Parallel circuit makes ½ as bright -Parallel diagram is really a series.
INTER-VIEW 2 & JOURNAL	-Manipulated placement of the wires. -Changed experimental design (battery upside down) -Said her skills got better through practice.		-Enjoyed circuit task. -Thought about circuits in between classes. -Doing the tasks got her comfortable with SI. -Initially frustrated with SI. -More engaged with activities.	-Will use SI -Inquiry gets students thinking. -Students may be initially frustrated. -Implementing SI may be hard. -Good way to introduce topics -Administration may not support SI.	-Understands complete circuits – parallel & series.

Figure 1. Data matrix for Noemie (continued).

the bob, the string diameter, and the string length. She did not write down the data from her tests with the pendulums. She changed her experimental design when she saw it was not working. Despite her initial doubt, she wrote in her reflection that "not knowing made me curious and wanting to know the answer," and this activity was "a good active-learning experience . . . inquiring myself makes me think more" (Pendulum Reflection One).

Between the first and second days of the pendulum, Noemie wrote, "I did think about this activity over the week. I am wondering . . . if my reasoning is correct" (Pendulum Warm-up Two). Thus, some processing of her actions in day one occurred between inquiry days, and it is possible this processing influenced her actions on day two. On the second day her frustration with this activity became apparent; when she finished the first task and was handed the second, she grimaced. As the first day, she did not record the results from her experiments. She was drawing conclusions based upon these data but not recording the data that allowed her to make those conclusions. Although her record keeping skills did not improve, Noemie did begin to control some variables as she tested one mass on different types of string, demonstrating an improvement in her ability to control variables.

Pendulum day three showed a great improvement in her ability to carry out a scientific inquiry through her control of variables and her attempts to carry out systematically her experiments. Noemie began by massing the bobs. She started the pendulums at the same point each time, measuring this point with the length of a ruler. She began keeping accounts of her data, the masses of the bobs, lengths of the string, angle of starting point, and the time it took each pendulum to swing. Like days one and

two, she modified her experimental design based upon the results she obtained. By the end of the day she had concluded correctly that mass does not affect period while string length does, although she still believed other variables to have an influence.

Throughout Noemie's reflections, lab notes, interviews, journals, and classroom comments, she expressed her frustration and annoyance with this activity. Although she was initially interested in the activity, by the second and third days she found it tiresome and repetitive. For example, she wrote, "I do think this pendulum exercise was interesting and challenging at first, but it is now becoming a little repetitive and less exciting" (Pendulum Reflection Three). Despite her boredom with the activity, her abilities at doing SI improved over the 3 days.

Noemie did not like working alone and believed working in groups and talking about results and ideas would have been beneficial. She wrote, "I think doing this in groups of two may be beneficial for me since I barely have any background information about inquiry. I feel that in groups, perhaps I would have a little more guidance, or reassurance, if I am doing the exercise the way I am supposed to" (Pendulum Reflection Three). Despite these comments, at the conclusion of these 3 days she seemed to believe that using guided SI in the classroom through group work would be a valuable tool in the classroom. Additionally, she believed encountering the pendulum on three separate occasions "could be a great way to get the students to reflect about their work and realize if they understand or not" (Pendulum Reflection Three). She also liked the creative aspect of giving students materials and a problem, believing this could spark students' interest.

The circuit tasks went much better for Noemie. The value she placed in group work was evident when she asked the instructor if they could work in groups. She

identified her theories of what would make the circuit work and attempted to design a setup that would test her ideas. Initially she could not get her design to work with one wire so she began using two wires, although at the urging of the instructor she returned to using one. She felt her battery getting warm but could not get the bulb to light. After much manipulation, she got the bulb to light and made a comment about this giving her confidence in her abilities. At the end of this day, she wrote, “When [you] conduct experiments, [you] must be very precise and accurate with little details” (Circuit Reflection One), demonstrating an understanding that accuracy and precision are important in conducting SI.

Between circuit days one and two Noemie thought about this activity and wrote, “Sometimes a couple days between tasks helps to provide fresh new ideas” (Circuit Reflection Two). Thus, Noemie was processing her thoughts about the task and developing new ideas to try in the next class. During this class she moved on to task two. She identified her theories about working circuits and made a series circuit to test her ideas. However, she could not make her idea work because she did not touch the wire to the bulb in the correct place, even though she did so successfully on day one. She changed her design repeatedly until she made it work. At the end of this day, she understood that placement of the variables mattered and realized the value of trying new designs if one did not work. Additionally she wrote, “I really appreciated the inquiry approach this time around and see how it will work well in a classroom” (Circuit Reflection Two). At the end of the second day, a class discussion occurred about the way a light bulb works and how to complete a circuit with a light bulb. Noemie wrote this

conversation helped her not to get frustrated, confirming her desire for group work and discussion in the classroom.

Noemie again thought about circuits outside of class time and wrote having time away from class allowed to her space out her thoughts and ideas. She wrote that between classes “I did think about circuits a little and remembered a couple of concepts from my small physics knowledge” (Circuit Reflection Three). These thoughts were helpful because she quickly processed that in order to complete task three, she needed to make a parallel circuit. Her first parallel circuit did not work so she modified her experimental design by changing the battery direction. This modification made the bulb light and it appeared Noemie completed the activity quickly and easily. She explained in this activity she was very careful with her setup; “I made sure that I always had good contact between the wires and the battery” (Circuit Reflection Three), again demonstrating an understanding of the need to be careful and systematic in doing SI.

By the end of these six activities, Noemie claimed her abilities of doing SI had improved through her practice with SI. She said

> Repetition is good and you get better when you do it yourself. So I think that watching someone do something is different than doing it yourself. And it’s only when you do it yourself that you can get the full understanding of how to do it. (Interview Two)

Additionally, she believed SI is a valuable addition to the science classroom because it encourages students to think, “gets them engaged and gets them motivated to know why” (Interview Two). She also thought that SI, “shapes personalities and the minds of the students better [by having] them figure it out first” (Interview Two). She expressed concerns about the implementation of SI in her classroom, primarily because of her and her students’ lack of experience with SI. She stated,

> I was never exposed to any . . . inquiry thinking . . . it was just brand new to me. At first I guess I didn't really like it because of the way I reacted when I did the pendulum . . . and then I just realized how much more engaged and how much more understanding I was getting from it. And I think that directly relates to how my students are going to react if they're not used to it. So that's why I think it's going to be challenging to employ in my future classroom. But in the long run it's better. (Interview Two)

Despite her concerns, it appears Noemie plans to use SI in the classroom because she values the thinking and processing that it will require of her students and believes that it will be more "stimulating" and "engaging" for the students.

Tracy's Experience

Tracy's perspective was more difficult to assess than Noemie's, not only because we had less contact time outside of class but also because of her behavior in class. When I observed her doing the tasks, she often merely sat in her chair, not trying any experiments. However, in her interview and reflections, she expressed multiple times that when she got frustrated she stopped working and thought about what it was she needed to do to make the tasks work. Although it was difficult to assess Tracy's understandings and abilities of SI, she went through a large paradigm shift concerning her views about inquiry during the 6-week experience with SI. Tracy's data matrix is presented in Figure 2.

Except for day one, Tracy sat at a table with two other students who were not participants. Unlike the other participants in this study, Tracy discussed her ideas with these students. Thus, it is likely her thoughts and experiences were influenced somewhat by her tablemates. In working with task one on pendulum day one, she made two different pendulums having two different variables and tested those without controlling variables. However, by the end of day one, she wrote she needed to start the pendulums at the same point, use the same string, and to "try to devise a more accurate way of timing

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-PRE & INTER-VIEW	-Identified a hypothesis	-Creativity in asking questions, developing hypothesis. -Observation sufficient for SI -There is one scientific method -Different scientists doing same experimental will get same results -Data and evidence are the same – says are different in interview. -Naïve ideas of data analysis -Scientists use previous research. -Running same procedure over and over gets same results. -Understands human error -Scientists have opinions			
PEND 1 (Task 1)	-Identified variables -Did not control variables, tests 2 variables at a time -Record keeping was only drawings -Created procedure to test her ideas		-Task was easy -Nervous without a procedure to follow -Thought about how to experimentally test her theories. -Confident with her procedure and results		Period affected by: Bob size Bob mass String length
PEND2 (Task 1, 2)	-Changed variables based on data -Began to keep records -Drew conclusions based on data -Changed experimental design -Used math in her thought process	-Math is necessary to do science -Human error is part of SI	-Reflection outside of class & decided to change experiment. -Hard to so SI w/o steps -Time away allowed her to clear her head. -Did not like activity but helps her understand how students feel		-Length of string matters. -Mass of bob matters
PEND3	Absent this day				

Figure 2. Data matrix for Tracy.

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
INTER-VIEW 1 & JOURNAL	Did not do this interview.			-SI makes students think -Will use SI	
CIRCUIT 1 (Task 1)	-Identified theories. -Designed experimental -Changed experiment based on data	-Important to be creative	-Can't think creatively -Frustrated with the task b/c couldn't figure it out	-Students may get frustrated with open nature of SI.	
CIRCUIT 2 (Task 2)	-Identified theories -Designed experiment to test theories. -Changed experimental design -Made conclusions		-Frustrated with the task. -Having time away helped with frustration.	-Let students figure out concepts. -Would do circuit inquiry with students -This lets students think.	-Parallel circuit to make it 2X brighter -Makes a series circuit that works.
CIRCUIT 3 (Task 3)	-Thought about this until she remembered parallel. -Designed her experi-ment to match her ideas -Changed her design through trial-and error		-Very frustrated "too much" -Found circuit more frustrating than the pendulum.		-Made a parallel circuit
INTER-VIEW 2 & JOURNAL	-Coordinated her theories with her evidence -Changed her design over time after seeing data.	-Creativity is necessary in science. -Easy to get bogged down with what things should look like. -Scientists change their design. -Recognizes scientists don't have a set procedure -Human error is a part of SI -Scientists work w/ other scientists.	-Frustrated w/ SI b/c has no skills to do it. Lots of experience w/ cookbook. -Liked coming back to activities -Thinking through activities was helpful.	-Helps students learn to think critically -SI takes longer to do -Classroom management will be hard -Would do SI in groups -Students write down ideas. -SI gets students thinking about concepts first. -SI as an assessment -Likes guided SI	Understood pendulum concepts better with time.

Figure 2. Data matrix for Tracy (continued).

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-POST		-Creativity is involved in experimental design, making predictions -Scientists repeat experiments -Observations sufficient for SI -Scientific method is not rigorous -Scientists are biased. -Is a difference b/w data and evidence			

Figure 2. Data matrix for Tracy (continued).

the periods" (Pendulum Reflection One), recognizing that some control of variables was needed. Her only record keeping was drawings of her pendulums; she did not record any period times. She concluded the end of the day by writing,

> I accomplished today's task easier than I thought I would. When the activity was first described I was nervous about conducting an experiment without a procedure. I had to sit and think about the question and figure out how I could test my theories. (Pendulum Reflection One)

Tracy thought about the pendulum task between days one and two. She wrote, "I realized that my variables were not different enough to provide distinctly different outcomes" (Pendulum Warm-up Two). Thus she planned to change her experiment by increasing the "weight of the large washer for more drastic results" (Pendulum Warm-up Two). She also said time away allowed her to return to the problem with "more enthusiasm" (Pendulum Reflection Two). She began the day by massing the bobs and creating new pendulums. She recorded the times of each swing and did multiple trials for each pendulum, marking an improvement in her SI abilities. At the end of task one she correctly concluded that length of the string affected pendulum period; however, she also incorrectly believed that mass of the bob was an influence. During task two, Tracy seemed unsure of what she was doing procedurally because she kept checking with her two tablemates. She continued keeping good records and controlled her variables much better than in task one.

At the end of day two, Tracy was frustrated and expressed dislike for the activity. She wrote that it is difficult for her to do these activities because she's "used to being given a procedure and following it" (Pendulum Reflection Two). Despite her dislike, she admitted that these tasks were "beneficial to my learning" and they might be good for

students in science classrooms (Pendulum Reflection Two). Tracy was absent on pendulum day three and thus did not proceed any farther with the pendulum tasks.

Tracy's frustration continued into the circuit tasks. With task one, she used two wires instead of one and got the bulb to light. When the instructor suggested she try using only one wire, she could not get the bulb to light. She tried several different setups, but none was successful. Tracy reflected. "I am not a creative thinker so I find this type of activity very frustrating" (Circuit Reflection One). Additionally, she considered her frustration to be similar to what her future students might feel if doing this activity. She wrote, students may "get very discouraged" by this sort of activity (Circuit Reflection One).

As in the pendulum tasks, Tracy found time between activities to be beneficial. She expressed this by writing, "It is very frustrating to do these kind of activities so having a break helps" (Circuit Reflection Two). In day two, Tracy started task two without ever successfully completing task one. She identified her beliefs of what would make the bulb light and designed an experiment to test it. However, the bulb did not light. She expressed her frustration to her tablemates. Next, Tracy lined the batteries up in series and, after manipulating the wire, got the bulb to light at twice the brightness. Regardless of her success at this task, based on my observation, I do not think she understood where to touch the bulb with the wire to make it light. Tracy did little recording of her data, although she did keep good drawings of her setups. Again she expressed at the end of the day her frustration and that time away would help her to start fresh next time.

Tracy's reflection after circuit day two showed a shift in her attitude toward SI despite her frustration with it. She elaborated on this reflection in her journal by writing,

> I've learned that I don't like inquiry activities. I started wondering why I disliked them so much and I realized that I don't have much experience with these type of activities. When I was in school I was given a lab and taught to follow the procedure. There wasn't much thought involved during the actual experiment. Therefore my inquiry skills are not very practiced. At first I didn't think I would do many inquiry activities in my classroom, but I've changed my mind. Because I have such trouble with them, I think it's important to start these activities at a young age so students get used to thinking creatively during science work. (Class Journal, July)

This was the first reference from her data that Tracy was learning something about SI and thinking of using it in her future classroom.

Circuit day three was no better for Tracy, who stated this was "too much" (Circuit Reflection Three). She began by testing her bulb and batteries individually, a way of controlling her variables. Her first setup was complicated but did not light. She tried four more setups, modifying each as she gathered data, but the bulb always lit twice as bright. She seemed very frustrated at this point and stopped working with the circuit. She sat for a long time then drew a parallel circuit. She started manipulating the batteries and wires, attempting to make the circuit look like her picture. She got the bulb to light correctly and said, "yes." She was happy with her success. She then wondered aloud if this was twice as bright instead of half as bright. She decided it was without comparing this design to her original task.

Assessing any change in Tracy's SI abilities was difficult. She showed improvement in her record keeping and in her ability to control variables, but not dramatically or consistently. What was striking about her was her initial weakness with SI and her reflections about her weakness, then her attitude about the importance of SI

changed, and she recognized the way SI could be used in her classroom and how valuable it could be in shaping the critical thinking skills of students. Ultimately Tracy summed up her descriptions of SI in her final reflection for the course. She wrote,

> When we were given the first inquiry activity I found out very quickly that I was very uncomfortable with this type of scientific investigation. I didn't like the 'open-endedness' of the process . . . by the end I was just frustrated and confused . . . I started to ask myself why I had such a hard time with inquiry labs. (Summary Reflection)

She realized her difficulties came from her lack of experience with inquiry. She concluded,

> I now totally see the benefit of inquiry labs. They allow the students to use their own thought processes and creativity to solve scientific problems. This is much more similar to how scientists approach problems in the real world. (Summary Reflection)

This demonstrated an acknowledgement of her weakness and her desire to prevent this from occurring in her students. Based on her experiences with SI, Tracy claimed she would use SI in her classroom. Although she expressed concern about classroom management when conducting SI, she believed SI would encourage students to think critically and could be used to have students think about science concepts before learning about them.

Pearl's Experience

Unlike the other participants, Pearl claimed to enjoy the SI tasks throughout the 6-week course. Her data matrix is found in Figure 3. After her first experience with SI and working with the pendulum, she stated, "Personally, I liked it . . . because you were able to think for yourself and develop your own experiment" (Pendulum Interview). If she ever felt frustrated with the tasks, she did not express it. On pendulum day one, Pearl seemed somewhat unsure of herself. She began by using a big washer and thick string

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-PRE & INTER-VIEW	-Has designed inquiry investigations. -Has drawn conclusions based on data	-Creativity to set up experiment, to look at & change variables, to elaborate on other studies. -Science "proves" and "disproves" -Observation is sufficient for SI. -One format for scientific method -Scientists get the same answer from same question, even if diff. methods -Data & evidence are the same. -Math is part of data analysis			
PEND1 (Task 1)	-Identified her theories - Identified variables -Designed an experiment -Did not control variables -Kept records of drawings		-Thinks through experiment first -Enjoyed setting up SI -Felt curious	-SI good way to introduce concepts	-Momentum of washer, string friction, gravity -Did not think her identified variables would affect period
PEND2 (Task 1)	-Drew conclusions from data -Changed experiment design -Didn't control variables	-Creativity is needed in designing experiments -Understands the need to control variables – states that next time she will test only one at a time.	-SI kept her engaged in the subject matter -Time away showed her she was being too complicated		
PEND3 (Task 2, 3)	-Identified theories -Identified variables -Records of drawings but not times -Drew conclusions -Changed experiment design		-Got more curious as time went on to know the answer -Time away allowed her to reflect and think about changes -It was fun! -Enjoyed the freedom.	-Will use SI in the classroom. -SI as a way to introduce concepts	
INTER-VIEW 1 & JOURNAL	-Identified variables. -Realized in the last experiment she needed to control variables. -Changed experimental design over time.	-Understands that thinking outside the box is necessary to science. -Inquiry is part of our everyday life. -The basis of inquiry is questions. -Scientists improve their experimental methods over time.	-Liked pendulum tasks -Value in designing her own experiment -Thought about the different variables and trial & error -Time away was good -Time away could be confusing if you forget what you're doing	-SI as a way to introduce concepts. -Will use SI -Likes guided inquiry -Time might be a problem with SI -Enjoyed the freedom -SI as an assessment strategy	-Has no idea what makes the pend. period work. -Believes you can't make a difference in the period.

Figure 3. Data matrix for Pearl.

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
CIRCUIT 1	Absent this day				
CIRCUIT 2 (Task 1)	-Identified theories & designed SI about them -Drew conclusions -Changed experiment -Manipulated variables -Kept records		-Time away lets your revise your mind -Enjoyed activity	-Hands-on lets students figure stuff out themselves -SI to introduce concepts	-Splits the wire in 2 -Complete circuits for flow of electrons
CIRCUIT 3 (Task 2,3)	-Designed inquiry -Kept records -Tested & manipulated variables -Drew conclusions -Identified theories & designed SI about them		-Enjoyed task.	-Will not use repetition in classes. -SI is a way to introduce concepts	-Series will make twice as bright -No idea about same brightness
INTER-VIEW 2 & JOURNAL	-Manipulated variables – tried wire at different places until it worked.	-Need to control variables. -Scientists do SI all the time. -Scientists don't have the answers.	-Liked the circuits. -Value in designing her own SI.	-Will use guided SI -SI introduce concepts -Might use repetition -SI as assessment tool	-Understands idea of a closed circuit
VOSI-POST		-Scientists use creativity -Observations sufficient for SI -Scientific method is standard steps -Scientists get the same answers regardless of their ideas. -Data & evidence are the same.			

Figure 3. Data matrix for Pearl (continued).

and holding the pendulum in the air. She did not control any variables at all, but she kept a simple record of the pendulum she created. She spent a good deal of time thinking and writing. In her interview she expressed that she did not think the materials available to her would make a difference in the pendulum period. Essentially, she stated, “I don’t think [length of the string, the weight of the bob, type of bob] would be a determining factor” (Pendulum Interview). Despite this belief, she still carried out experiments and tested variables to see if any did make a difference. At the end of the day, she shared her thoughts about SI by writing, “It caused me to be more curious about the idea of the pendulum than just getting to the correct answer” (Pendulum Reflection One). Additionally, she wrote, “This activity shows the many other ways to present a concept to a class” (Pendulum Reflection One).

Between days one and two, when asked if she thought about the pendulum problem over the past week, Pearl simply wrote, “No” (Pendulum Warm-up Two). However, in her reflection she wrote, “Time away made me realize how complicated I had made the experiment” (Pendulum Reflection Two). Thus, it is difficult to assess whether she thought about the pendulum between sessions and if the time away made any difference to her experimental design in day two. During day two, Pearl still did not control variables. She began the pendulum swing each time by letting the pendulum hang and giving it a push with her finger to start it. Her record keeping was not as good as in day one; she made no drawings of the pendulums she tested nor did she record the times of each swing. As she collected data and thought through her ideas, she changed the experimental design to test new ideas. She completed task one and moved on to task two, about which she spent the rest of the class thinking and writing.

Pearl spent most of the last pendulum day thinking and writing. Her record keeping was better than in day two, yet not as complete as in day one. She modified her experimental design as she collected data. After about 20 minutes, she completed task two and moved on to task three.

At the end of the pendulum experience, Pearl claimed that as time went by, "I became more engrossed with the pendulum tasks that allowed me to be more interested, intrigued, and ultimately curious to know what the answer could be" (Pendulum Reflection Three). She maintained throughout this activity that it was "fun" and that she enjoyed the freedom to design her own experiments and work at her own pace (Pendulum Reflection Three). She also wrote the time away allowed her to reflect and think about "how you were going to either continue or conclude your investigation" (Pendulum Reflection Three). Additionally, she stated,

> I enjoyed the fact that we were able to walk away because, you know, sometimes you need to be able to take a break . . . so you might be able to look at something differently, or maybe you missed something, or maybe you can add on something to the experiment. (Pendulum Interview)

These two statements implied that she valued time away and used it to process what she had done and what she might do differently the next time she saw the activity. She never controlled her variables in the tasks, yet in her pendulum interview she stated, "I should have just stuck with one variable and then deviated from there and then asked all my questions." Even though she did not demonstrate the ability to control variables, she showed an understanding that controlling variables was important and would have affected her experimental outcomes.

Because of an absence from class, Pearl missed circuit day one and began task one on circuit day two. She began task one by trying to make the bulb work without

stripping the wires. When that did not work, she stripped the wires for her next attempt, which also did not work. She used two wires instead of one, but still could not get the bulb to light. She tried a new battery, manipulated several variables, and finally made the bulb light. She kept drawings of her setups and even made a simple table showing what she had tested and discovered. She was the only participant to organize her circuit findings in tabular form. Like the pendulum tasks, Pearl wrote she "liked the circuit tasks" (Circuit Interview). She also wrote she valued this type of activity in the classroom because it "allow[s] the student to have a hands-on experience and allow[s] them to figure out how things work" (Circuit Reflection Two).

On circuit day three, Pearl finished task one and moved to task two. She originally created a series circuit but could not get it to work. When it did not work, she took the circuit apart and tested each individual battery to be certain they worked, thus controlling her variables and being systematic in her investigation. After testing each battery and assuring they worked, she returned to her design and made the bulb light. As in day two, she kept good records and drawings of what she was doing over time. She moved on to task three, but seemed to have little idea of how to make it work. She modified her experiments to test her different ideas but ran out of time before she could complete the task.

Pearl expressed she enjoyed both tasks, liked SI, and would use it in her classroom. Her abilities at doing SI did not improve dramatically, but she showed some improvement in her ability to control variables and be systematic in carrying out an experiment as well as keeping records of what she did experimentally. Although she wrote, time away "enables you to revise your mind, take a breath. The next time you look

at the experiment you might see something different, have a new idea, or construct the procedure a different way," she also wrote it was not likely she would use repetition of SI in her classroom (Circuit Reflection Two). Her understanding of SI changed in reference to its use in the classroom. She believed SI to be more engaging for the students and better than having them just listen to the teacher tell them a concept. Finally, when asked what about this class helped her to better understand SI she stated,

> The hands-on. I know that I've had a little bit of hands-on and a little bit of notes but now I understand the difference where you actually have to have that part where they're processing. There have been times I've done hands-on and didn't think about it, just did it. So it's like I see the importance in it and that questioning helps to process the ideas (Circuit Interview).

In summary, one can conclude that Pearl gained better understandings and abilities of SI through her experiences with the pendulum and circuit. Additionally, she claimed she would try to use SI in her classroom as a way to introduce students to scientific concepts.

Mischa's Experience

Mischa's experience with SI was not as positive as Pearl's but not as frustrating as Tracy's and Noemie's experiences. Her data matrix is found in Figure 4. She began the first pendulum task by using two types of string of the same lengths, holding each of them in her hand. She identified multiple variables to test and kept written records of the swing times of each trial. However, she did not control the variables in her experiments. Like Tracy, most of Mischa's previous lab experience had been procedural. At the end of the day, she reflected, "Inquiry is kind of a new concept to me because I am so used to having my experiments planned out for me as well as never really stopping to think or reflect on what I've done" (Pendulum Reflection One).

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-PRE & INTER-VIEW	-Has experience carrying out scientific investigations, cookbook-style (designed by others) -Can draw conclusions	-Creativity in hypothesis design. -A rigid scientific method but w/ different reasons to perform an experiment -Observation is enough for SI -Scientists have bias & opinions -Same experimental design gets the same results -Data makes up the evidence. -Data analysis involves organization of data.			
PEND1 (Task 1)	-Identified variables -Did not control variables -Kept some records -Drew conclusions based on data		-Activity was fun -Hard to come up w/ prediction w/ limited information -Had to think about the outcome -Has done cookbook labs, inquiry is new	-Use SI in the classroom	-Mass of bob, string thickness affects period
PEND2 (Task 1)	-Changed experimental design to control variables (dropped pendulum from the same point). -Tested more than one variable at a time. -Record keeping improved	-Human error is involved in SI -Are always more questions to be asked and more experiments to test.	-Outside class thought about how to be more scientific -Changed her experimental setup, because she felt doubt		
PEND3 (Task 2,3)	-Record keeping was bad – only drew pictures; before she was keeping times -Controlled variables better	-Math is involved in doing SI	-Thought about what she did instead of go through the motions. -Repetition was good to a point.	-Will use SI similarly to this activity if teaching pendulums -SI as form of assessment	-Mass affects period.
INTER-VIEW 1 & JOURNAL	-Self-identified she began to make more accurate measurements over time. -Changed her experimental design to control some variables but did not control all.	-Creativity is needed to do SI -Scientists don't have all the answers	-Liked designing SI -2 times good but 3rd time was redundant -Good to start with your ideas before jumping into activity	-Good to get students minds working -Let students design experiments	

Figure 4. Data matrix for Mischa.

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
CIRCUIT 1 (Task 1)	-Identified theories -Changed experiment when it didn't work. -Drew conclusions based on data	-Scientists change their designs -Keep trying until something works	-Liked circuit better than pendulum b/c it was easy to tell if it was correct		
CIRCUIT 2 (Task 1, 2)	-Identified theories and designs SI based on theories -Even after it works, changed her design to see if another setup will work -Drew conclusions based on data		-Felt confident because she made it work	-Simple activity allows students to play around w/ materials, even if they don't understand yet	-Series circuit -Thinks a more elaborate setup w/ extra wires (in series) won't work
CIRCUIT 3 (Task 3,4)	-Identified theories (resistance) -Designed SI to test theories -Changed experiment	-Some trial and error in science	-Thought about what might work to make it dimmer b/w classes	-Will use guided inquiry	-Uses more wire but it's in series
INTER-VIEW 2 & JOURNAL		-Scientists are creative w/ their thoughts and experimental designs -Need to be open to ideas to find out what works	-Liked circuits better than pendulum -Liked yes/no answer -Worried that she might be wrong -Repetition was fine b/c materials changed	- SI lets students think -Students might not be able to do everything -Start w/ SI to find out what students think -End class w/ explanations	-Knows must complete circuit
VOSI-POST		-Scientists are creative in hypothesis and exp design -Observation good for SI -Scientific method but does not have to go in specific steps -Scientists working together will get the same answers -Evidence is supportive data			

Figure 4. Data matrix for Mischa (continued).

Mischa changed her experimental design for day two based on thoughts she had outside of class. She wrote about the time away, "I was able to think about errors I may have made and ways to improve my experiment to make it better or slightly more accurate" (Pendulum Reflection Two). Essentially, she realized she needed to control variables and began to drop the pendulum from the same point each time. She acknowledged this control by writing, "My second experiment seemed to be a better measurement of period because I used more constant variables such as length and when I timed the swing" (Pendulum Task Two). Although she controlled the start of the pendulum and string length, she still tested multiple variables at once and held the pendulum in her hand. She continued to keep good records and modified her experimental design as necessary.

In pendulum day three, Mischa finished task one and began task two. She spent a lot of time thinking and writing, but I never saw her do an experiment. She finally concluded incorrectly that mass was the variable that affected pendulum period. At the end of the day she reflected that inquiry, "forces you to think more in depth about what you are doing instead of just going through the motions" (Pendulum Reflection Three).

In terms of repetition of the activity, she enjoyed it to a certain extent but claimed that she was frustrated with it by the third day. She wrote,

> I liked that I had an opportunity to change or add to my first method. That gave me a chance to improve my strategy that I originally thought of in an effort to make my data more accurate in my mind. I definitely think it was advantageous to have a chance to perform and change the experiment on two occasions, but by the third time you've been talking about it you kind of start running out of ideas and it becomes redundant. (Pendulum Reflection Three)

Despite this perceived redundancy, Mischa wrote she would allow students to come back to their experiments and modify them when they have new ideas.

Mischa had more success with the circuit activities. On circuit day one, she began working with one wire but could not get the bulb to light. After modifying her design three times, she found a successful setup and made the bulb light. She kept good drawings of each of her setups. She concluded that day's activity by writing, "I enjoyed this inquiry activity better than the pendulum because it was immediate gratification whether you were on the right track. Even if it took several designs, at least you knew what wasn't correct" (Circuit Reflection One).

On circuit day two she finished task one and moved on to task two. Mischa's first setup worked, and she decided to see if another setup would also get the same results. She modified her first setup to make a more complicated design. Her belief was this setup would not make the bulb light at twice the brightness; however, when she tested it, she found that it did. She finished task two and moved on to task three but did not get far before time was out. Based on her successes this day, she wrote, "You get a lot more confidence in your inquiry when things are actually working for you" (Circuit Reflection Two).

Between circuits day two and three, Mischa thought about the activity outside of class and wrote, "I thought about how I could make the light bulb glow dimmer" (Circuit Reflection Three). As she returned to task three she stated aloud, "I'm stumped." Her initial drawings for task three looked like her second setup from circuit day two, yet she tried it anyway and did not get the desired result. She thought through her ideas and created a new experiment that would test her new idea. This did not work either and she decided she was done with that task and moved on to task four.

Overall, Mischa's abilities at doing SI improved somewhat because she began controlling variables. She is the only participant who expressed a change in her understandings of SI as done by scientists over the course of these experiences. She stated,

> I guess it didn't really dawn on me that someone has to come up with these [experimental methods] somewhere . . . It probably only dawned on me a week ago when we started doing inquiry. So that was the big like epiphany, like, oh wow, these scientists don't necessarily know what they're doing but they have to design these things all by themselves and they make huge breakthroughs. (VOSI-M Interview)

These comments demonstrate she began to process and understand what scientists do and the challenges they face in their research. Additionally, she began to understand SI as it may appear in the classroom because she made several statements about the value of SI to get students thinking and planning out their own experimental designs.

She did not express her frustration as openly as Tracy, but she also seems to have struggled with the concept of inquiry based upon her past experiences with lab work. However, like Tracy, the concept of SI is something she began to value over time. She summed up her feelings about SI in her final interview by saying,

> I like it more and more the more we do it. At first, because it was so different from how I learned and how I've learned in the past it was really a new concept and I was like, ok, where are my notes. …. It's just a matter of changing how you learn and how you do things. And I like it more and more the more that I do it; the transition was the hardest part and now I'm starting to like it (Interview Two).

She expressed in reflections and in interviews that because of her change in understanding she planned to use SI in her classroom as a way of assessing what students know, letting students think critically, and to introduce big ideas and concepts to the students.

Mischa had two concerns about SI that were not expressed by any other participant. Her first worry was that she would be too controlling of the activities. She wrote, “It will be hard for me to step aside and let the students do all of the thinking” (Class Journal, July 12). A second worry was a student might get “stuck in the mindset that what they were doing was working, only to learn that they were wrong and what the right answer really is” (Class Journal, June 26). This last comment was likely based on personal experience because she spent the entire pendulum activity certain that mass of the bob mattered and was surprised to discover that length of the string was the influencing variable. Although she expressed concern about conducting SI, she stated “I am anxious to use inquiry in my classroom” (Class Journal, July 12). She believed SI could be used in the classroom as a form of assessment and to develop students’ critical thinking skills.

Anna’s Experience

Of all the participants, Anna had the most experience with SI, yet she still showed improvements in her abilities to conduct SI over the 6 weeks and learned new ways SI might be implemented in the classroom. Of all participants, she was the least reflective about these activities and did not talk about SI in her interviews as much as the other participants. Her data matrix is found in Figure 5.

On the first day, Anna initially was not controlling any variables. However, she demonstrated a gain in SI abilities because she realized when she was holding the pendulum her arm was swinging. To fix this problem, she taped the pendulum to the table to make her measurements more precise. She also tested each of her variables individually. The records she kept were good, including the times of each period and the

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
VOSI-PRE & INTER-VIEW	-Has experience designing SI -Has changed experimental design because of a problem. -Has done cookbook work -Has drawn conclusions based on data -Controlled variables w/ the pendulum	-Creativity in SI -Observations enough for SI -General set of steps to SM, but not all steps may be used -Scientists may interpret things differently -Scientists communicate -Evidence implies conclusions -Analysis (physical & mental) looks for trends in data			
PEND1 (Task 1)	-Initially did not control variables -Realized she wasn't being uniform so redesigned it -Identified variables -Keeps good records -Drew conclusions based on data	-Understands controlling variables is important	-It was interesting and neat to set up her own experiment.		-Mass affects period -Applying energy in the swing affects period -Mass does not matter length does
PEND2 (Task 1)	-Identifies new variables -Identifies her theories and tests them -Modifies day 1 experiment -Keeps good records	-Hard to plan an experiment w/o having to change the plan -Record keeping is important	-During interview w/ AS thought about what she wanted to try -Time away was bad b/c forgot day 1		-Thought heavier string would matter but it didn't
PEND3 (Task 2)	-Systematically tests one variable -Good record keeping -Changes experiment -Controls several variables	-Flexibility to experimental design	-Time away helped to start fresh and be more flexible (she redesigned her activity from day 2)	-Would use shorter, more frequent sessions	
INTER-VIEW 1 & JOURNAL	-Changed her experimental set up as she realized she wasn't being accurate and precise.	-Organization and patience key to doing SI. Creativity too. -Work on things and then step away and see how it's going	-Liked activity at 1st but over it by 3rd day -Lost motivation -Thought about the activity between days -Time away makes you "fresh" – better attitude	-Would use SI in some in the CR. -Have students write down & think through their ideas -Would use groups to get them thinking	-Began to understand period is caused by length, not mass

Figure 5. Data matrix for Anna.

TASK	Abilities	Understandings	Personal Reflections	Classroom Application	Science Knowledge
CIRCUIT 1 (Task 1,2)	-Designed an experiment based on her ideas -Changed experiment to find out if another setup would work too -Drew conclusions from data	-Knows need creativity -Knows to change experimental design when one doesn't work. -Need to keep records			-Stripped the wire in the middle & puts bulb there
CIRCUIT 2 (Task 2,3)	-Changed her design when it didn't work -Kept good qualitative records	-All components of experiment are important	-Time away gave her a better attitude -Enjoyed it some		-Started with parallel circuit, changed to series, back to parallel
CIRCUIT 3 (Task 3)	-After her set-up didn't work, she tested the individual variables -New setup (not in parallel) -New setup when 1st didn't work		-Frustrated that she couldn't get it to work -Her idea was right but setup didn't match her idea		-Thinks they're in parallel when they're not
INTER-VIEW 2	-Changed her design throughout as she found things that did / did not work	-SI is essential to science	-Liked circuit more than pendulum b/c knew answer immediately -Nice to have time away but bored by 3rd time	-Coupled inquiry in the classroom -Likes breaking activity into chunks	
VOSI-POST	-Experience designing SI	-Creativity in all steps of SI -Observation good for SI -Steps to SM but may not be used in this order -Scientists may analyze things differently - Data & evidence are different			

Figure 5. Data matrix for Anna (continued).

types of pendulums she tested. By the end of the first day, she had correctly concluded that bob mass did not affect pendulum period but string length did.

She wrote she did not think about the pendulum between classes “except in my interview with [the researcher]” (Pendulum Warm-up Two). She wrote that as a result “I just remembered what new things I wanted to try” (Pendulum Warm-up Two). Thus, she did not think about the pendulum on her own, but as a result of completing her VOSI-M interview. In pendulum day two, Anna continued her systematic investigation of what influenced the period by identifying and testing a new variable, the thickness of the string. Additionally, she began to control the way she let the pendulum fall by lining the washer up to the same starting point each time. She also kept good records of her experiments. She finished task one and moved on to task two but did not get far before time was over for the day. In the time she did have, she set up a very elaborate experiment with a complicated data table to solve the problem.

Anna thought about pendulum task two between classes because when she started on pendulum day three, she simplified her complicated setup. She summed this up by writing, “I found time away from it helped. In the second task I began by having a very extensive plan, but when I came back and looked at the task after time away, I realized my plan wasn’t necessary” (Pendulum Reflection Three). She expressed in her interview and reflections some frustration with these activities by the third day. For example, she said, “By the third day I was over this” (Interview One). She continued to use a systematic method of dropping the pendulum from the same starting point each time. By the end of class she was using a protractor to be precise about her dropping point. Overall, she was very systematic in her approach to the pendulum activities, keeping

accurate records of her experiments and becoming better at controlling the variables in her experiments.

Anna recognized that she learned to control variables over the course of the three days with pendulums. She summed up her gain in this SI ability by saying,

> I think when I started working on it I wasn't taking many factors into account and by the time I started the third day I realized I was dropping it from different angles each time as the rope got longer so that's why my answers weren't valid anymore. . . . So as I got into the project I had to add more factors in like making sure it's the same angle. (Pendulum Reflection Three)

She also said she would use reflection with SI in her classroom by having students "write [their ideas] out first so that they've thought it through on their own" (Interview One). Overall, she claimed to like these activities because she "got to think and it wasn't sitting in class learning; it was doing something and learning by it" (Pendulum Reflection Three).

On circuit day one, Anna initially tried to use two wires until the instructor suggested she use only one. She manipulated her setup but could not get it to work. A battery test revealed her battery was dead so she obtained another one. With the new battery her setup worked, and she moved to task two. She began this task by incorrectly lining the batteries up in parallel. She could not get the bulb to light.

On day two, Anna returned to her parallel circuit setup. She could not get the bulb to light up because she was touching the wire to the wrong location on the bulb. She changed her circuit to a series circuit, but it still would not work. Finally, she tested the batteries and found one was dead. After her experience on day one with a dead battery, not testing her batteries before she tried to make it work marked a lack of systematically approaching the problem. Once she replaced the dead battery, the bulb lit. She moved to

task three and created a drawing of what she believed would work to solve the problem. In her test of the setup, it did not light. Before she could make modifications, time was over for the day. Throughout the day, she maintained good drawings and written records of what she did.

Anna continued work on task three during day three. She had the bulb lined up in parallel correctly but could not get the bulb to light. She tested her batteries and found they worked. Then she tested her bulb and found it did not work. Although she did not test these materials individually before starting, her testing each of them when the setup did not work suggested an understanding that there was more involved to success than her experimental design. Because she could not get it to light in her first parallel circuit, she tried a second setup, which was actually a series circuit even though she believed it to be parallel. She got it to light but realized it was twice as bright. At this point she seemed frustrated. She reversed her battery direction and this time lit the bulb at the correct brightness.

Throughout her work with the pendulums and circuits, Anna maintained the most systematic approach to experiments, which is not surprising considering she had significantly more research experience than the other participants. Yet she still demonstrated a change in her abilities to do SI. Her control of the variables became more precise with time.

Anna was the participant who was most vocal about letting students leave their tasks and then encounter them on another day. While several other participants thought this was a good idea, Anna stated or wrote several times that she would use SI in her

classroom over several shorter blocks of time rather than in one large block. She summed up these thoughts by saying,

> Originally I would have thought that doing just one big project would have been better because the students might stay focused on it but, our [attention] spans are shorter the younger you are and I think if you give them a big chunk now they're not going to concentrate on it for the big two hours if you give it to them. But breaking it up into smaller chunks I think is more effective. (Interview Two)

She recognized that her students are likely to become bored or frustrated with the activities over time as she did. However, she believed stepping away from the activities prevents the activity from being a "blur" and makes "a bigger impact on what [the students] think about it and how they remember it" (Interview Two).

Participants' Descriptions of Scientific Inquiry Experiences

Although each participant had her own experience with SI, there were five common themes to the experiences over time between the participants. These themes were that participants ultimately enjoyed the inquiry tasks, that they felt frustrated by the repetition, that they thought about their experiments outside of class, that they found the time between activities to be refreshing; and that they felt doubtful at the beginning of the tasks. The following section includes a short discussion of these themes.

Four of the five participants enjoyed the inquiry tasks, felt curious about them, and liked the concept of inquiry. Noemie wrote she was "curious and wanting to know the answer" (Pendulum Task One, Day One). Pearl said, "I liked both [tasks]" and concluded inquiry "is a good thing" (Interview Two). Mischa said, "I like [inquiry] more and more the more we do it" (Interview Two). Despite their enjoyment of inquiry, four of the participants expressed frustration with the activities. Except for Pearl, the participants agreed that repetition of the activities was frustrating and boring for them by their third

encounter with the problem. Referring to the circuit problems, Anna said, “By the third time I was like, oh, working with batteries again” (Interview Two). In reflecting about the pendulum tasks, Noemie wrote, “The second and third sessions were less exciting and more tedious” (Pendulum Reflection Three). Tracy wrote, “to think critically like that is really hard for me, and I get really frustrated” (Interview). Thus, the participants initially found the inquiry activities and open-ended nature to be interesting but later became very frustrated with the lack of structure and repetition of the problems.

Although four of the participants expressed frustration with the repetition of the problems, time away from each problem had two effects on participants’ descriptions of their experiences with SI. The first is that all five of the participants thought about their experiments outside of class. For example, Mischa wrote, “I started to think I may have been going about my experiment the wrong way” (Pendulum Warm-up Two). Anna said she realized in time away that one of her experimental set-ups was “too elaborate” (Interview One). In addition to thinking about their experiments outside of class, Anna, Noemie, Tracy, and Pearl claimed the time between activities was good because it gave them a fresh start. For example, Tracy wrote, “Having a break gives me time to clear my head and return to the problem with more enthusiasm” (Pendulum Reflection Two). In reference to the time between activities, Anna said, “I think you start with a fresh attitude” (Interview One). Ultimately, the time between activities gave students an opportunity to think about their experiments and return to the SI tasks with a better attitude.

A final theme that emerged relating to participants’ descriptions of their SI experiences was a feeling of doubt or uncertainty upon first encountering these open-

ended tasks. Noemie, Tracy, and Mischa all expressed initially they felt discomfort with the nature of these SI activities. Tracy reflected extensively about her unfamiliarity with this sort of activity in her inquiry reflections and in her class journal. For example, she wrote, “I was nervous about conducting an experiment without a procedure” (Pendulum Reflection One). She also reflected she realized she did not like the activities because “I don’t have much experience with these type of activities” (Class Journal, July). Despite their discomfort with these activities, all three claimed they would use SI in their classrooms.

Participants’ Science Content Knowledge

This research study did not involve examining participants’ science content knowledge. However, one of the domains that emerged was participants’ science knowledge and a theme that emerged was the extent of their understanding of physics. The SI activities were focused around physics content, specifically knowledge of pendulums and circuits, and as participants completed the SI tasks, they demonstrated knowledge. Thus, a discussion of participants’ knowledge of pendulums and circuits over the course of the study is appropriate. One of the criteria for choosing participants in this study was a lack of physics experience. Thus, none of the participants had degrees in physics, although all participants had some exposure to physics in either high school or college. Despite having exposure to SI experiences with pendulums and circuits, over time the participants’ understanding of these physics concepts changed very little.

In the pendulum tasks, all participants initially believed multiple variables influenced the period of the pendulum. These variables included mass of the bob, diameter of the string, length of the string, size of the bob, force of release, and angle of

release. Little change in these beliefs occurred during participants' 3-day experience with pendulums. By the end of the tasks, four of the participants still believed multiple variables had an effect on period. For example, Pearl concluded, "the weight and string texture and length [have] an effect" (Pendulum Task Two, Day Three). Noemie's final experiments involved trying to "Establish relationship between: string length, string diameter, weight size, starting point angle" (Pendulum Task Two, Day Three). Anna was the only participant who understood length of the string was the variable affecting pendulum period. In her last experiment she recorded the following information: "Angle = 45 degrees each trial. String = <2mm thickness. Weight = large bolt. Only change = length" (Pendulum Task Two, Day Three). By only changing length, she tested if it was the variable that effects the period. Thus, only one participant learned from her experiments that string length was the determining variable.

Participants demonstrated a better understand of the science of circuits upon their initial encounter with the circuit tasks. All participants began circuit task one by attempting to complete a circuit, and several wrote about the flow of current in their lab recordings. For example, on Pearl's first encounter with Circuit Task One, she wrote she needed to "give the current a path" and "to connect the battery and light bulb so electrical current can flow" (Circuit Task One, Day Two). Despite their understandings of completing a circuit, only Anna understood the very specific way the light bulb must fit into the circuit to make it light. Based on observation, the participants seemed surprised when the bulb did not light even though it appeared their circuits were complete. The participants modified their experiments to try to complete the circuit again. Pearl obtained new batteries (Circuit Task One, Day Two); Noemie removed her tape (Circuit

Task One, Day One), while Mischa stripped more wire (Circuit Task One, Day One). No one tried to reposition the light bulb in her circuit. After one day of working on Task One, all participants made the bulb light. But based on the researcher's observations, it was purely by chance that the bulbs lit, not because of an understanding of the specific way the circuit had to be aligned. At the end of day two, the course instructor showed all students the inside of a light bulb and asked them to rethink the way their circuits must be aligned.

Circuit tasks two and three involved creating a series and a parallel circuit to make the bulb light at varying intensities. Most participants had a general understanding of these concepts before they began the tasks. Tracy, Noemie, and Pearl set up the correct series circuit on their first attempt while Anna and Mischa had more complex set-ups. All participants solved this task in less than one day. The third task was to make the bulb light at half the brightness, which required a parallel circuit design. Both Noemie and Anna understood the difference in the two types of circuits. For example, Noemie wrote, "the batteries need to be in parallel" (Circuit Task Three, Day Three). Mischa understood the concept of resistance because she wrote, "there needs to be some sort of resistance," but she did not initially create a parallel circuit (Circuit Task Three, Day Three). By the end of the day, Anna, Tracy, and Noemie had correctly completed this task while Pearl and Mischa were still struggling. The participants demonstrated understandings of the physics of circuits after completion of this activity. The knowledge they gained from these SI activities was about the correct wiring of a light bulb in a circuit and was likely due to a lesson on light bulb wiring.

Classroom Implications

This chapter's final section includes a discussion of the ways the participants envision SI in a science classroom. An anticipated outcome of this research study was that participants would consider using SI in the classroom; thus, several interview and reflection questions were written that would elicit responses about the classroom. However, all participants mentioned the classroom in non-classroom specific questions, too. Because the classroom became such an important theme related to SI, I have included it in a separate section in order to present how the participants envision SI in the classroom. After their experiences with SI, all five participants claimed they would use it in their future classrooms. Some had very definite ideas of how they might incorporate it into their classrooms while others were less certain. Although inquiry was brand new for Noemie, Tracy, and Mischa, and they faced more frustrations than Pearl and Anna, they still valued it as a tool in the classroom. Several themes emerged related to classroom implications: using SI to encourage critical thinking skills; teacher-facilitated SI activities; using SI as a way to introduce science concepts; repetition of SI activities; using SI to assess student understanding; and difficulties with implementing SI in the classroom.

Using SI to Encourage Critical Thinking in Students

One reason participants came to value SI was because it encourages student thinking. Noemie said, "[SI is] definitely something that is useful for the student and gets them engaged and motivated to know why" (Circuit Interview). Tracy reflected, "Students need to do these activities early on to learn to think inquisitively" (Circuit Reflection Two). Pearl said she understood inquiry is "more engaging versus just telling

the students [the concepts]" (Circuit Interview). Mischa wrote, "inquiry forces the students to think for themselves . . . instead of just going through the motions of a cookbook experiment and not learning anything about it themselves" (Class Journal, June 26). These comments demonstrate the participants liked SI for its ability to encourage students to think about information.

Guided SI

The participants liked the idea of SI as an activity guided and facilitated by the teacher instead of completely open and led by the student. Noemie summed up these feeling by stating, "I would definitely not go all the way with [SI], all student oriented" (Pendulum Interview). When asked about SI in her classroom, Anna emphatically responded she would use coupled inquiry because she liked the idea of students developing their own questions based on something introduced by the teacher. She said this allows students to "come up with questions based on another activity you've kind of guided them to. So you know they're on the right track" (Circuit Interview). Mischa even admitted she might have trouble letting go as a teacher by writing "It will be hard for me to step aside and let the students do all of the thinking" and allowing the students to do activities openly (Class Journal, July 12). Additionally, most of the participants mentioned they would do SI activities in groups. For example, Noemie believed her frustration with the pendulum activity might not have been so great if she had been allowed to work with a partner and discuss her ideas with the partner. She wrote, "I feel that in groups, perhaps I would have a little more guidance, or reassurance on if I am doing the exercise the way I am supposed to" (Pendulum Reflection Three). Because of

her experience, she wrote she would use grouping with students "to get the students to share their thoughts, ideas" (Pendulum Reflection Three).

The Use of SI to Introduce Scientific Principles

The participants envisioned SI as a way to introduce science concepts. Noemie said SI could be used to "introduce science concepts" to students (Pendulum Interview). Pearl claimed she would do a lab in a similar manner to what she encountered with these SI activities at the beginning of her class period and then would end the day by "introduc[ing] the concept" associated with the lab (Circuit Interview). Mischa expressed a similar plan for SI in her classroom, stating, "I would just maybe start the class with my inquiry stage and then change it up in the end and actually explain it to them" (Circuit Interview). Mischa concluded, "You get a much deeper understanding when you're actually trying to figure it out for yourself rather than just writing down what the teacher is telling you" (Circuit Interview). Ultimately, these participants seemed to recognize SI is a way to introduce students to a concept and encourage them to think about that concept instead of having a teacher introduce the concept to students.

Repetition of SI Activities

Except for Pearl, the participants believed the idea of some repetition of SI activities would be beneficial for students. Mischa claimed she liked "the idea of being able to revise or add to the experiment when new ideas are discovered, so I would give [the students] the chance to do that" (Pendulum Task Three). Anna especially liked the idea of breaking an activity up into smaller bits and allowing students to return to the activity multiple times because it would allow students to bring new, fresher ideas to their SI activities (Circuit Interview). However, few wanted to repeat the activities if their

students became frustrated. Additionally, Pearl was not likely to allow students to return to their activities; she said, “I wouldn’t draw it out” (Pendulum Reflection). The reason she gave for not repeating SI activities was that “time is of the essence” (Pendulum Reflection) and repetition of the activities took too much classroom time.

SI as an Assessment Tool

Several participants saw SI as a way to assess students’ content knowledge. For example, students could write their ideas about the concept they are studying both before and after the SI problems. Mischa stated inquiry can “show you what the student knows about a topic” (Pendulum Reflection Three). Pearl also believed SI could be a good assessment tool and said it can help you “see what they’re thinking” (Circuit Interview). They believe SI is a way for students to identify their thoughts and beliefs about a concept before they have studied that concept. By being aware of the students’ knowledge base, the teacher can structure class time to introduce the science concept in an appropriate manner.

Problems Associated with SI in the Classroom

All five participants had concerns about using SI in their classrooms. Some of these concerns echo those voiced by in-service teachers in other research studies. As I mentioned in Chapter 2, previous studies revealed teachers believe SI is time consuming, do not feel prepared to teach SI, do not think students can handle SI, and are uncomfortable managing SI activities (Costenson & Lawson, 1986; Martin, 2001; Welch et al., 1981).

Tracy, Mischa, and Noemie worried about students’ becoming frustrated with SI activities. Noemie worried about the confidence of her students if some struggled with an

activity while others succeeded. She wrote, "If you get some students that can't continue, it's not going to bring good feelings about themselves" (Pendulum Interview). She was also unsure of how students would react if "they were not used to [SI]" (Pendulum Interview). Because she cannot anticipate how students might react, she described inquiry as "a challenge" to employ in the classroom (Circuit Interview). Mischa and Tracy expressed concern for students because of their own frustrations with SI. Mischa wrote that because of her experience with SI she can relate to students who might "get frustrated when they aren't given the facts of the work to simply complete for accuracy" (Class Journal, June 26). Tracy had similar feelings and wrote, "I'm not a creative thinker so I find this type of activity very frustrating. I think students who think like I do would feel the same way and get very discouraged" (Circuit Reflection One). These three participants may be transferring their frustrations with the SI experience to their future classrooms and their interactions with students.

Tracy, Mischa, Anna, and Pearl expressed worries about the amount of time SI might take in the classroom. Tracy stated that knows these labs are "more time consuming" (Interview). Mischa seemed concerned with the amount of content she would have to "cover" in her class and wondered if doing SI would conflict with her coverage. Although Anna stated, "The thing I didn't like about [SI] was that it was a little more time consuming," she believes it will be worth it because of the abilities, such as "ownership" and critical thinking, which students gain from doing SI (Circuit Interview). Essentially, they thought conducting SI in a more guided or coupled manner, with teacher control over several aspects of the tasks, would prevent the SI activity from taking up too much time.

An additional worry for Tracy was classroom management. She stated, “I can’t imagine doing inquiry in a classroom where there’s not very good classroom management. Because in my experience if you give students that much freedom it’s really hard for them to maintain focus” (Interview). She realized a cookbook lab is easier to manage because students are simply following straightforward directions but in SI labs the teacher has to constantly monitor students. Although she said she anticipates this to be hard at first, she will “just have to try it.”

Despite their concerns, all participants stated they would use SI in their classrooms. Some even had some very specific ideas of how they might alleviate their worries about using SI. For example, Anna was worried that, because of the student-driven nature of SI, safety and procedural problems might arise in her chemistry classroom. She stated, “If I’m teaching chemistry you can’t give them too much freedom because they might burn themselves with acid or something . . . But I think . . . if you’re guiding them into it it’s probably a little safer” (Circuit Interview). Essentially, she decided guided or coupled inquiry solves this problem because it allows the teacher to demonstrate procedures and safety to students before they design an SI experiment. Thus, despite their concerns, the participants claimed the benefits of SI outweighed any of the disadvantages.

Summary

This study examined five preservice teachers’ descriptions of their experiences with repeated SI tasks. Data collected and analyzed included VOSI-M survey, SI notes, reflections about SI, class journals, researcher observations, and interviews. Based on data analysis, five domains emerged from this study. The five domains are

understandings of SI; abilities of SI; personal feelings about the SI experiences; SI in the classroom; and science content knowledge.

Participants' demonstrated naïve understandings of SI prior to and throughout the study. Three themes of understanding were seen in all participants. The first was that scientists are creative in conducting SI. The second, and only understandings likely to have been a result of their experience, was understanding that variables must be controlled in conducting experiments, and the third was the nature of the scientific method.

At the beginning of the SI experiences, all participants demonstrated the following abilities of conducting SI: identification of personal theories of why or how the tasks work; manipulation of variables; collecting data; and drawing conclusions based upon data. Three other abilities improved over time in all participants: controlling variables; keeping accurate records; and modifying experiments based upon the results of previous experiments.

Each participant had unique and varied experiences with SI during the 6-week course. However, five themes emerged about participants' personal feelings about their SI experiences. These themes were that they enjoyed the inquiry tasks, that they felt frustrated by the repetition, that they thought about their experiments outside of class, that they found having time between activities to be refreshing, and that they felt doubtful at the beginning of the tasks.

Few participants gained new understandings of science content knowledge from their experiences. At the end of the pendulum tasks, only one participant had learned string length was the variable that determined the period of a pendulum. In dealing with

circuits, participants' knowledge of circuits remained unchanged throughout their experiences. The only knowledge they gained was where a light bulb should be wired into a circuit, and this was because of a classroom discussion of the wiring of a light bulb.

All participants claimed they would use SI in their classrooms, although in very different ways. The themes that emerged related to the classroom were (a) using SI to encourage critical thinking skills, (b) using SI to introduce science concepts, (c) using SI to assess student understanding; (d) using teacher-facilitated activities; (e) repeating SI activities; and (f) difficulties with implementing SI in the classroom. Importantly, all participants claimed they would use SI in the classroom, valuing it as a method that could assess student knowledge, encourage students to think critically, and introduce scientific concepts in a more engaging manner.

CHAPTER 5

SUMMARY, CONCLUSION, AND DISCUSSION

The use of scientific inquiry in K-12 science classes is emphasized in national standards documents, such as *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996). Because SI is an important facet of science education, science teachers need to understand SI in order to use it in the classroom. The purpose of this study was to study five preservice science teachers enrolled in an initial certification and Master's-degree program who experienced SI in a science teaching methods class and present their descriptions and experiences with SI. In this study, I asked the following research questions:

1. How do preservice science teachers describe the experience of repeated, guided inquiry activities in their coursework?
2. What are preservice science teachers' understandings and abilities of SI throughout experiences involving scientific inquiry and reflection?

From the results, I found these preservice teachers express several common domains and themes about their experiences with SI. These themes are presented in three sections in this chapter. The first section answers the two research questions by presenting participants' descriptions of their experience with SI and their understandings and abilities of SI. The second section examines the effectiveness of the inquiry experiences that occurred within the context of a science education methods course. The

final section presents implications of this research study for science education and future research.

Preservice Teachers' Descriptions of Their Experiences with Repeated Scientific Inquiry

The first research question of this study examines how participants describe their experiences with guided SI activities. The five themes that emerged from the domain of personal reflections are as follows: (a) participants enjoyed the SI tasks, (b) repetition of the tasks frustrated the participants, (c) participants thought about their SI experience outside of class, (d) participants were refreshed by time away, and (e) participants felt doubtful about how to proceed with SI when they first encountered the SI tasks. Although three of the themes are negative feelings associated with SI, participants ended the 6-week course with positive views of SI and expressed plans to use SI in their classrooms.

The first theme is that four of the five participants enjoyed the challenge of the SI tasks. At their first exposure to inquiry tasks, several participants expressed curiosity about the task and wanted to learn the science concepts associated with the SI task. For example, Noemie wrote, "not knowing [the answer] made me curious and wanting to know the answer" (Pendulum Reflection One). Because of their enjoyment of the open-ended and engaging nature of the SI tasks, participants claimed they will carry SI in their classrooms. For example, Noemie said

> I think it's something that is useful for the student and gets them engaged and gets them motivated to know why . . . it's definitely something that I want to try to implement in my future classroom . . . because I think it shapes personalities and the minds of the students better to have them figure it out first . . . it's just a lot more stimulating. (Circuit Interview)

The second theme is that most of the participants were bored and tired of the activity by the second and third exposure to the pendulum task. The repetition of both the pendulum and circuit activities seemed redundant rather than beneficial. Mischa wrote,

“by the third time you’ve been talking about [the task] you kind of start running out of ideas and it becomes redundant” (Pendulum Reflection Three). Despite their boredom, most of the participants continued trying new experiments on the third day, and several of them discovered new ideas. Although the participants expressed frustration with the repetition of activities, they continued to improve their abilities and understandings of SI through their third exposure to each task. For example, Tracy’s third day with circuits was when she made the most progress (Researcher Observation, Circuit Day Three). Thus, even though participants were bored, the repetition fostered improvements in their abilities to do and understand SI. Their persistence and continued effort on the 3 successive days helped them solve the tasks.

The third and fourth themes concern the time participants had between activities. All five of the participants thought about their SI activities between class sessions. Additionally, four participants found the time away to be refreshing. For example, Anna expressed that, despite her boredom with repeating the task, the repetition was helpful because it allowed her to “step away from the task . . . and then start fresh” (Pendulum Reflection Three). Ultimately the time between the same activities allowed students to process what they had discovered during their prior sessions with SI. Additionally, the time away allowed them to approach their next task with a better attitude and some new, fresh ideas.

Three of the participants felt doubtful about how to proceed when they first encountered the SI tasks. For example, Noemie wrote, “I was doubting myself at first” (Pendulum Reflection One). This is the pattern for Noemie, Tracy, and Mischa: initial curiosity about the task but uncertainty of how to proceed. Tracy summed this up in her

first day’s reflection by writing, “I was nervous about conducting an experiment without a procedure . . . however, in the end I felt confident and satisfied with my experimental procedure and results” (Pendulum Reflection One). The doubt and frustration expressed by these participants is similar to that found in participants in other studies (Brown & Melear, 2006, Melear et al., 2000). For example, one participant in Melear et al.’s study (2000) stated, “I have never felt so stupid in my entire life.” In this study, participants eventually appreciated their frustrations with doing inquiry and made empathetic statements about the frustration and doubt their students would feel in their classroom. The doubt they felt might be beneficial to them when they are classroom teachers. If they can remember their uneasiness because of the open nature of the activity, they may be able to empathize better with students who are encountering SI for the first time in a science classroom.

Finally, all participants show an interest in using SI in the classroom and describe SI as a valuable tool to use with students. Mischa summed up her opinions of SI by stating she would use SI in the classroom by starting with it and getting “[students’] ideas of what they know already and what they think would work” (Interview Two). The participants viewed their SI experiences as valuable lessons, demonstrating to them the positive aspects of using SI in the classroom. Tracy summed this up best by writing, “I see the benefit of inquiry labs. They allow the students to use their own thought processes and creativity to solve scientific problems” (Journal entry, Summary Reflection). In their journals and interviews, all participants claimed they would attempt to use SI in their future classrooms. Thus, all participants describe SI to be a positive addition to the science classroom.

Preservice Teachers' Understandings and Abilities of Scientific Inquiry

Research Question 2 asks about the abilities and understandings of participants throughout their experiences with SI. This section presents both the participants' understandings and abilities of SI. The abilities and understandings of SI that informed this study are derived from the *National Science Education Standards* (NRC, 1996) and through a composite list generated by researchers (Schwartz et al., 2001). Understandings of SI were assessed through the use of the VOSI-M questionnaire and through responses to interview and reflection questions. Abilities of SI were assessed through participants' notes about their SI experiments, their journals, and responses to interview and reflection questions. The understandings and abilities of SI demonstrated by the participants have implications for these preservice teachers' future classrooms.

Understandings of SI

The understandings of SI that form the framework for this study deal primarily with nature of science and involve an understanding of the way inquiry is carried out by scientists conducting authentic research. Thus, in order for participants to understand SI as it is laid out in this study, they have to understand aspects of NOS. VOSI-M emphasized SI through the lens of NOS. Examples of understandings of SI assessed by the VOSI-M instrument are understanding that creativity is used in conducting SI, understanding that there are methods to conducting SI but that there is not one "scientific method," understanding that there is a difference between data and evidence, and understanding that different scientists may develop alternate models and theories for similar experimental results.

Based on analysis of the initial completion of VOSI-M, the participants demonstrated naïve views of SI as it is done by scientists and generally showed little understanding of the enterprise of SI at the beginning of this study. By the end of the study, participants showed a combination of naïve and advanced understandings. Understandings of SI that were shown by at least two participants at the end of the study are listed in the right column of Table 7. Naïve understandings are marked N and advanced understandings are marked A. As seen in the table, 14 understandings of SI were demonstrated by at least two participants. However, taken as a group, the participants' understandings of SI, in terms of how scientists conduct SI, changed little over the course of the study.

A comparison of participants' understandings of SI with those put forth by Schwartz et al. (2001) is found in Table 7. This comparison indicates participants understood approximately half of what is put forth by science educators. Science reform efforts advocate that students understand these components of SI and how scientists conduct SI in order to be scientifically literate. Because these preservice teachers did not show advanced understandings of how scientists conduct SI, it is unlikely they will be able to convey these concepts adequately to their students when they are classroom teachers unless they learn these concepts in another course.

For the most part, if participants had a naïve understanding of an aspect of SI at the beginning of the course, it remained naïve at the end of the course. For example, two participants claimed data and evidence are the same thing at the beginning and the end of the study. Similarly, the advanced understandings of SI demonstrated at the beginning of the study remained advanced at the end of the study. In another example, the two

Table 7

A Comparison of Understandings by Schwartz et al. (2001) with Understandings Demonstrated by Participants

Understandings of SI (Schwartz et al., 2001)	Participants' Understandings of SI
Knowledge of methods used to conduct investigations instead of one "scientific method."	Scientists follow specific procedural steps (N). Scientists might not use these steps always (A).
Understanding the role of investigations within research agendas.	Scientists are proving things (N).
Recognition of assumptions involved in designing and conducting scientific inquiries.	Scientists change their experimental designs based upon evidence that emerges (A).
Recognition of limitations of data collection and analysis.	Scientists have beliefs and opinions that may influence their data (A). Scientists need analyzed data to draw conclusions (A).
Recognition and analysis of alternative explanations and models.	Nothing was mentioned.
Understanding the reasons for using controls and variables in experiments.	Variables must be controlled (A).
Understanding the distinction between data and evidence.	There is a difference between data and evidence (A). There is not a difference between data and evidence (N).
Understanding the relationship between evidence and explanations.	Nothing was mentioned.
Understanding the role of communication in the development and acceptance of scientific information.	Scientists do not work alone; they share their work with others (A).
	Scientists use creativity in SI (A). Scientists need to keep accurate records (A). SI is subject to human errors (A). Scientists repeat their experiments (N).

participants who recognized the distinction between data and evidence did so at both the beginning and the end of the study.

Only two themes of advanced understanding were identified at the end of the study in all participants: the creativity of scientists and understanding why variables must be controlled. However, all participants understood that scientists are creative at the beginning of the course, so nothing in this study influenced or changed this

understanding. The second understanding all participants showed by the end of the course was an understanding of why variables must be controlled. This represented a change in understanding because in the beginning only one participant, Anna, understood why controlled variables are needed and by the end all participants understood why.

Only two understandings of SI changed in the participants during the 6-week course. As discussed above, by the end of the course, all participants understood controlling variables led to more successful experiments. This understanding is linked to their experiences working with SI tasks. In learning to control variables while conducting experiments, participants discovered why controlling variables was important to the task. For example, Mischa understood controlling variables gave more accurate results and wrote, “My second experiment seemed to be a better measurement of the period because I used more constant variables” (Pendulum Task 2).

The second understanding to change during the study deals with the nature of the scientific method. At the beginning of the course, all participants believed scientists follow a specific scientific method. By the end of the course, three of the participants believed there is not one scientific method, one still thought there is a scientific method, and one did not complete the second VOSI-M questionnaire and could not be assessed. However, it is more likely that a class discussion of the scientific method within the context of NOS changed their views of the scientific method than their actual experiences doing inquiry. And despite this discussion, one participant still maintained at the study’s conclusion that scientists follow only one scientific method in conducting SI.

Thus, one conclusion of this study is that preservice science teachers gained only one understanding of SI by experiencing and performing the SI tasks provided in the

context of their methods course. This conclusion is similar to other findings from studies involving participants conducting SI and understanding NOS or SI. For example, Wilson (2003) examined changes in participants' understandings of NOS and SI and found that participants views of NOS and SI advanced from naïve to informed for six concepts; however, five concepts remained unchanged. Another study examined one secondary science teacher's approaches to teaching inquiry and assessed his students' understandings of NOS and SI (Schwartz et al., 2001). Despite their experiences with SI and the teacher's use of explicitly relating NOS and SI concepts to students, these secondary students maintained naïve views of most NOS and SI concepts. All of these studies, including mine, conclude that having experiences with SI do not sufficiently advance participants' understandings of NOS or SI, even when SI is explicitly related to participants.

The results of this study are dissimilar to a study involving preservice elementary teachers (Haefner & Zembal-Saul, 2004). These students conducted SI in the context of a life science course, and the researchers assessed their views about science. Over time, participants' understandings of science shifted from science as a product to science as a process view, which demonstrated advancement in their understandings of SI. Thus, these preservice teachers developed understandings of the scientific enterprise because of their SI experiences.

One difference between Haefner & Zembal-Saul's (2004) study and this research was how participants' understandings of the scientific enterprise were assessed. In this study, the VOSI-M questionnaire was the primary means of assessment while Haefner and Zembal-Saul asked participants to discuss and provide examples of their ideas about

science and scientific practices. Melear et al. (2000) also successfully used open discussions to assess participants' understandings of scientific processes and inquiry. Their open-ended assessment showed their participants gained more sophisticated understandings of SI after conducting authentic SI experiments. Perhaps the participants in this research study would have shown a similar shift if their understandings of SI had been assessed more openly rather than through the NOS lens of VOSI-M. It is possible they have understandings of SI that are not known because they were not provided an open opportunity to explain their knowledge and understandings of the processes involved in conducting SI.

Previous research into science teachers' understandings of NOS, which included aspects of SI, demonstrated that pre- and in-service teachers best learn NOS concepts when the material is related to them explicitly through reflective journaling and discussion (Abd-El-Khalick et al., 1998; Gess-Newsome, 2002; Lederman et al., 2001). Although explicit reflection about SI was part of the research design, very little explicit reflection about understanding SI in the way scientists do SI was included in this study. The only place SI understandings were explicitly related to participants was in the interview and reflection questions that asked how their actions were like what scientists do. However, the subtle nuances of understanding SI that were assessed by VOSI-M were never explicitly related to participants. Thus, their lack of understanding SI, as emphasized by VOSI-M, reinforces the literature findings that teachers do not understand NOS and SI if they are not explicitly related to them. In the future, including in-class discussions of what comprises SI and what scientists do in conducting authentic research should help students gain better understandings of SI.

Overall, participants in this study did not demonstrate understandings of SI consistent with the recommendations of the *NSES* (NRC, 1996) and Schwartz et al. (2001). Lessons that explicitly relate SI understandings to participants may be helpful for future teaching of this course. However, participants' experiences with SI did help them develop understandings of how SI might be used in a science classroom and how it might benefit students. For example, most participants reported that SI is a way to introduce scientific concepts, that it requires students to think critically, and that it allows students to work through ideas and concepts on their own. Mischa summed this up by writing,

> [Inquiry] will not only show you what the student knows about a topic, but it also tells you how well their thinking process is and if they can formulate an experiment on their own without any help or outside information. (Pendulum Reflection Three)

This type of understanding is important for future science teachers who will be expected and encouraged to use SI in their classrooms because this understanding helps them comprehend the benefits of SI. Anna recognized that having students perform inquiry activities can help them understand why scientists conduct SI. She said, "It's important to use inquiry in the high school to expose those students to the scientific method and what science in the real world looks like" (Circuit Interview). Thus, she recognized that conducting SI could help students develop better understandings of the enterprise of science.

I expected that the use of VOSI-M and the follow-up interviews would comprise part of the experience for participants because I believed answering these questions would make them more aware of the characteristics of SI. For example, questions on VOSI-M asked about data, evidence, and the scientific method, and I anticipated participants would mention these things in their written data and interviews. However,

these characteristics of SI were not mentioned by participants unless they were specifically asked about them. Based upon the lack of change in participants' understandings of SI, it appears that VOSI-M and follow-up interviews did not have the anticipated effect of making participants more aware of the components of SI**.** This suggests a disconnect between their answers to VOSI-M and the follow-up interviews and their in-class work with the SI activities**.**

Abilities of SI

The *NSES* (NRC, 1996) stress that students have abilities to conduct SI in the classroom. These abilities include identifying questions to investigate, conducting scientific experiments, using math skills in investigations, formulating explanations based upon evidence, recognizing there are alternative explanations in SI, and communicating scientific points of view. Participants' abilities to do SI were assessed through their written lab notes, their reflective and course journals, and my observations of their experiments. In their first 2 days experiencing the SI tasks, all participants demonstrated four abilities of SI: identifying personal beliefs of how to solve each task, manipulating variables, collecting data, and drawing conclusions based upon their data. By the end of this study an additional three themes emerged in all participants, showing an improvement in participants' abilities to conduct SI. All demonstrated improved abilities to control variables, keep accurate records, and modify experiments based upon their previous experiments. Table 8 presents a list of the abilities demonstrated by the participants at the end of the study. Each abilities was demonstrated by at least two participants. The participants' abilities are placed with corresponding abilities presented by *NSES*.

Table 8

Abilities Demonstrated by Participants with Corresponding Abilities of SI presented by NSES (NRC, 1996)

Abilities of SI (NRC, 1996)	Participants' Abilities of SI
Identify questions and concepts that guide scientific investigations.	Identified personal theories of why something worked and tested those theories.
Design and conduct scientific investigations.	Manipulated variables. Controlled variables. Collected data. Kept accurate records. Drew conclusions from analyzed data.
Use technology and mathematics to improve investigations and communications.	Used mathematics in experimental design and data analysis.
Formulate and revise scientific explanations and models using logic and evidence.	Modified experimental design through practice and data collection.
Recognize and analyze alternative explanations and models.	(Nothing was observed.)
Communicate and defend a scientific argument.	(Nothing was observed.)

The participants' increased abilities to conduct SI are similar to a study conducted by Melear et al. (2000). These researchers found that college and graduate students who had experiences conducting authentic SI improved their abilities to design experiments, interpret data, formulate results, and present their findings. Although the abilities gained in Melear's students were not exactly the same as those gained by participants in this study, both studies provide evidence that having experiences conducting SI leads to an increase in abilities to conduct SI.

All participants demonstrated an improvement in controlling variables. Several participants reported they realized in the middle of their experiments that they were not controlling their variables and consequently they could not draw any conclusions from

their experiments. For example Anna said in her pendulum interview, “I first started out trying to hold the pendulum in the air and just swing it. And then I saw my arm moving all over the place . . . so I taped it to the side of the table.” Thus, she realized during her experiment that she was not controlling the swing of the pendulum, one variable. Other participants did not realize the need to control variables until their experiments were finished. For example, Pearl said in discussing her pendulum experiments, “It was too many variables and by the third experiment I said, ‘I have too many things, I can’t conclude anything’” (Pendulum Interview). This demonstrates that she understood the need to control her variables. This understanding was translated into an ability when she began the circuit tasks. With the circuits, she tested only one variable at a time, controlling the other variables to make the bulb light (Circuit Tasks Two & Three). Others realized they were not being systematic in their experimental procedure and designed more rigorous and better-controlled tests as they progressed with the tasks. The participants’ improvement in controlling variables is similar to the results in microgenetic studies. Participants in previous microgenetic studies demonstrated more sophisticated investigative abilities over time and more accurately tested variables as they had more experiences with investigations (Kuhn, 1995; Kuhn et al., 1992; Schauble et al., 1995).

This improvement in participants’ abilities has implications for their future classroom teaching. The participants’ demonstrated abilities of controlling variables, keeping good records, and being systematic are abilities that science teachers and the *NSES* want to see in science students. Results from microgenetic studies indicate when participants work on a problem for repeated sessions and switch to a new problem, they typically maintain their abilities to conduct SI (Schauble, 1996). Because these

participants experienced repeated SI and their abilities improved, it is possible they might carry these abilities to other experimental tasks, especially those they conduct with their students. This would be helpful to them as they guide their students in inquiry activities.

Additionally, because these preservice teachers experienced a change in their abilities to conduct SI and recognized they changed in their abilities, it may help them to see some of their future students making mistakes similar to those they made. It should also help them to understand how to correct those mistakes in their own students. Their improved abilities should help them model proper methods of doing SI in the classroom. However, in order for these classroom benefits to occur, the participants must remember their experiences with SI and what they learned and make a conscious connection between their actions and the actions of their students.

Effectiveness of the Case

This research project is a case study that examined an inquiry experience in a science methods course by analyzing participants' descriptions of SI experiences. It also evaluated participants' understandings of SI and abilities to conduct SI after their experiences with repeated guided SI tasks. The units of analysis for this case study were the five participating preservice science teachers. Based upon the data collected and analyzed from these participants, the experience of guided, repeated inquiry activities was perceived by the participants as a beneficial way to introduce SI to preservice teachers.

This SI experience was based upon the microgenetic method used in developmental psychology research. While not an initial question in this study, the effectiveness of the case was evaluated using the characteristics of the microgenetic

method used to design the SI problems. These aspects are (a) problems' having cause and effect variables, (b) having participants identify their personal beliefs of what will solve a problem, (c) repetition of the inquiry experience, and (d) having participants reflect about their SI experiences. Based upon the participants' data, each of these aspects appeared to have had an influence on the way participants viewed SI.

Cause and Effect

The first aspect of the SI experience was the inquiry problems with cause and effect variables. The problems were designed to be conceptually similar to science content found in middle and high school physical science and physics classes. Yet, for most of the participants, the content was challenging because they were not familiar with the principles of physics and thus had to work to find the answers. The pendulum problem challenged the participants more than the circuit problem. After 3 days working with the pendulum, none of the participants had determined the exact variables that influenced the period of the pendulum. Mischa and Tracy believed mass was the variable that influenced the pendulum period. Mischa said, "I kept going with mass because the results I was getting made it seem like I was on track" (Pendulum Interview). By the end of the third day, Anna was the only participant who had concluded length influenced the pendulum period instead of mass (Pendulum Task Two, Day Three). However, she still was not certain length was the only variable affecting period.

Initially, the circuit problem was also difficult for participants, but by the end of the tasks, all participants, except Tracy, claimed it was easier than the pendulum. For example, Mischa said,

> You knew it worked because the light came on and so it was just much better for me because I thought, oh, this is working. You know if it wasn't

> working, I knew right away and I could change my design. (Circuit Interview)

At the end of the first day working with circuits, the instructor explained the structure of a light bulb and how a circuit is completed. It is likely these instructions caused the participants to gain insights and ideas about working with circuits that affected their work during circuit days two and three. For example, Noemie wrote, “Looking at the big broken bulb was very informative” (Circuit Reflection Two). She wrote that seeing the inside of the bulb helped her “understand the principle behind it” (Circuit Reflection Three). She said she knew she had to line up the wire to the battery and bulb in a specific way, but “I didn’t know why” until she saw the inside of the bulb (Circuit Interview).

Overall, these two problems challenged the participants’ curiosity without being so difficult that they got completely frustrated and quit. There are many instances where participants demonstrated manipulation of variables to determine the cause and effect relationships of the problems. For example, Noemie discussed manipulating of the circuits: “I realized you could switch the battery upside down.” In the pendulum, Anna considered multiple causes for the pendulum swing, including starting angle, length of string, and mass of bob.

Identification of Personal Beliefs

The second aspect of the inquiry experience was having participants identify their beliefs about what would solve each problem before they actually attempted to find the answer through hands-on methods. This is similar to the microgenetic method in which the researcher asked the participants what they were going to do and why it was going to work (Kuhn et al., 1992). In this study, participants initially were asked to explain how they thought the task could be solved and to sketch out their experimental design. This

allowed me to assess the participants' initial beliefs before they began hands-on manipulation of the materials.

The participants' written explanations of their beliefs of what would solve each task was one data source. From this data, it is clear the participants used prior knowledge of physics concepts to attempt to solve the problems. It also demonstrates that many of the participants, despite their use of prior knowledge, were not certain what would solve the task. In answering a question about the pendulum swing, Pearl wrote, "gravitational pull and friction of the string [will slow the pendulum] because an object in motion stays in motion until another force stops it" (Pendulum Task One, Warm-up). While these two concepts are not related to the variables influencing the pendulum, Pearl believed they were and explained why she began her pendulum experiments using a heavy string and a light string. Additionally, Pearl's comments are evidence that she was actively thinking about how to solve the problem and used her preexisting ideas in designing pendulums.

Tracy's initial ideas about circuit task one explained her approach to the task. Instead of following the directions to create a circuit with only one wire, she cut her wire into two pieces to solve task one (Circuit Task One). Her answer to the warm-up question before she began the task implied her belief that the circuit could not be completed with one wire. In her pre-plan she wrote, "Cut the wire into two pieces and attach one piece to each end of the battery with tape and then both pieces to the light bulb" (Circuit Task One). This is exactly what she attempted in her first experiment. These comments about their initial beliefs provided an understanding of why each participant began each task as she did.

In order to assess participants' feelings about thinking through their experiments before attempting them, participants were asked pertinent questions during interviews and reflection. Their answers imply it was a beneficial exercise that allowed them time to review what they had learned in previous physics classes, which provided them the opportunity to write down their ideas of what might solve the problem. For example, Noemie stated, "it was good" to write down her thoughts before she started (Pendulum Interview). Mischa summed up the benefits she found to writing out her thoughts by saying,

> I think it's good to start with an idea before you just jump into it because if you just jump into it you don't know how you're going to design it or what you're going to do with the actual experiment. But if you start writing down your ideas of how you're going to make it work, how you think it will work, then you have a better idea of how to set the experiment up. (Pendulum Interview)

This answer demonstrates that Mischa was using the scientific process by thinking through her ideas about how best to perform an experiment before she did the actual experiment, an important component of SI. Anna summed up this importance by stating she was "used to" thinking through her thoughts before an experiment because of her graduate research and that she considered this action to be "part of the scientific process" (Pendulum Interview). The finding that participants assessed their previous knowledge and used it to think about their experimental designs is similar to work conducted in microgenetic studies (Kuhn et al., 1995). Kuhn et al. suggest having their participants think through their beliefs before conducting investigations helped them to shape their experiments.

Repetition

The third characteristic of the tasks from the microgenetic method is the repetition of the problems. Ultimately, repetition of each problem was beneficial in three ways. First, it allowed participants time away to process their thoughts about each problem. Second, participants found the time away from each task to be refreshing. Third, participants thought repetition of tasks would be a useful tool to use in their science classrooms.

Participants worked with each problem on three separate occasions: They worked with pendulums for 3 days and with circuits for 3 days. The only complaints about this SI experience were in reference to the repetition of the problems. All participants, except Pearl, expressed feeling of boredom and frustration at having these problems three times. Even though most participants reported boredom with the repetition of the tasks, they all demonstrated improvements in their abilities to do SI with each repetition, even when they were bored or frustrated. For example, participants reported that the third time with the task was boring: Tracy wrote this was "too much" (Circuit Reflection Three). Yet they made improvement in their abilities throughout all 3 days. For example, both Pearl and Mischa demonstrated drastic improvements in their control of variables on their third pendulum day. Overall, the participants reported, despite their frustration, the repetition was good and allowed them to modify their experiments. For example, Anna wrote,

> I found that time away from [the task] helped. In the second task I began by having a very extensive plan, but when I came back after time away, I realized my plan wasn't necessary. (Pendulum Reflection Three)

Thus, despite their dislike of the repetition it was a valuable part of the SI experience.

The proposition of this study was that having participants repeat activities would allow them to fluctuate between disequilibrium (caused by their actions in class) and

equilibrium (reached through reflection and their time away from the activities) about the science content. During the time away participants worked through their beliefs and ideas about the problems and brought new thoughts with them the next time they worked with the problems. For example, Anna said she processed the pendulum task outside of class because “the end of the second day was when I came up with that horrendous data table and the beginning of the third time is when I trashed it” (Pendulum Interview). Mischa said she also processed the pendulum task outside of class and admitted, “that would have never happened if there hadn’t been a break between those two sessions” (Pendulum Interview). Additionally, participants also liked the time away because it allowed them to alleviate some of their frustrations with the activities. Anna said, “It helps to step away from it and come back” (Pendulum Interview), and Tracy wrote, “Having a break gives me time to clear my head and to return to the problem with more enthusiasm” (Pendulum Reflection Two).

Microgenetic studies show participants’ abilities at conducting experiments improve with repetition (Kuhn et al., 1992). Kuhn et al. (1992, 1995) suggest repetition allows participants to identify the weakness in their investigative strategies and to change and strengthen their strategies over time. In my study, participants’ abilities to conduct SI improved over time, and it appears the repetition of the activities contributed to this improvement.

Finally, the participants expressed that they would allow students in their classrooms to repeat their inquiry activities. They believed that working on their inquiry activities on multiple occasions would allow students to understand the content more thoroughly. For example, Anna envisions using repetition of SI in her classroom and said,

> I think because they're coming back to it they can remember it more rather than being this one day in a blur of days . . . I think . . . it will make a bigger impact on what they think about it and how they remember it. (Interview Two)

It is ironic that although the participants expressed tedium and boredom with the repetition, they claimed they will use repetition in their classrooms. Thus, the benefits of the repetition must have outweighed the feelings of frustration.

Reflection

The fourth aspect of the microgenetic method used in this study was that participants wrote reflections about their experience at the end of each day. Gess-Newsome (2002) used journaling with preservice science teachers and saw that their understandings of NOS and SI increased over time. Unlike Gess-Newsome's participants, the participants in this study did not increase their SI understandings; however, journaling was likely helpful to them in thinking through the methods they used to solve the problems. For example, reflecting helped them come to some closing conclusions for the day's activity. Several participants wrote what did not work in their day's experiments and what they might try the next time. After pendulum day one, Tracy wrote she would "try to devise a more accurate way of timing the periods" in her next attempt (Pendulum Reflection One). She was thinking ahead and recognizing she needed to be more systematic. As with the initial identification of beliefs and ideas, reflection allowed the participants to process cognitively what they had learned for the day and generate questions they had about the activity.

The four aspects of the microgenetic method discussed previously were used to create an inquiry experience that would allow preservice science teachers the opportunity to experience SI. Overall, the participants had positive experience with SI. Additionally,

they gained ideas about how to use SI in their future classrooms, and they recognized why SI is a useful tool for the science classroom. Thus, this SI experience was beneficial to the participants and a valuable way to introduce SI concepts to these preservice science teachers through hands-on, active experiential learning about inquiry.

Conclusions

There are four conclusions that are drawn from this study based on the previous discussion of the research questions and the effectiveness of the case. The conclusions are as follows:

1. These preservice science teachers' experiences with SI increased their abilities to do SI.
2. This SI experience increased participants' understandings of how they might use SI in their classroom.
3. The SI experience changed only one area of understanding SI.
4. The SI experience did not increase participants' physics content knowledge.

Over time, participants became more systematic in their investigations. They improved their abilities to keep accurate records, control variables, and modify experiments based upon experimental evidence. Additional abilities to conduct SI were demonstrated by several participants, but not by all. Based upon their experiences, participants gained SI abilities that will be helpful to them as teachers facilitating their students' classroom investigations.

After experiencing SI, participants discussed ideas they had about using it in their future classrooms. During reflection and interview questions, participants repeatedly

mentioned ideas they were getting based upon their experiences. Because these are preservice teachers, it is not surprising that they would consider the classroom; however, the extent and depth to which they thought about SI in their classroom was unexpected. Participants in this study demonstrated a number of themes associated with SI in the classroom: (a) using SI to encourage student thinking and to introduce science concepts, (b) having teachers facilitate or guide activities, (c) allowing students to repeat activities, and (d) recognizing there are difficulties associated with implementing SI in the classroom. Because participants only demonstrated two themes of understanding and three themes of abilities, their experiences with SI most affected their ideas and beliefs of conducting SI in the science classroom.

One expectation of this study was that students experiencing SI activities would change their understandings of SI. Participants' SI understandings were assessed with an instrument that emphasized understanding SI as a scientific enterprise instead of a classroom instructional method. Because their understandings were assessed through this NOS lens, participants showed only one change in their understanding of SI that could be attributed to their experiences. Understanding the nature of the scientific method and understanding why to control variables were the only two understandings that changed from naïve to advanced over the course of this study.

Essentially, there was no connection between the understandings of SI that formed the conceptual framework of this study and the understandings of SI gained by participants through their experiences with SI. Instead of gaining an understanding of the scientific enterprise of SI, participants gained an understanding of SI as students might learn and conduct it. Additionally, the instrument used to assess participants'

understandings of SI examined this from a NOS point of view instead of an experiential point of view. Assessing participants' understanding through a non-NOS lens might have yielded different results to this study. If participants had been asked to explain openly the process of conducting scientific inquiry, they may have shown understandings, such as recognizing the difficulties in planning experiments, the challenges to interpreting and analyzing data, and the challenges and competition involved in receiving funding.

Based upon participants' experimental data and written and verbal comments, the participants had no real change in their understanding of the physics concepts of pendulums and circuits. In both science labs and the science classroom, inquiry is not done merely for the sake of inquiry. Instead, inquiry is done to gain science knowledge. Thus, this experience with SI would have been considered more successful if participants had gained some science knowledge in addition to their improvement in inquiry abilities. The lack of change in knowledge of physics is regretful because one of the advantages of using the microgenetic method is participants often gain scientific knowledge in addition to their increase in investigative abilities (Kuhn et al., 1992, 1995).

Finally, if participants had been assessed with a test that measured only their physics knowledge, they might have shown some improvement. Their knowledge was assessed through lab notes and interviews rather than a more formal means. If they had been directly asked what variables controlled the pendulum and circuit, their answers might have shown more insight into the factors affecting the pendulum and circuit.

Implications for Science Education

Science inquiry is currently a highly emphasized aspect in the field of science education. It is one of the standards found in the *NSES* (NRC, 1996) and AAAS (1990)

emphasizes it as one of the essential components of gaining science literacy. Thus, teacher preparation programs often focus on SI and attempt to teach SI to their students so these future teachers will use SI in their science classrooms. One area of past research focused on preservice science teachers' having authentic experiences doing SI in a science lab (Melear et al., 2000; Schwartz & Crawford, 2003; Schwartz et al., 2000; Wilson, 2003). Brown and Melear (2006) defined authentic inquiry as investigations of scientific phenomena where "the learner observes the phenomena, manipulates/'tinkers with' materials, asks questions, designs investigations, conducts experiments, analyzes data, and reports results." Authentic SI typically involves an apprenticeship in a science lab or conducting science research in a science class. For example, in Wilson's (2003) study, science teachers engaged in authentic research into binary stars, and Melear et al. (2000) had students investigate plants while working with scientists. The research using authentic inquiry has shown mixed results about students' abilities to learn the concepts associated with SI and NOS (Schwartz & Crawford; Wilson).

One of my personal goals in conducting this study was to investigate a way to introduce SI to preservice science teachers without having them conduct authentic research or overwhelming them with educational theory. With the current shortage of science teachers, many preservice science teachers are going through alternative certification programs that do not allow time for students to conduct authentic research. Additionally, some colleges' science education programs do not provide the opportunity for students to conduct research. Furthermore, Roth (1998) found that students who have completed secondary and undergraduate programs were not likely to encounter SI in their coursework. Finding a method that allows preservice teachers the opportunity to

experience SI in a manner that is not as time-intensive as conducting authentic research could be a valuable addition to the science education field. This research study was an attempt to introduce preservice teachers to SI by modeling it as it might appear in a science classroom. In this study, participants' experiences occurred in an artificial context, not the way they would occur if they were conducting authentic science research. Instead, they engaged in SI the way middle or secondary students might experience it in the classroom to demonstrate how it might be used in a middle or secondary science classroom.

This study demonstrated a successful way to introduce SI to preservice teachers by having them experience guided, repeated inquiry tasks. By the end of their experiences, each of the participants had definite ideas of how SI could be incorporated into their classrooms. For example, participants were not introduced to the scientific concepts behind the experiments until after their third time with the task. Borrowing from her own experience, Pearl said she would start out a new concept in class with an inquiry experience because it is both "an introduction and an assessment . . . I can see what it is they understand and what it is they can figure out" (Interview Two). Because these preservice teachers will be expected to implement SI into their classrooms, allowing them to develop their own understandings and ideas of how it can be used will assist them in using SI successfully in the future.

This study also showed that preservice science teachers gained SI abilities by conducting SI. Because the *NSES* (NRC, 1996) explicitly state that teachers need to have the abilities to do SI, this study provides a method for teachers to learn these abilities, thus fulfilling this teaching standard. Although these participants were not learning how

to conduct authentic inquiries or how to run complicated experimental procedures and set-ups, they learned the value of keeping accurate records, thinking through and planning experiments before trying them, manipulating and controlling variables, and conducting systematic experiments. The abilities they gained are similar to the abilities they are likely to see, or not see, in their future students. Hopefully, their SI experiences have taught them what abilities they want to see in their students as they conduct classroom SI.

One additional implication of this study for science education is in the area of understanding inquiry. Science teachers need to understand SI as part of the scientific enterprise. However, it may be beneficial to their science students if they also understand what it can do for the classroom and how it may be implemented in their classroom. If teachers do not understand what SI looks like, then they are less likely to implement it effectively in their classrooms. In this study, preservice teachers having experiences with SI began to develop a classroom understanding of how it could be used. These students' understandings were assessed with VOSI-M, a NOS instrument. However, the results of assessing them with an instrument that measured understanding in a classroom would be valuable. Although VOS-M is a valuable way to assess understanding inquiry as scientists perform it, there is a need to assess preservice science teachers' understandings of SI in the classroom because that is another way to understand SI. Thus, an area of future research in science education might be development of an assessment instrument for measuring classroom understandings of SI and using this new instrument with preservice science teachers.

Future Modifications to the Scientific Inquiry Experience

This experience demonstrated SI to preservice science teachers and helped them understand how it could be used in the classroom. There are several modifications that could be done if the study is duplicated. The first modification involves the nature of participant writing. Participants wrote on prepared worksheets, which were required to collect sufficient data. However, students often spent more time trying to complete the worksheet than actually working on the SI problems. In the future, students should be asked to keep a lab notebook that documents their actions and experimental methods. This way students could work at their own pace to keep notes of their actions rather than answering specific questions asked by the researcher. Finally, at the day's conclusion of the activity, students should receive a worksheet containing the reflection questions.

Another change that could be made in the future is allowing students to work in pairs. There are advantages and drawbacks to having students work alone. For this research study, having participants work alone allowed the researcher to attribute ideas, thoughts, and feelings to each participant. An advantage to working individually is that it allows changes to occur solely within the individual solving the problems. Thus, in this study, any changes seen in participants occurred because the participants worked through their ideas, took information from their experiments, and assimilated and accommodated this information with their previous understandings. Thus, the changes were truly internalized by each participant.

However, there were drawbacks to working alone. First, several students expressed frustration with working alone. Each believed that if she did not have the correct answer then she was stuck for the day. It might have been beneficial for the

participants to have a partner with whom to talk about ideas and experiments. This idea is supported by Vygotsky's (1978) theory of development, which suggests social interactions are involved in the development of cognition. Additionally, scientists often share information and ideas with other scientists when conducting research. Having students work in pairs might help them understand the importance of communicating with others when conducting SI, thus modeling the work of scientists.

A third modification deals with the repetition of each activity since three repetitions of two activities required a large amount of class time and bored the participants. If an instructor felt that time was an issue, having two repetitions of the two activities could be a modification. However, I observed change in several participants during the third session of each problem, so if time permits, then having three repetitions of each activity is recommended.

A final modification could be having explicit classroom discussions about what comprises SI and the concepts associated with the SI problems. In this study, participants were encouraged to think about authentic inquiry done by scientists in only a few reflection and interview questions and were never specifically asked about physics concepts. Because participants did not associate their actions with those of scientists doing authentic SI, it might be beneficial for this topic to be explicitly discussed as NOS researchers recommend. In addition to answering reflection questions relating their actions to those of scientists, having class discussions about SI and the way scientists perform inquiry could help students make connections between their actions and SI. Finally, encouraging discussion of participants' findings involving the scientific concepts associated with their experiments might have helped them to understand their

experimental results and learn physics knowledge. These discussions could help students better understand the concepts of SI, pendulums, and circuits, which would be helpful to them as future science teachers.

Future Research

Participants in this research study demonstrated understandings of how to use SI in a science classroom and their abilities to conduct SI advanced over the course of the 6-week study. However, they did not demonstrate understandings of what constitutes authentic SI. The results of this research study demonstrate a need for further research into preservice science teachers learning about SI.

A longitudinal study of these specific participants would be a useful addition to this research because these participants expressed a desire to use inquiry in their future classrooms. Following these five participants into their student teaching experiences and studying how and if they use SI in the classroom would provide valuable information to the science education community about how effective this experience was at preparing teachers to use SI. Although the participants believe they will use SI, it would be interesting to know if they use SI and how they use SI. If they do not use SI, it would be beneficial to know why they do not use SI and what barriers are in place in the classroom that prevent them from using SI.

Other continued research into this subject would be to repeat this experience with another group of preservice science teachers. In further studies, the modifications described above would be used. It would be beneficial to know if having explicit discussions of what constitutes authentic SI and the scientific concepts associated with their experiments would have a more profound affect on future participants’

understandings of SI and scientific content knowledge. It would also be interesting to find if students' abilities to conduct SI would change if they worked in pairs or if that change could be attributed to working individually.

One final suggestion for future research is to use these SI experiences with in-service science teachers because research suggests many practicing science teachers feel barriers to doing inquiry (Welch et al., 1981). Determining how in-service teachers describe the experiences and if the experiences affect their understandings and abilities of SI would be a valuable addition to science education. Additionally, if in-service teachers learn about SI and become more comfortable doing SI after these experiences, these experiences may show a method to use in continuing education classes for science teachers.

Summary

In this research study, I demonstrated that preservice science teachers perceive this as an effective way to experience science inquiry in a science education methods class. Students who participated in this study showed changing and improving abilities to conduct SI over the course of their experiences with SI. Participants did not express deep understandings of SI in the context of authentic research carried out by scientists. Instead, they demonstrated understandings and ideas of ways to implement SI in a science classroom. Despite participants' conducting investigations with pendulums and circuits, their knowledge of physics content did not change over the course of the study.

The four aspects of the microgenetic method contributed to the SI experience of preservice science teachers. Preservice teachers were exposed to SI through cause and effect problems, identification of their personal beliefs, repeating SI tasks, and reflecting

about each activity. Each of these helped participants learn about SI and gave them ideas of how SI can be used in a science classroom.

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APPENDIXES

APPENDIX A

Pendulum Tasks

Task 1: Create a pendulum with the fastest possible period. Create a second pendulum with the slowest possible period.

Pre-activity

1. Predict what design will allow you to successfully complete this activity.

Task 2: Through experimentation, try to determine the mathematical relationship between the variables that determine the pendulum period. (For example, are the variables directly related? Does one variable have 10 times the effect of another?)

Pre-activity

1. Predict what design will allow you to successfully complete this activity.

2. How might a scientist attempt to solve this problem?

Task 3: Using what you have learned in the previous 2 tasks and any materials that are available to you, design an inquiry lesson about pendulums that you might use in your science classroom.

APPENDIX B

Circuit Tasks

Task 1: Choose one wire, one battery, and one bulb. Using these three items make the bulb light up.

1. Predict what design will allow you to successfully complete this activity.

Task 2: Using two batteries, any amount of wire, and the same bulb from task 1, make the bulb light up at twice the brightness as it did in task 1.

Pre-activity

1. Predict what design will allow you to successfully complete this activity.

2. How might a scientist attempt to solve this problem?

Task 3: Using two batteries, any amount of wire, and the same bulb from task 1, make the bulb light up at the same brightness as it did in task 1.

1. Predict what design will allow you to successfully complete this activity.

Task 4: Using what you have learned in the previous 2 tasks and any materials that are available to you, design an inquiry lesson about electric circuits that you might use in your science classroom.

APPENDIX C

Demographic Survey

1. Name:

2. Gender: M F

3. Why are you enrolled in this course?

4. Please list any science classes you have taken, or are currently taking. These can be from high school or college.

5. Do you have any experience conducting science research? If so, please explain.

6. Do you have any experience teaching? If so, please elaborate.

APPENDIX D

VOSI-M

1. Scientists perform experiments/investigations when trying to find answers to the questions they put forth.

    a. Do scientists use their creativity and imagination during their investigations?
    b. If yes, then at which stages of the investigations do you believe scientist use their imagination and creativity? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    c. If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

2. a. Write a definition of a scientific experiment.
    b. Give an example from something you have done or heard about in science that illustrates your definition of a scientific experiment.
    c. Explain why you consider your example to be a scientific experiment.

3. A person interested in birds looked at hundreds of different types of birds that eat different types of food. He noticed that birds that eat similar types of food tended to have similar shaped beaks. For example, birds that eat hard-shelled nuts have short, strong beaks, and birds that eat insects from tide pools have long, slim beaks. He concluded that there is a relationship between beak shape and the type of food birds eat.

    a. Do you consider this person's investigation to be scientific? Why or why not?
    b. If you do not think how work was scientific, how would you change the investigation to be scientific?

4. Some people have claimed that all scientific investigations must follow the same general set of steps or method to be considered science. Others have claimed there are different general methods that scientific investigations can follow. What do you think? Choose one of the following answers.

    a. Yes, there is one scientific method. If you believe this is true, what are the steps of this method?
    b. No, there is more than one scientific method. If you believe this is true, describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.

5. There are several scientists, working independently, asking the same question (for example they all want to find out what Georgia looked like 10,000 years ago or the structure of a certain protein).

   a. Will they necessarily come to the same conclusion? Explain why or why not.
   b. Does your response change if the scientists are working together? Explain.

6. a. What does the word "data" mean in science?
   b. Is "data" the same or different from "evidence"? Explain.

7. a. What is data analysis?
   b. What is involved in doing data analysis?

Notes

1. Question 1 was taken from VNOS-C (Lederman et al., 2002) and questions 2 – 7 were taken from VOSI (Schwartz et al., 2001).
2. When this questionnaire was administered, each of the questions appeared on a separate sheet of paper to encourage participants to respond freely and in detail.