University of South Florida
Scholar Commons

Graduate Theses and Dissertations

Graduate School

2008

Personal epistemological growth in a college chemistry laboratory environment

Linda S. Keen-Rocha
University of South Florida

Follow this and additional works at: http://scholarcommons.usf.edu/etd

Part of the American Studies Commons

Scholar Commons Citation

Keen-Rocha, Linda S., "Personal epistemological growth in a college chemistry laboratory environment" (2008). *Graduate Theses and Dissertations.*
http://scholarcommons.usf.edu/etd/327

This Dissertation is brought to you for free and open access by the Graduate School at Scholar Commons. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Scholar Commons. For more information, please contact scholarcommons@usf.edu.

Personal Epistemological Growth in a College Chemistry Laboratory Environment

by

Linda S. Keen-Rocha

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
Department of Science Education
College of Education
University of South Florida

Major Professor: Dana L. Zeidler, Ph.D.
Kathy Carvalho-Knighton, Ph.D.
Elaine Howes, Ph.D.
Kofi Marfo, Ph.D.
Noreen Poor, Ph.D.

Date of Approval:
May 9, 2008

Keywords: chemistry education, laboratory instruction, microcomputer-based, pedagogy, intellectual development, student images

© Copyright 2008, Linda S. Keen-Rocha

Dedication

I dedicate this dissertation to the most important people in my life.

To my husband and best friend, Michael Rocha: for your encouragement, love, support and understanding.

To my daughters Jennifer and Heather: for your friendship, hugs, love, and support.

To my dad and mom, Lawrence and Myrtle Keen: for encouraging me to be the best I could be.

To my sister, Debbie Allen: for being not only my sister, but a friend.

To the memory of my grandmother, Leah Keen: for your unconditional love, inspiration, and support.

Acknowledgements

I wish to thank my committee members, Dr. Kathy Carvalho-Knighton, Dr. Elaine Howes, Dr. Kofi Marfo, and Dr. Noreen Poor for their feedback, support, and guidance through this dissertation.

Thanks to Dr. Kathy Carvalho-Knighton for providing me with a multitude of opportunities and experiences as a graduate research and teaching assistant in chemistry and chemistry education.

Foremost, I wish to thank my major professor and mentor, Dr. Dana Zeidler. His faith in my abilities, insights and guidance has been indispensable to my education.

I thank all the teachers who have guided me in my learning experiences from Florida, Hawaii, Maryland, and Virginia. I express my gratitude for these individuals, who opened up the world by instilling a passion in me for learning, thinking, and knowledge.

A special thanks to Kristy Loman Chiodo for performing the interviews for this study as well as the students that participated in this study.

Finally I thank my family (Michael, Jennifer, and Heather), my sister (Debra A.) and friends (Loretta H., Chyrisse T., and Linda M.) who supported all my efforts and gave me encouragement until the very end. And most of all thanks to my two grandsons, Rod and Jake Eason for all the hugs, kisses, and laughter you gave freely during the last few years of this experience.

Table of Contents

List of Tables

List of Figures

Personal Epistemological Growth in a College Chemistry Laboratory Environment

Linda S. Keen-Rocha

ABSTRACT

The nature of this study was to explore changes in beliefs and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) for future research. This research employed a mixed methodology, foregrounding qualitative data. The total population consisted of 56 students enrolled in several sections of a general chemistry laboratory course, with the qualitative analysis focusing on the in-depth interviews. A quantitative NOS and epistemological beliefs measure was administered pre- and post-instruction. These measures were triangulated with pre-post interviews to assure the rigor of the descriptions generated.

Although little quantitative change in NOS was observed from the pre-post NSKS assessment a more noticeable qualitative change was reflected by the participants during their final interviews. The NSKS results: the mean gain scores for the overall score and all dimensions, except for amoral were found to be significant at $p \leq .05$. However there was a more moderate change in the populations' broader epistemological beliefs (EBAPS) which was supported during the final interviews. The EBAPS results: the mean gain scores for the overall score and all dimensions, except for the source of ability to learn were found to be significant at $p \leq .05$. The participants' identified the laboratory work as the most effective instructional feature followed by the post-laboratory

activities. The pre-laboratory was identified as being the least effective feature. The participants suggested the laboratory work offered real-life experiences, group discussions, and teamwork which added understanding and meaning to their learning. The post-laboratory was viewed as necessary in tying all the information together and being able to see the bigger picture.

What one cannot infer at this point is whether these belief changes and beliefs about laboratory instruction are enduring or whether some participants are simply more adaptable than others are to the learning environment. More research studies are needed to investigate the effects of laboratory instruction on student beliefs and understanding.

Chapter One: The Problem

Introduction

There is growing recognition in educational and psychological research regarding how learners' epistemologies play an important role in helping them construct knowledge. Epistemology, the study of knowing and knowledge, has been one of the major foundations of the philosophy of science education. Amid the fundamentals of epistemological research are questions relating to the nature and form of human knowledge and about the processes by which such knowledge is verified.

Science students, science educators, and scientists hold different images of learning science. Many of their own ideas about science and the construction of scientific knowledge differ. These differences are observed more often by students when engaged in learning environments in the physical sciences such as chemistry and physics. The most effective chemical pedagogical techniques used in learning chemistry are those that create a cognitive conflict with an inadequate mental model held by a learner, leading to dissatisfaction with his or her current view. As learners move from secondary school through college, they experience a developmental progression in their attitudes toward knowing, learning, and teaching. Therefore, it is important for college science faculty, in their roles as instructors, to assume a new level of responsibility for understanding the various dimensions of epistemological beliefs of their students, as well as what beliefs they hold themselves. Pedagogical techniques designed to help science students attain the intellectual maturity they will need to function effectively as science professionals must attend to and promote the epistemological development of the learner.

Facilitating meaningful learning in college science education contexts has been the focus of many research studies, particularly within the body of literature concerning student learning. The image that researchers have about knowledge and knowing centers on a range of research avenues that include the following: epistemological beliefs (Schommer, 1990), epistemological theories (Hofer & Pintrich, 1997), reflective judgment (King & Kitchener, 1994), and epistemological reflection (Baxter Magolda, 2004). These areas are part of a larger body of research categorized as "personal epistemology" (Hofer & Pintrich, 2002).

The field of "personal epistemology" examines what learners believe about how knowing occurs, what counts as knowledge, where knowledge resides, how knowledge is constructed, and how knowledge is evaluated (Hofer, 2004). An extensive body of research indicates that educators need to focus on how epistemological beliefs influence student learning.   Learning always requires the development of an epistemological perspective about the content within the context of a certain domain of knowledge (e.g.; science). Epistemology as defined by Hofer and Pintrich (1997) concerns the nature and justification of human knowledge, while epistemological beliefs denote "the theories and beliefs they hold about knowing, and the manner in which such epistemological premises are part of and an influence on the cognitive processes of thinking and reasoning."

Students have a range of images of science also referred to as the Nature of Science (NOS) beliefs. Abd-El-Khalick and Akerson (2004) suggest that students' understanding of the NOS is impacted by their personal epistemological beliefs, aka worldview beliefs. Students learning of the NOS is mediated often by motivational, cognitive, and worldview factors. Lederman (1998) defines NOS as the characteristics of the scientific enterprise that are accessible and relevant to one's everyday life and include the following aspects: creativity, culture, empirical basis, tentativeness, theory based and socially embedded. Therefore, learners' personal epistemology about the nature of scientific knowledge and knowing can be their domain-specific epistemology of science (Hogan, 2000). Ryder, Leach, and Driver (1999) studied undergraduate science students' images of science and suggested three main epistemological positions concerning the NOS: knowledge claims as description; knowledge claims as distinct from data, yet provable; and knowledge claims as going beyond the data. The range of images presented by science learners' can offer a profile of epistemological and sociological reasoning of each individual. Epistemological belief systems have been shown to affect a plethora of students conceptual understanding of how science connects to real world problems that are embedded in socioscientific issues (Ryder, et al., 1999; Zeidler, Walker, Ackett, & Simmons, 2001). Students have had a wide range of exposure to science including K-12 education, undergraduate science, interactions with science instructors, televised scientific documentaries, and scientific issues reported through various forms of news media. These experiences with science give students episodic knowledge about science. According to Ryder, et al., (1999) from a social reasoning perspective these episodic experiences of the world of science will form the basis of external and internal dialogue about science through which student images of science are constructed, sustained, and changed. In other words, depending on the context, the learner will draw on different forms of reasoning.

The remainder of this chapter presents the problem statement, the nature of the study as well as introduces concepts and issues central to the research: nature and development of personal epistemology, the role of student images of science, the nature of chemistry learning, the possible link between personal epistemology and NOS, the role of the laboratory instructional environment, and research methodology issues. In addition, the research questions are presented followed by the study's significance for chemistry education research.

Nature of the Study

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research. This study used a semi-naturalistic mixed-methods approach to investigate the following: whether students' personal epistemological and nature of science (NOS) beliefs change by the completion of a semester general chemistry laboratory course and what laboratory pedagogical practices (pre-lab, laboratory work, or post-lab) that students believe were essential to their understanding of the laboratory material. In addition, the study examined what laboratory pedagogical practices students believe influenced their personal epistemological and/or NOS beliefs.

The consensus among researchers is that quantitative and qualitative research, also known as, mixed-methods research can complement each other by providing richer insights and raise more interesting questions for future research than if only one method is considered (Gall, Borg, & Gall, 2003). By definition, mixed-methods research is where the researcher combines qualitative and quantitative research techniques to answer research questions when the constructs and their measures can be specified in advance of data collection, but also use qualitative methods to discover additional constructs that are relevant to the study's goals.

A mixed-methods approach to evaluation can increase both the reliability and validity of evaluation data. The validity of results can be strengthened by using more than one method to study the same phenomenon. This approach called triangulation is considered the main advantage of the mixed-method approach.

A search of academic data bases or the Internet would identify a variety of studies in the behavioral, educational, health and social sciences that utilize a mixed-methods approach (Tashakkori & Creswell, 2007). These studies are considered “mixed” because they utilize qualitative and quantitative methods in one or more of the following ways: (1) two types of research questions (with both methods); (2) two types of data collection procedures (e.g., surveys and interviews); (3) two types of data (e.g., numerical and textual); (4) two types of data analysis (e.g., statistical and thematic); and (5) two types of conclusions (e.g., emic and eitic representations, “objective and subjective, “ etc.) (Libarkin & Kurdziel, 2002; Tashakkori & Creswell, 2007).

There will be three data collection phases for this study, which will be described in the methodology section. In the first phase of data was collected from the participants using a quantitative assessment to determine the participants’ current understanding of chemistry knowledge, as well as surveys to determine their current personal epistemological beliefs of the physical sciences, current nature of science beliefs, and current beliefs about laboratory practical work.

The second phase of data collection occurred during the semester course. During this phase, since the researcher was the instructor an outside interviewer conducted the initial semi-structured interviews with volunteering participants to further examine their beliefs. In addition, the participants completed a laboratory instructional questionnaire after each laboratory experience to assess their reaction to the three broad areas of instructional methods associated with each laboratory activity (e.g., pre-laboratory, laboratory work, and post laboratory). Data was collected regarding the participants preferred laboratory instructional methods.

The final phase of data collection occurs at the end of the semester. During this phase, the initial belief assessments concerning personal epistemological and NOS beliefs were re-administered The data from the pre and post assessments and surveys was analyzed to determine if the participants' beliefs changed by the completion of the semester course.   This was followed with an outside interviewer conducting a final semi-structured interview with those participating in the initial interviews. Data was collected regarding the participants' actual and preferred laboratory instructional method(s) and current personal epistemological and NOS beliefs.

Reliability usually measures the extent to which the results of an instrument or study would be replicated given the same sample. Reliability is an important pre-condition for establishing validity (Lincoln & Guba, 1985). However, the qualitative research tradition recognizes that participants and their interpretations of research instruments are dynamic. Therefore, exact replication of results is not an assumption of this study. Initial and final interviews were implemented to assist in checking the validity of the participants' scores on the EBAPS and NSKS. The initial scores of the interview participants were compared to their initial interview responses. This method was repeated with the final scores and interviews. The Cronbach alpha coefficient as well as Pearson correlations are reported and used as indicators of internal consistency and to describe the strength and direction of the linear relationship between the dimensions of each instrument.

This study was of an exploratory nature to lay a foundation for focusing on more specific features of epistemological and NOS reasoning in light of specific instructional features (pre-lab, laboratory work, or post-lab) for future research. Therefore the use of the word "growth" in the title of the dissertation may be a misnomer. It is a bit too presumptuous to infer growth patterns from two data points. The design of the study makes it difficult to explain the observed changes either as indicators of the general effects of instruction or of a particular form of instruction. In any event there is not sufficient data to make definitive claims about “growth”. The word change may be a more suitable term.

Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants’ responses to the pre-post assessments. A paired-samples t-test (repeated measures) was used to compare the pre-post mean scores for the participants. The variability for the paired-samples t-test was calculated using eta squared. The effect size (d) was interpreted using the guidelines from Cohen (1998). In this dissertation, effect sizes were calculated from the mean gain score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. To interpret the effect size values the following guidelines from Cohen (1998) were used: 0.20 = small effect, 0.50 = moderate effect, and 0.80 = large effect. Pearson product-moment correlation was used to determine the degree that quantitative variables were linearly related.

The variability for the paired-samples t-test was calculated using the formula for eta squared. Eta squared can range from 0 to 1 and represents the proportion of variance in the dependent variable that is explained by the independent variable. To interpret the eta squared values the following guidelines from Cohen (1998) was used: 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect. Variablity is defined here as t^2 divided by t^2 plus sample size minus 1 (eta squared = t^2 / t^2 + N-1). The data analysis is discussed further in chapters three and four.

Research Issues

Nature of Personal Epistemology

Personal epistemology has its origins in the theories of cognitive development and the studies of student intellectual development (Hofer, 2004). Over the last twenty-five years, researchers have conceptualized personal epistemology in two ways: as a cognitive developmental process that proceeds in a patterned, one-dimensional, developmental sequence (Baxter Magolda, 1992; King & Kitchener, 1994) and as a belief system (Schommer, 1994; Schraw, Bendixen, & Dunkle, 2002). Those who view personal epistemology as a developmental progression have suggested that learners move through a developmental sequence that reflects an evolving ability to coordinate the objective and subjective aspects of knowing (Baxter Magolda, 1992; King & Kitchener, 1994; Kuhn & Weinstock, 2002). According to Pintrich (2002), many in the field hold the belief that the construct of personal epistemology involves the nature of knowledge and knowing. This construct includes beliefs about (1) the certainty of knowledge, (2) the justifications for knowing, (3) the simplicity of knowledge, and (4) the source of knowledge (Bendixen & Rule, 2004). Baxter Magolda (2004) views these beliefs as the core of personal epistemology. The overarching purpose of this study is to investigate the nature of personal epistemology in the context of the learner's views about thinking and beliefs about knowledge and knowing in science in general, and chemistry in particular. Figure 1 presents a graphic organizer of the major themes related to core epistemological beliefs which are addressed in this section, and relevant to the main focus of this study.

Development of Personal Epistemology Over Time

Since the 1960s, numerous studies have presented countless links between epistemological beliefs and learning (Hofer & Pintrich, 1997; Schommer & Walker, 1997). A learner's individual epistemological beliefs have become the focus of research in the educational, particularly the psychological literature, and mathematical and science education. Research studies indicate the more learners believe that knowledge is simple, certain, and handed down by an authority figure, the more likely they are to generalize complex contextual information, perform poorly on assessments, misinterpret tentative conclusions, and seek single solutions when multiple solutions are more suitable (Schommer, 1990). In science education investigations of learners' belief systems in relation to scientific concepts have revealed that held beliefs will influence learners' behavior and processing of information while other studies have demonstrated that learners' belief systems about their failures or successes affect their effort and performance (Kuhn, Amsel, & O'Loughlin, 1988). Analysis of the literature suggests that epistemological beliefs are multidimensional and multilayered. That is, learners possess general beliefs about knowledge, as well as beliefs about academic forms such as scientific knowledge.

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological beliefs in light of specific science laboratory instructional features for future research. This study investigated the development of personal epistemological beliefs in the context of whether students' personal epistemological beliefs of science (chemistry) change by the completion of a semester general chemistry laboratory course.

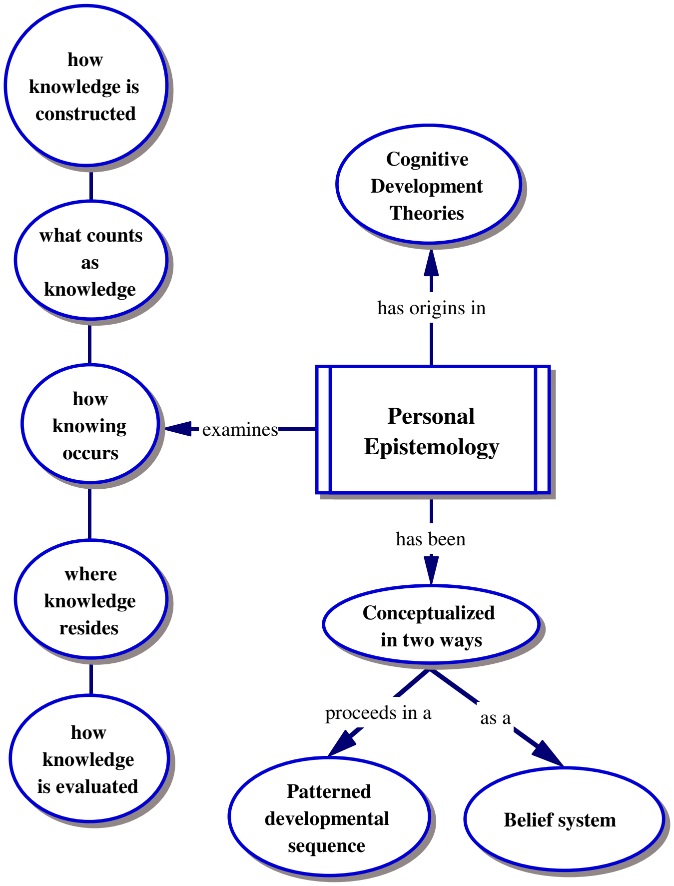


Figure 1 Graphic summary of personal epistemology

Constructivist Manner and Cognitive Disequilibrium

Personal epistemological beliefs vary from naïve (novice), dualistic beliefs in the existence of fixed truths to the sophisticated (expert), relativistic beliefs that knowledge is tentative, personal, and relative to a variety of contexts (Bransford, Brown, & Cocking, 2000). The term naïve (novice) is used particularly in relation to learners who have an inclination to believe that truth is certain, absolute, and transferred by an authority. The term sophisticated (expert) on the other hand, is used in relation to learners who believe that truth is relative, changing, and actively constructed by the learner.

The consensus among researchers is that personal epistemologies may develop in a constructivist manner (Hofer & Pintrich, 1997; King & Kitchener, 1994) but the actual process or mechanism is undefined. Bendixen and Rule (2004) identified cognitive dissonance and personal relevance as two potential conditions for the mechanism of epistemological change. Cognitive dissonance, a psychological event, refers to the uneasiness felt when a discrepancy occurs between what the learner already knows and new information. Therefore, dissonance occurs when there is a need to accommodate new ideas. However, if learners are called upon to learn something which contradicts what they already think they know, particularly if they are committed to that prior knowledge, they are likely to resist the new learning unless it has personal relevance. Under these conditions having a share in the outcome, an interest in the topic or emotional involvement may promote epistemological belief change.

Change in epistemological beliefs takes place when learners are challenged to reconstruct naive beliefs into more sophisticated ways of knowing (Hofer & Pintrich, 1997). Evidence from some studies suggests that education influences epistemological development (Perry, 1970; Schommer, 1993) specifically in college curricula that exposes the learner to a variety of educational viewpoints. Learners who develop expertise in knowing and learning through advanced education and life experiences may be more able to see multiple perspectives and offer tentative explanations when defending their perspectives of what constitutes knowledge and beliefs. Exposure to advanced education and life experiences may cause cognitive conflict that results in the reconstruction of naive epistemological beliefs into more relativistic, sophisticated beliefs about knowing (Belenky, Clinchy, Goldberger, & Tarule, 1986; Schommer, 1994). However, other studies suggest that the realization of a sophisticated, critically aware view toward knowledge is rare even in adulthood (King & Kitchener, 1994; Kuhn, 1991) and that an advanced education may have a smaller effect than predicted (Hofer &

Pintrich, 1997**).** Figure 2 provides a general summary of pedagogical factors that are theoretically linked to students' epistemological theories.

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research. This study investigated what laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) that students believe were essential to their understanding (cognitive dissonance) during the semester general chemistry laboratory learning experience. In addition, the study examined the extent that the laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) the students believe influenced their personal epistemological and NOS beliefs about science during the semester general chemistry laboratory course.

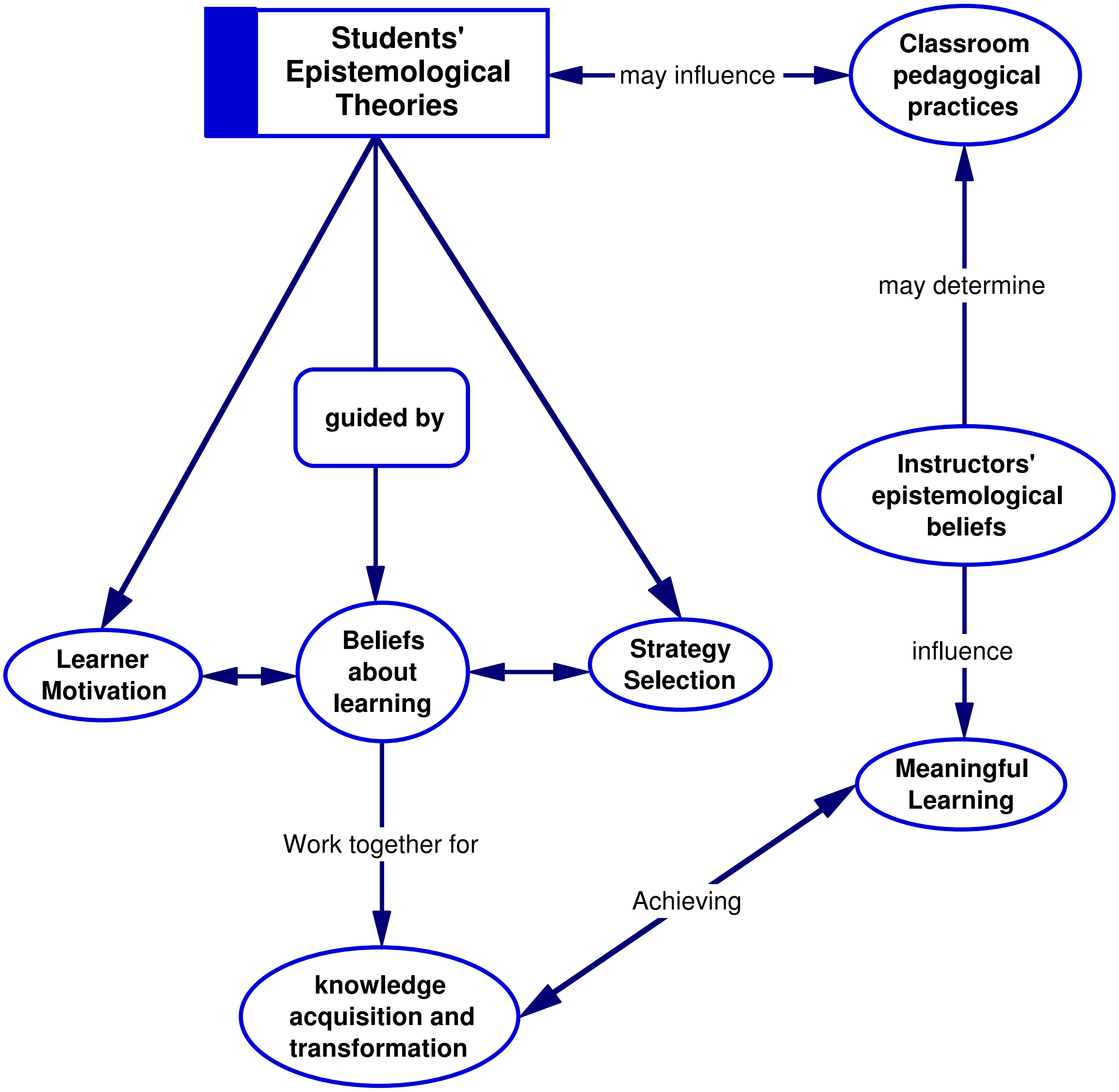


Figure 2 Graphic summary of pedagogical factors connected to students' epistemological theories

Nature of Science

The phrase Nature of Science (NOS) is used in discussing issues such as what science is, how science works, the epistemological and ontological foundations of science, how scientists operate as a social group, and how society influences and reacts to scientific endeavors (Clough, 2006). According to Khishfe and Lederman (2005) there is no consensus among scholars on a specific definition for the NOS. The NOS in general refers to the epistemology of science, science as a way of knowing, or the beliefs and values associated with the development of scientific knowledge (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). The characteristics of NOS include the concepts that scientific knowledge is tentative, empirically based, subjective (theory-laden), to a certain extent the product of human inference, imagination, and creativity, and socially and culturally embedded.

Conceptions of the NOS have changed with developments in different scientific disciplines. For instance, in physics there has been a change from the classical deterministic conceptualization to a quantum indeterministic conceptualization of the discipline. These changes in the conceptions of the NOS have mirrored shifts in emphasis and focus in the areas of the history, philosophy, and sociology of science.

Nature of Students' Images of Science

Science students develop images of science from an early age as a result of messages communicated through daily experiences, education and the media. These images of science profile the mental representations of science that inform a learner's decisions about how to respond within a scientific context (Leach & Driver, 1997). At the core of students' images of science is their beliefs and understanding about the Nature of Science (NOS).

Naïve personal images of science have been identified as a major obstacle to the achievement of conceptual change in science education (Bransford, et al., 2000; Schommer, 1993; Songer & Linn, 1991; Thoemer & Sodian, 2002,). Lederman (1992) concluded from a review of the literature on students' understanding of the NOS that students' views reflect misconceptions about the nature of scientific knowledge. The NOS is a complex and theoretical concept that involves reflecting on the scientific enterprise in ways not encouraged by the usual textbook-based science curriculum (Bell, 2001).

Students' images of science provide reference points that enable them to act within a scientific environment (Ryder, et al., 1999). Students can draw on these images when discussing science and in choosing an appropriate course of action during a scientific task.

This study investigated the development of the Nature of Science (NOS) in the context of whether students' NOS beliefs change by the completion of a semester general chemistry laboratory course. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to NOS beliefs in light of specific science laboratory instructional features for future research.

Nature of Chemistry Learning in the Laboratory

Chemistry is an experimental science. The social nature of chemistry learning is established by the human interaction that occurs in the general chemistry laboratory, just as in any research or larger scientific community. In addition to the social nature is the perspective that knowledge is not transmitted from person to person but is constructed by student interactions through self-thought and communication (Driver, 1989). The actual learning of chemistry requires that student's converse in order to have their views accepted or rejected. In addition, this learning requires that learners listen to and analyze the views of other learners as well as the experts.

Laboratory instructional environments have had a long standard and central role in the science curriculum. Laboratory instruction is viewed as an important component of undergraduate chemistry education. The value of chemistry laboratory instruction has been questioned on the grounds of both cost and meaningful learning for many years. Although it has the potential to enrich the formation of chemistry concepts by fostering inquiry, intellectual development, manipulative skills, and problem-solving skills, it often fails to reach its full potential (Hofstein, 2004). Literature reviews of laboratory instructional environments have found it can be a learning environment in which very little meaningful learning takes place (Domin, 1999). The instructional activities are often “cookbook” in makeup with emphasis on collecting data using specific, detailed procedures with expected results. Almost no attention is placed on planning the investigation or analyzing data in order to interpret results. That is, students spend more time determining if they have obtained the “right” answer than actually thinking about the chemistry principles being applied and developing manipulative and observational skills (Johnstone & Al-Shuaili, 2001).

Berg (2005) discusses how the learner’s epistemological views of laboratory instruction can influence their cognitive processes. The student view that knowledge is a set of accumulated facts and he or she is a receptor of knowledge can create a conception of laboratory instruction as an illustration of facts and learning of procedures. The learner view that knowledge is an integrated set of constructs in which the learner constructs knowledge can stimulate a conception of the laboratory activity as a situation where knowledge is generated and the learner is learning not only procedures, but also scientific methods.

The effect that experiences and instructional strategies within the educational setting have on a learner's personal epistemological beliefs and attitudes is a major research interest. By definition, attitudes convey our evaluation of someone or something such as the notion "I like laboratory work" (Berg, 2005). Developing positive attitudes towards learning chemistry is one of the important goals of instruction. These can be divided into two affective aims; attitudes to chemistry (i.e., confidence, interest, motivation) and chemistry (scientific) attitudes. Attitudes are believed to be formed by affective, behavioral, and cognitive processes.

There is a need to know more about how the learner makes sense of the epistemological aspects of their instructional environments. For instance what practices are most relevant, how are they interpreted through the students' existing beliefs and knowledge, and which beliefs are being altered in the process.

This study sought to gain insight into which laboratory pedagogical methods the students believe influenced their understanding of the material being presented as well as their personal epistemological and NOS beliefs of science (chemistry) during a semester general chemistry laboratory course. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research.

Problem Statement

> "To many students, a 'lab' means manipulating equipment but not manipulating ideas."
>
> Lunetta, 1998, p. 250

Epistemology is defined as a theory of knowledge. As a subject of long-time interest to philosophers personal epistemology has become a topic of interest to educational psychologists and science educators (Hofer, 2001). Personal epistemological beliefs relate to the nature of knowledge and knowing. The two general areas that characterize the research of personal epistemological beliefs include: (1) examining the nature of development and change in how learners think about knowledge and knowing and (2) examination of how these beliefs can facilitate or constrain learner achievement, learning, reasoning, and thinking. With interest in the subject growing, several questions have surfaced in the context of college science laboratory instruction. What is personal epistemological development and why is it important to college science laboratory instruction? First, what does one mean by personal epistemological development? Research in this area broadly addresses personal epistemological development as a learners' thinking and beliefs about knowledge and knowing and usually includes some of the following ideas: definition of knowledge, how knowledge is constructed, how knowledge is evaluated, the self and the learning process, and metacognition (Benedixen & Rule, 2004; Hofer, 2001).

Other important issues to address include the images of science that undergraduate science students hold, how and if students' epistemological beliefs are linked to their images of science, how different instructional situations in the chemistry laboratory affect a learner's image of science and personal epistemology, what conceptual changes occur during instruction, and how student images of science affect that change. Perhaps even more important is why personal epistemology matters and what its implications are for student achievement. Are learners epistemological beliefs a result of the instruction they receive, do these beliefs determine how instruction is received, or is there a symbiotic interaction between the two? Research dealing with the importance of personal epistemological development in learning chemistry has increased dramatically within the last decade. According to Hofer (2001) epistemological perspectives play a significant role in learning experiences in which learners encounter new knowledge.

Given the parallels between personal epistemology and NOS beliefs, it is easy to concede that a relationship must exist between the two. As both constructs deal with beliefs about knowledge, it may be rational to assume that NOS is a part of the science beliefs component of personal epistemologies. According to Hogan (2000), research that defines learners' knowledge about the NOS more as a belief, than as declarative knowledge overlaps with studies on the psychological construct of epistemology. Personal epistemologies can act as standards for judging the validity of knowledge claims (Hewson, 1985; Hofer & Pintrich, 1997). Therefore, personal beliefs learners have about the nature of scientific knowledge and knowing can be considered to be their domain-specific epistemology of science. This does not imply that all the knowledge a learner possesses about the scientific enterprise is an epistemological belief. However, studies on the relationship between personal epistemologies and NOS are virtually nonexistent. What is unclear is what effect NOS instruction has on learners' epistemological development.

The way students approach and view the laboratory learning environment is affected by students' personal epistemological beliefs and images of science. As discussed earlier some students hold the conception that knowledge is a set of accumulated facts and view laboratory learning as an illustration of facts and learning of routine procedures. On the other hand, the conception that knowledge is an integrated set of constructs and that students construct their own knowledge may promote a view of laboratory learning as an endeavor in which knowledge is generated and the student learns not only procedures, but also the nature of science (Berg, 2005).

Despite the research most of the epistemological and NOS studies have investigated the college science classroom (e.g. lecture) (Dagher, Brickhouse, Shipman, & Letts, 2004; Hofer, 2004; Hofer, 2000; Wenk & Smith, 2004) and only investigated general NOS and epistemological beliefs related to learning outcomes in the laboratory (Bell, 2004; Hofstein & Lunetta, 1982; Ryder, et al., 1999; Wickman, 2003). It remains to be determined whether certain effective instructional practices are linked to the development of specific epistemological and NOS beliefs. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research. The major intent of this study was to determine whether students' NOS and personal epistemological beliefs of chemistry change by the completion of the semester course, as well as what laboratory classroom instructional practices did the students believe were necessary to their understanding of the laboratory material, and may of influenced their NOS and personal epistemological beliefs during a semester general chemistry course.

Definitions

Two constructs are central to this study's purpose: personal epistemological beliefs and nature of science. The constructs are defined to convey the meaning and the operational definition that is given to them.

Personal epistemological beliefs (PEB): Epistemology is a branch of philosophy that is directed toward theories of an individual's beliefs about the nature of knowledge and learning (Schommer, 1993). The core dimensions of personal epistemology include: (1) the nature of knowledge (structure and stability of knowledge) and (2) the nature of knowing (source and justification of knowledge claims). For the purpose of this study, personal epistemological beliefs will be defined as beliefs about the process of knowing and the nature of knowledge as related to science and learning science (Hofer & Pintrich,1997).

Nature of Science (NOS): NOS sometimes described as images of science is a broad area of human endeavor which includes the values and beliefs inherent to scientific knowledge, and its development. The consensus view of NOS objectives from science education scholars such as Lederman, Abd-Khalick, Bell, and Schwartz (2002) is extracted from international science education standards documents. These scholars define NOS as involving aspects related to the following terms: creative, empirically-based, human imagination, inferences, tentative, theory-laden, and socially and culturally embedded. For the purposes of this study, NOS refers to the epistemology of science or science as a way of knowing that includes the beliefs and values inherent to the development of scientific knowledge.

Possible Links Between PEB and NOS

According to Hofer (2002) personal epistemological beliefs deal with questions such as “how do we know what we know,” as well as a person’s beliefs about the nature of knowledge. Learners’ personal epistemological beliefs are unlikely to be equally relevant or advanced across a variety of subject contexts. This implies a need for a specific subject focus when considering learners’ personal epistemological beliefs. Similarly, NOS knowledge deals with learners’ personal epistemological values and beliefs inherent to scientific knowledge and its development (Abd-El-Khalik, Lederman, Bell, & Schwartz, 2002). Both constructs deal with the beliefs about knowledge.

Personal epistemological beliefs of science refer to learners’ understanding of how scientific ideas are built, including their knowledge about the process of knowing about scientific knowledge (Songer & Linn, 1991). In general, NOS refers to the epistemology of science, or science as a way of knowing that includes the values and beliefs inherent in the development of scientific knowledge. Studies concerning learning science suggest that student beliefs about NOS and science learning influence achievement (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Jehng, Johnson, and Anderson, 1993; Schommer, 1990).

The features of NOS can be useful in assisting learners to think about their epistemology. Investigating NOS can provide characteristics that differentiate science knowing from other ways of knowing and explicitly assist learners examine their rationale in forming ideas (Duschl, Hamilton, & Grandy, 1992).

Research Questions

Question 1

What range of personal epistemological beliefs (development level), and images of chemistry (NOS) do undergraduate science students have at the beginning of a general chemistry laboratory course?

Rationale. Personal epistemologies are quite simply a learner's beliefs about the nature of knowledge (Hofer & Pintrich, 1997). Studies of personal epistemology attempt to determine how learners focus their conceptions of knowledge and knowing and how these are used to develop an understanding of the world (Hofer, 2002).

Indeed sophisticated epistemological beliefs are not essential for survival. However, when considering credibility of sources, how to weigh evidence, and how to make decisions about the world, we see that each of these constructs depends on our underlying beliefs about knowledge. According to Hofer (2002), the importance of these beliefs can be seen in action everyday from selecting politicians and serving on juries, to the choices we make in our daily lives.

Research has shown as well as having a conceptual understanding of science, the importance of students' understanding the NOS. This understanding includes the students' epistemological "values and beliefs inherent to scientific knowledge and its development" (Add-El-Khalik, Lederman, Bell, & Schwartz, 2001). According to Ryder, Leach, and Driver (1999), knowledge relating to science can be viewed as involving two interrelated areas, the knowledge of science and the nature of science. The knowledge of science involves concepts, ideas, laws, models, theories and experimental procedures of science. The NOS may include the social and cultural aspects of science, how scientists decide what to investigate, how to interpret data once collected, and how to believe findings published in research journals.

Bringing undergraduate science students inside of science involves introducing both areas of knowledge. Research studies have identified two basic arguments supporting the significance on learning of student's images of science (Ryder, et. al., 1999). The first argument is that from a learning perspective evidence from studies suggests that students' approaches to learning are influenced by their images of the nature of the discipline (Leach, Ryder, & Driver, 1997; Schommer, et. al., 1992; Songer & Linn, 1991). For instance, students holding the view that the endpoint of a laboratory investigation is the data collected and not the interpreting of that data using theoretical insights. The second argument is from a "cultural perspective" that when these science students graduate they will be required to make decisions that require an understanding of the nature of science such as critiquing a research paper, preparing documents on scientific issues, or informing the public on scientific evidence. It is possible for individuals to have epistemological beliefs that are both sophisticated (more relativistic) and naïve (more dualistic) (Brownlee, 2002). Magolda (2002) suggests that direct observation or interview is the best way to investigate a subject's beliefs.

This study examined undergraduate science students' initial images of the NOS and personal epistemological beliefs of chemistry during a semester general chemistry laboratory course using the *Epistemological Beliefs Assessment for the Physical Sciences* (EBAPS) and the *Nature of Scientific Knowledge Scale* (NSKS). The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research.

Sub-Question 1-a

Do students' images of the nature of chemistry (NOS) change over the course of laboratory instruction by the completion of a semester general chemistry laboratory course?

Rationale. According to Lunetta (1998), many students view laboratory as a means of manipulating equipment but not manipulating ideas. The science laboratory has been thought of as one of the best places for the building and refining of student images of scientific knowledge. The purpose of laboratory instruction is to develop a student's knowledge of the natural world, understanding of scientific concepts, understanding of how scientists undertake empirical investigations to address a problem of interest, and the ability to use standard laboratory instruments and procedures in investigations (Leach, Millar, Ryder, Sere, Hammelev, Niedderer, & Tselfes, 1998; Millar, Le Marechal, & Tiberghien, 1998). Students carrying out laboratory activities must draw upon understandings of the nature of the data, the scientific claims, the ways in which these claims and data are related, and the purposes of using certain instruments, procedures and techniques. Encouraging learners to self-reflect on their learning may provide insight into how laboratory instruction may influence their science images. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to changes in NOS beliefs in light of specific science laboratory instructional features for future research. This study sought to investigate if during instruction student images of the NOS (chemistry) change during a semester general chemistry laboratory course.

Sub-Question 1-b

Do students' personal epistemological beliefs about science (development level) change by the completion of a semester general chemistry laboratory course?

Rationale. Bell (2004) explains in terms of epistemological outcomes that students develop images of science from their laboratory investigations and learn about their own learning. Studies involving student images of science indicate that these images influence student learning and participation during laboratory instruction (Sere, Leach, Niedderer, et al., 1998; Tibergein, Veillard, Le Marechal, Buty, & MIllar, 2001; Ryder, et.al., 1998). Buehl and Alexander (2004) point out that as student beliefs became more sophisticated, the learning strategies they used also became more sophisticated. However, little is known about how science laboratory experiences and instruction develop students' images of science thereby influencing their personal epistemological development.

According to Hofer and Pintrich (1997) there is a consensus in the field of research on personal epistemological beliefs about a trend toward developmental progression, especially for those who experience a college education. Nevertheless, there is little agreement on what causes the change (Hofer & Pintrich, 1997; Hofer, 2000; Paulsen & Wells, 1998; Schraw, 2001). Student's personal epistemological beliefs have been shown to influence attitudes and behavior in a variety of contexts, including the academic areas (Schommer, 1990). A literature review by Schommer (1994) described that “epistemological beliefs may help or hinder learning” as the beliefs “affect the degree to which learners: (1) actively engage in learning, (2) persist in difficult tasks, (3) comprehend written material, and (4) cope with ill-structured domains.” Students' epistemological beliefs and images of science affect their mindset, metacognitive practices, and study habits.

Evidence from studies suggests that having a more mature epistemology in science contributes to better learning of science content (Hammer, 1994; Schommer, 1993; Songer & Linn, 1991). In addition, more mature epistemologies in science are associated both with understanding how to evaluate competing evidence in science and understanding that the existence of uncertainty in science does not weaken science’s usefulness in decision making in light of controversies (Schwab, 1962). Despite the importance of developing mature scientific epistemologies, studies of college students repeatedly demonstrate that college students enter (and often leave) college with fact-based views of knowledge and authority-based means of making decisions (Baxter Magolda, 1992; Hofer & Pintrich, 1997; King & Kitchener, 1994). The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological belief changes in light of specific science laboratory instructional features for future research. This study sought to investigate the extent student personal epistemological beliefs change by the completion of laboratory instruction.

Question 2

What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

Rationale. Supporting meaningful learning in chemistry requires the implementation of appropriate pedagogical practices. Within the laboratory learning environment inquiry-based instruction, cooperative groups, self-reflection, use of learning technologies (e.g. MBL), pre- and post-laboratory activities, and small-group discussions can facilitate the development of a student's personal epistemology (Drayton & Falk, 2002; Felder & Brent, 2004; Tapper, 1999). However, interviews in an epistemological study of instructional strategies by Hofer (2004) evoked a sense from the students that altering their personal epistemological beliefs might also alter a sense of self. It appears that learners filter their perceptions of instructional practices through their own epistemological perspectives.

Learners need to be afforded the time necessary for the "deep processing" of these principles with higher-order cognitive tasks (pedagogical strategies). Through the use of higher-order pedagogical strategies students are able to integrate their new experiences with prior knowledge, establish a context for the laboratory instructional activity, and determine its relevance, all of which are characteristics of intellectual development (epistemological change) (Felder & Brent, 2004). Science education research literature (Hofstein & Lunetta, 2004; National Research Council, 1997) emphasizes the importance of rethinking the role and practice of laboratory instructional environments. According to Hofer (2004), we need to know more about how learners make sense of the personal epistemological aspects of their instructional environments, what pedagogical strategies are most salient, and how learners interpret those strategies through their lens of images and beliefs. In this study, NOS instruction was not purposively implemented, however several of the laboratory activities offered inquiry-based aspects necessary for NOS instruction and are indicated in chapter three. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to their learning and specific science laboratory instructional features for future research. This study explored the laboratory pedagogical practices students believe were essential to their understanding during the semester general chemistry laboratory learning experience.

Sub-Question 2-a

What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their personal epistemological beliefs about science (development) during the semester general chemistry laboratory course?

Rationale. According to Hofer (2004) there is limited empirical evidence that explains what fosters changes in personal epistemological beliefs. However, it has shown that students' perceptions of instructional practices are interpreted through the lens of their epistemological beliefs. Researchers agree that epistemological beliefs develop over time and that better-educated students are more advanced in terms of their epistemological beliefs (Schommer, 1994, Valanides & Angeli, 2005).

Developmental models suggest that disequilibrium through educational pedagogy fosters a movement to stimulate cognitive conflict and subsequent reorganization. Empirical studies have also identified connections between personal epistemological beliefs, critical thinking, and reasoning skills (Valanides & Angeli, 2005). For example, Kuhn (1991) showed that evaluative epistemologists were more likely than others to use counter-arguments and generate alternative perspectives.

Studies suggest that epistemological beliefs can change when students work collaboratively and are given opportunities to reflect on their thinking and evaluate their beliefs such as in a laboratory setting (Hofer, 2001; Valanides & Angeli, 2005).

Schwab (1978) provides a broad framework for thinking about what occurs in educational settings. Schwab describes four “commonplaces”: the learner, the instructor, the learning environment in which learning takes place, and the subject matter. Three of the four commonplaces is addressed in this study, but narrowed to address the major constructs under investigation. More specifically, reference to the learner includes both the background of the student participants and exploration of their individual personal epistemological beliefs of science (chemistry). This study limited the focus to the laboratory environment and the subject matter of concern in chemistry. Various instructional elements that may carry an epistemological impact would need further investigation. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research.

Laboratory instructional pedagogy expected to have epistemological significance fall into one of three categories: pre-laboratory activities, laboratory work, and post laboratory activities. Although pilot observations in other general chemistry laboratory classes suggest that each of these might carry epistemological meaning, we do not know how students make such interpretations. This suggests the need for a study that explores these instructional practices in context. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological beliefs in light of specific science laboratory instructional features for future research. This study sought to investigate and identify the laboratory instructional practices that students believed influenced their personal epistemological beliefs during the semester general chemistry laboratory course.

Sub-Question 2-b

What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

Rationale. As stated previously the consensus definition of NOS is that it refers to the epistemology of science, science as a way of knowing or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992; Tao, 2003). The delivery of science (chemistry) instruction in most classrooms today rely heavily on textbooks that suggest that scientific knowledge has evolved in a linear and comprehensive manner (Zeidler, Walker, Ackett, & Simmons, 2002). By engaging learners in activities that bring to light the characteristics of science (chemistry), a more comprehensive representation of the NOS can be explored.

According to Bell (2004), attempts to improve learners' understanding of the NOS fall into two generalized instructional categories: (1) implicit approaches, where gains in understanding NOS stem implicitly through process skills and/or inquiry based instruction and (2) explicit approaches, where specific aspects of the NOS are addressed purposively and explicitly, usually in the context of the history or philosophy of science or inquiry-based instruction. Studies suggest that explicit approaches appear to more effective in facilitating understanding of the NOS (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002).

Coburn (2004) suggests that laboratory instruction can assist learners in developing an understanding of the NOS. However, learners will not learn about the NOS simply by performing a laboratory activity. Laboratory instruction can help learners understand the NOS if the activities are more open-ended and include reflective, active discussion sessions. In this study, NOS instruction was not purposively implemented, however several of the laboratory activities offered inquiry-based aspects necessary for NOS instruction and are indicated in chapter three. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to NOS beliefs in light of specific science laboratory instruction features for future research. This study sought to investigate and identify the laboratory instructional practices that students believed influenced their NOS beliefs during the semester general chemistry laboratory course.

Significance of the Study

Understanding the influences that learners' personal epistemologies and images of science have on their performance is one of the primary concerns of educational research. Previous research suggests that most college students are quite naïve in their images and epistemological understandings of science (Abd-El-Khalick & Lederman, 2000). Learners' personal epistemological beliefs and images of science can be profoundly influenced by the instructional context or learning environment. There is some evidence that indicates learner beliefs can strongly affect how they approach certain learning situations (Schommer, 1990). To help the learner advance from naïve belief that knowledge is simple, absolute, and certain instructors should use pedagogical activities that provide opportunities for the learner to discover that knowledge must be adapted, when applied and interpreted in different situations, thus revealing the dynamic and complex characteristics of the structure and nature of knowledge (Paulsen & Feldman, 1999).

The way a learner approaches and views the laboratory is affected by the learner's epistemological and NOS beliefs. The view that knowledge is a set of accumulated facts and the learner is a receptor of knowledge may lead to the view that laboratory is just an illustration of facts and learning of routine procedures. However, a view that knowledge is an integrated set of constructs and that the learner constructs knowledge may promote a view of laboratory as an endeavor in which knowledge is generated and the learners not only learn routine procedures, but also the nature of science.

Research in chemistry education focuses on understanding and improving chemistry learning. Research that focuses on understanding what goes on in chemistry courses is especially useful if one is trying to improve the teaching and learning of chemistry (Phelps, 1994). The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research. In addition, the study explored and laid a foundation for focusing on more specific features of reasoning related to their learning and specific science laboratory instructional features for future research. This chapter describes the main purpose of this study as determining whether students' NOS, and personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry course as well as, what laboratory pedagogical practices students' believe influenced those changes during a semester general chemistry laboratory course.

Summary

This chapter presented the problem statement, the nature of the study as well as introduces concepts and issues central to the research: nature and development of personal epistemology, the role of student images of science, the nature of chemistry learning, the possible link between personal epistemology and NOS, the role of the laboratory instructional environment, and research methodology issues. In addition, the research questions were presented followed by the study's significance for chemistry education research.

Chapter two presents a review of relevant studies in the science education and educational psychological literature focusing on the research questions described in earlier in this chapter. Chapter two is divided into six main sections and consisted of a review of relevant studies in the science education and educational psychological literature focusing on the research questions described in Chapter 1. The research literature includes reviews of: (1) models of personal epistemological development; (2) multidimensional models of personal epistemological development; (3) the nature of science; (4) research methodology issues; (5) the applicability to college science education; and (6) the nature of laboratory instruction.

Chapter three describes in six sections the design and methodology of the research study. Section one restates the purpose of the study, elaborates on the rationale behind the research questions, and presents an overview of the analysis, design, and methodology. Section two describes the context and participants of the setting. Section three discusses the research instruments, measures, and techniques which include the: (1) Chemical Concepts Inventory (CCI), (2) Epistemological Beliefs Assessment for the Physical Sciences (EBAPS), (3) Nature of Scientific Knowledge Scale (NSKS), (4) Students' Reflective Assessment of Laboratory Methods, and (5) In-depth semi-structured interviews. Section four identifies the forms of pedagogical treatment involved in the laboratory instruction. This section offers an overview of the laboratory environment and pedagogy. Included is a discussion of the three general instructional features under consideration for this study, pre-laboratory, laboratory work, and post-laboratory. Section five summarizes data collection giving a general overview of the phases of data collection and the researcher's role during the study. Section six summarizes the how the data is analyzed by describing the potential quantitative and qualitative analysis methods implemented for the study. The last section discusses aspects used in monitoring the reliability and validity of the data collection and analysis.

Chapter four presents a description of the participant sample followed by the presentation of the quantitative analyses of the study's first research question and sub-questions. The questions are presented with the quantitative results of the analyses for all the participants (N=56) and of the twenty whom participated in the interviews. The results are discussed and related back to the key NOS and personal epistemological beliefs literature.

Chapter five presents a description of the development of the participant's personal epistemological beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-b. The characterization of personal epistemological beliefs with the results of the analyses of the participants' responses to interview probes is presented. The combination of interviews and quantitative measures provides a glimpse into some students' personal epistemological beliefs changes during the course of a semester and what the participants' believed influenced their beliefs. The results are discussed and related back to the key personal epistemological beliefs literature.

Chapter six presents a description of the development of the participants' NOS beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-a. The characterization of NOS beliefs with the results of the analyses of the participants' responses to interview probes is presented. The combination of interviews and quantitative measures provide a glimpse into participants' NOS belief changes during the course of a semester and what the participants' believed influenced their beliefs. The results are discussed and related back to the key NOS beliefs literature.

Chapter seven characterizes the findings of the instructional features of the second research question and sub-questions 2-a, and 2-b. The characterization of laboratory instruction with the quantitative and qualitative results from the Student Evaluation of Laboratory Instruction Questionnaire as well as the results of the analyses of the participants' responses to interview probes is presented. This provides a glimpse of the participants' overall beliefs concerning the laboratory aspects of the semester course. The results are discussed and related back to the key laboratory education literature as well as the NOS and personal epistemological beliefs literature.

Chapter 8 of this dissertation presents an overview of the study, limitations to the study, a summary of the major findings, and areas for future research.

Chapter Two: Literature Review

Introduction

This study was primarily concerned with developing an understanding of the relation between a student's images of science, personal epistemological beliefs and laboratory classroom instructional practices. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research. In addition, the study explored and laid a foundation for focusing on more specific features of reasoning related to learning and specific science laboratory instructional features for future research. Therefore, this chapter comprises a review of relevant studies in the science education and educational psychological literature focusing on the research questions described in Chapter 1.

The first and second section of the review considers models of personal epistemological development beginning with a discussion of five major uni-dimensional epistemological models of development followed by a description of two multidimensional models of epistemological beliefs.

The third section is literature based on research concerning student's images of science. The section begins with a research-based definition of NOS, followed by a discussion of how students view NOS. This section concludes with a general overview of NOS instruments and the nature of NOS and personal epistemology.

The fourth section discusses research methodology issues related to the potential instruments used to assess students' NOS and personal epistemological beliefs. The discussion begins with a general overview of the types of instruments followed by two sections that review instruments currently used to assess the aforementioned beliefs in general and in the domain of science.

The fifth section relates to the applicability of promoting epistemological growth in the college science classroom through the use of certain pedagogical applications. The discussion begins with an overview of epistemological orientations in learning science followed by a description of assessing epistemological levels in the classroom in order to promote epistemological growth. The remainder of this section discusses six pedagogical applications identified in the literature that facilitate epistemological growth.

The final section consists of a review of the literature on science laboratory instruction. The section begins with a description of the nature of laboratory instruction, how the developmental levels relate to laboratory instruction, and concludes with a discussion of science laboratory pedagogy and instruction.

Models of Epistemological Development

Epistemological Intellectual Development

The leading body of research in the area of personal epistemology suggests that learners move through a patterned sequence of development in their beliefs about knowledge and knowing as their ability to make meaning develops (Hofer, 2001). Each of the five developmental models has its origins in the traditions of cognitive development. These models have similar origins and parallel paths but significant differences as well. According to Hofer (2001), these models share with the traditional models of cognitive development a constructivist, interactionist, cognitive developmental view of the learner's developing understanding of the world.

This section reviews the five major uni-dimensional developmental models of epistemological beliefs: Perry's Model (Perry, 1970), Belenky's Ways of Knowing Model

(Belenky, Clinchy, Goldberger, and Tarule, 1986), the epistemological reflection model (Baxter Magolda, 1992, 2002, 2004), Model of Reflective Judgment (King & Kitchener, 1994, 2002, 2004), and epistemological reasoning skills (Kuhn, 1991; Kuhn, Cheney, & Weinstock, 2000; Kuhn & Weinstock, 2002). Table 1 presents an overview of the five major developmental models to be covered in this section of the review.

Table 1 Uni-Dimensional Models of Epistemological Beliefs

Level	Perry (1970)	Belenky et al. (1986)	King and Kitchener (1994)	Baxter-Magolda (1986)	Kuhn (1991)
Low		Silenced			Realist
	Dualism	Received Knowing	Pre Reflective Thinking	Absolute Knowing	Absolutist
Medium	Multiplism	Subjective Knowing	Quasi Reflective Thinking	Transitional Knowing	Multiplist
Medium-High	Relativism	Procedural Knowing		Independent Knowing	Evaluativist
High	Commitment Relativism	Constructed Knowing	Reflective Thinking	Contextual Knowing	

Perry's Model

One of the most influential researchers in the area of epistemological beliefs was William Perry. However, Perry never conceptualized his groundbreaking work as the study of learners' epistemologies but as the intellectual and moral development of college learners. In the late 1950s and early 1960s, Perry conducted a longitudinal study of the interaction between the degree of reliance on outside authority and epistemology with white male Harvard liberal arts students over the course of their undergraduate education with open-ended and relatively unstructured interviews. Upon analysis of these interviews, Perry noticed trends in the learners' descriptions of their educational experiences and developed a scheme for learners' intellectual development. Perry determined that these learners moved through several positions in the various intellectual and moral challenges they encountered in college by adopting varied perspectives toward knowledge and learning (Pavelich & Moore, 1996). Perry associated these varied perspectives with different levels of educational experience. According to the study learners, usually freshman proceed from Levels 1 and 2 blind acceptance of authority (there are right and wrong answers) referred to as dualism to the belief some authorities are right while others are wrong (Levels 3 and 4) known as multiplicity. The next position, contextual relativism (Level 5) constituted a major shift in the learner's epistemological thinking because they now valued opinions supported by evidence in some context. Learners moving from Level 5 to Level 6 held a view that one actively and personally constructs knowledge. Finally, the position of commitment (Levels 7-9) is where the learner recognizes the need for commitment in one's beliefs and about the degree of reliance on outside authority. Learners in the dualistic stage (black-and-white) believe that external authorities can tell them the right answers to the questions while more mature learners trust their own ability to make decisions. Piaget's influence on Perry's research includes recognition that learning and development follows a linear sequence and that learning is stage-driven. Perry found that the students in his study entered college at number of levels, including Level 1 and reached at least Level 6 upon graduation with a few reaching Level 9 (Felder & Brent, 2004).

Women's Ways of Knowing

The Perry model has been challenged by Belenky et al. (1986) because its validation was based almost entirely on interviews with males and fails to account for gender differences in developmental patterns. In Women's Ways of Knowing, the authors Belenky et al. (1986) discuss the results of their study that examined women's perspectives of truth, knowledge and authority. A diverse sample of 135 women, with 90 women being college-educated, of different ages and varied ethnic and class backgrounds were interviewed in a manner similar to the one conducted by Perry on their life experiences as learners and as knowers. The interview approach of Belenky et al. (1986) differed from Perry in several points. First the initial interview question “What stands out for you in your life over the last few years?” was much broader. Second, specific aspects of the participants were targeted while Perry’s questions were nondirective. Finally, the more educated participants received a more detailed series of questions with respect to ways of knowing. Transcripts of the interviews were examined to identify five different perspectives on knowing displayed by the subjects. Most of the perspectives had counterparts in the Perry model but differed in certain ways that the authors attributed to gender differences in patterns of intellectual development. Belenky et al. (1986) proposed a new classification model after initial attempts to apply Perry’s model to the participant’s responses failed. The levels of the Belenky model are silence (1), received knowing (2), subjective knowing (3), procedural knowing (4), and constructed knowing (5).

The silence level is characterized by women experiencing a passive, voiceless existence, listening solely to authority. Few women in the study and none with college experience fell into this category. At the second level received knowing, women view knowing as originating outside the self and can memorize, and repeat whatever the authorities say. A parallel to Perry’s dualism exists, however while dualists are often outspoken and sometimes confrontational with others about their ideas and attempt to align themselves with authority figures, received knowers are more concerned with getting along with others and tend to feel separated from authorities.

The third level, subjective knowing, rejects authorities and others as reliable sources of truth and analytical reasoning as a basis for judgment, relying instead on intuitive reaction and personal experience. With procedural knowing, the women recognize that intuition can be wrong and replaces it with observation, analysis, and other individual's expertise, sometimes rigidly and inappropriately. Two gender-related patterns of this category were identified as separate knowing and connected knowing. Separate knowing resembles the latter stages of Perry's multiplicity (Level 4). Belenky et al. (1986) proposed two different patterns for procedural knowing: separate knowing and connected knowing. Separate knowers work hard to eliminate subjective feelings from their decision-making process. They rely on critical thinking to arrive at truth, subjecting all ideas and beliefs, including their own to intense scrutiny and doubt. However, women who exhibit this pattern are less likely than men exhibiting this pattern to do their challenging in confrontational public forums. Connected knowers take the opposite approach and treat personal experience as the most reliable source of knowledge. Unlike subjective knowers, however, they believe that other individual's experience is at least as valuable as theirs and they go to great lengths to understand and identify with others, honoring their points of view and ways of thinking and avoiding negative judgments. Thus, while doubt is the first response of separate knowers, it is the last resort of connected knowers.

The final level, constructed knowledge, acknowledges both intuition and the ideas of authorities and others as valid sources of knowledge. Individuals at this level make mature use of both objective logic and subjective feelings when making judgments. The individual may reject the idea of absolute truth at this level. The individual recognizes that all knowledge is contextual and the knower plays a vital role in constructing it. This level resembles Level 5 (contextual relativism) of Perry's model.

King-Kitchener Model of Reflective Judgment

Subsequent models of learners' beliefs about knowledge and knowing resemble the stance proposed by Perry (1970) and Belenky et al. (1986), although based on populations more varied with regard to age and educational background. For instance, King and Kitchener (1994) sampled over 1700 learners from a wide age range and concentrated on general epistemological beliefs that trigger reasoning in nonacademic contexts. In their efforts to understand the processes used in argumentation King and Kitchener (2002) interviewed the participants over the course of 15 years. Participants were presented with four different, ill-structured tasks and a series of follow-up questions to assess various aspects of their beliefs about knowledge and justification of those beliefs. Extensive testing and analysis of the RJM revealed that educational activities tended to improve reasoning on ill-structured activities and that older, more educated learners tended to receive higher scores. King and Kitchener found that learners' assumptions and beliefs about knowledge were related to how they chose to justify their beliefs.

In the 1980s, King and Kitchener (2002) used the data from their study to develop and validate a model of how the learner develops reflective judgment from late adolescence through adulthood. The Reflective Judgment Model (RJM) considers how the learner evaluates knowledge claims and justifies his or her beliefs about arguable issues (King & Kitchener, 2004). The model's levels constructed from John Dewey's work on reflective thinking closely parallel the first six levels of Perry's model. Dewey argued that reflective judgments, are initiated when a learner recognizes that there is controversy about a problem that cannot be answered by formal logic alone, and involve careful consideration of one's beliefs in the presence of supporting evidence. The stages of the RJM closely echo those proposed by Perry (1970) and elaborate upon epistemological views beyond relativism. The RJM describes a progression in the development of reflective thinking leading to the ability to make reflective judgments in seven stages within three levels. Each stage represents a qualitatively different epistemological perspective. The seven stages grouped into three levels include pre-reflective thinking (stages 1-3), quasi-reflective thinking (stages 4-5), and reflective thinking (stages 6-7).

King and Kitchener's 3-level pre-reflective thinking corresponds to Perry's dualism and multiplicity positions. Learners at the first two levels of pre-reflective thinking believe in the certainty of knowledge, that single correct answers exist for all questions, make judgments based exclusively on direct observation and the word of authorities. Learners at the third level of pre-reflective thinking accept the existence of uncertainty but believe that it is only a temporary guess, and do not use evidence to make judgments about uncertain issues. King and Kitchener's 2-level quasi-reflective thinking resembles Perry's multiplicity position (Level 4). Quasi-reflective thinkers use evidence to make judgments about uncertain issues, but realize that one cannot know with certainty. Stage 4 quasi-reflective thinking is characteristic of the reasoning of a majority of college students (King & Kitchener, 2004). Learners at the lower stage (4) believe that all judgments are distinctive, with evidence being interpreted according to the learner's beliefs, and so the quality of the judgments cannot themselves be judged. Learners at the higher stage (5) of quasi-reflective thinking are moving toward the recognition that uncertainty is a part of the knowing process, the ability to see knowledge as an abstraction, and the recognition that that knowledge is constructed becoming more sophisticated in the use of evidence to justify conclusions. King and Kitchener's 2-level reflective thinking is analogous to Perry's positions on relativism (Levels 5-7). Reflective thinkers accept the doubt in decision-making but rarely experience powerlessness. The reflective thinkers make judgments and decisions by carefully weighing of all available evidence, the reasonableness of the solution, and the practical need for action.

Baxter Magolda's Model of Epistemological Reflection

Marcia Baxter Magolda (2002) a social constructivist, views of cognitive development are grounded in the constructive developmental tradition. Constructivists believe that knowledge is fundamentally subjective in nature, assembled from our perceptions and commonly agreed upon principles. According to this view, learners construct new knowledge rather than simply acquire it via memorization or through transmission. Learners construct meaning by assimilating information, relating it to our existing knowledge, and cognitively processing it. Social constructivists believe that this process works best through discussion and social interaction, allowing the learner to test and challenge his or her own understandings with those of others. For a constructivist, laws exist because they have been constructed by individuals from evidence, observation, and deductive or intuitive thinking, and, primarily, because certain communities (scientists) have equally agreed what constitutes valid knowledge.

According to Bock, (1999) Baxter Magolda's research which has a noticeably academic focus (Magolda, 2002) has contributed to our understanding of the development of complex reasoning among college students. Baxter Magolda's work was influenced by Perry's interest in understanding learners' viewpoints on learning in college as well as Belenky et al.'s (1986) reference to possible gender differences.

Beginning in 1986, Baxter Magolda conducted her longitudinal study by interviewing 101 first year college students (51 females and 50 males) in an attempt to understand their "ideas about learning from a student perspective". The semi-structured interviews were conducted over the course of their undergraduate education, as well as the year after their graduation in hopes of examining learners’ patterns of cognitive development in order to explain discrepancies between what she observed in learners’ patterns of cognitive development and Perry’s (1970) model of development. This study extended Perry’s theoretical framework and King and Kitchener’s (2002) reflective judgment model. Her recognition of the similarities between Perry’s work and Belenky’s theory of women’s ways of knowing provided additional motivation for her to examine gender related patterns of knowing (Bock, 1999).

Baxter Magolda’s interview questions referred predominantly to classroom and learning experiences and allowed participants to voice their opinions freely. For instance, the opening question (i.e., “Tell me about the most significant aspect of your learning experience in the past year.”) reflected an open-ended approach similar to Perry (1970) and Belenky et al. (1986) yet focused on learners’ educational experiences. Baxter Magolda developed the Measure of Epistemological Reflection (MER) that consisted of short answer questions in order to triangulate the interview data.

Baxter Magolda identified six principles that contributed to both the process and the results of her study:

1. The making of meaning is influenced by each learner’s worldview and by interaction with others and is influenced by the context of the learner’s experience.
2. That ways of knowing can best be understood through the principles of naturalistic inquiry, which protect the honesty of stories and experiences.
3. Reasoning patterns are not mutually exclusive and shift over time with changing contexts.
4. Patterns are not dictated by, but related to gender.

5. Learner stories and interpretations cannot automatically be generalized to other contexts.
6. Ways of knowing and reasoning patterns within the learners were presented as levels in order to describe the predominant ways of knowing.

Baxter Magolda tried unsuccessfully as Belenky et al. (1986) to apply Perry's model to participant responses. Therefore, she proposed her own model, the Epistemological Reflection Model. Even though, Baxter Magolda's assessment of beliefs is academically focused she addressed a number of beliefs that were not necessarily epistemological in nature (i.e., beliefs about the role of the instructor, learner, instructor and evaluation) in the development of her model. Baxter Magolda identified four knowledge stages that described the various levels of reasoning characterized in her Epistemological Reflection Model: absolute knowing, transitional knowing, independent knowing, and contextual knowing. According to this model, college students may be found at any of four developmental stages, exhibiting either of two gender-related patterns of behavior in all but the last stage.

Absolute learners believe that all knowledge that matters is certain, all question have one correct answer, and authorities have the knowledge and the answers. Learners in this stage exhibit the receiving knowledge pattern, the lowest of the epistemological patterns, and function in a passive way. Learners at this level and pattern tend to be female. This pattern corresponds with Belenky's level of received knowledge (2), and King and Kitchener's early pre-reflective thinking stage (1). Learners in the mastery pattern of absolute knowing tend to be male feel free to ask questions and challenge authority. This pattern corresponds with Perry's level of late dualism (2), and King and Kitchener's early pre-reflective thinking stage (1).

Learners at the transitional knowing stage believe some knowledge is certain and some is not. Authority figures have the responsibility to communicate the certainties, and the learners must make their own judgments regarding the uncertainties. In the impersonal pattern (male), learners make judgments using a logical procedure prescribed by authority figures. This pattern corresponds with Perry's stage of multiplicity subordinate (3), and King and Kitchener's late pre-reflective thinking stage (2). In the interpersonal pattern (female), learners collect ideas however base judgments on intuition and personal feelings. This pattern corresponds with Belenky's level of subjective knowledge (3), and King and Kitchener's late pre-reflective thinking stage (2).

The uncertainty of some knowledge is accepted at the stage of independent knowing. Learners take responsibility for their own learning rather than relying heavily on authorities or personal feelings. In the individual pattern (male), learners rely on objective logic and critical thinking. This pattern corresponds with Perry's multiplicity stage, level 4, Belenky's level of procedural knowledge, separate pattern (4), and King and Kitchener's stage of quasi-reflective thinking (4-5). Learners in the inter-individual pattern (female), rely on caring, empathy, and understanding of others' positions as bases for judgments. This pattern corresponds with Belenky's level of procedural knowledge (4), connected pattern, and King and Kitchener's stage of quasi-reflective thinking (4-5).

Contextual learners (male and female) believe that all knowledge is contextual and individually constructed. This shift alters both the source and process of knowing (Baxter Magolda, 1992). They use all sources of evidence and remain open to changing their decisions if new evidence is presented. This pattern corresponds with Perry's level of contextual relativism (5-7), Belenky's level of constructed knowledge (5), and King and Kitchener's stage of reflective thinking (6-7).

Kuhn's Model of Reasoning Skills

Kuhn's argumentative model (1991) pertains more to general knowledge beliefs. Kuhn (1991) studied beliefs about knowledge in her attempt to understand the reasoning that occurs in everyday lives by presenting three ill-structured problems (i.e., what causes learners to fail in school?, what causes unemployment, and what causes prisoners to return to crime?) to a cross-sectional group ranging in age from teens to the sixties. The key factors of Kuhn's design included the broader sample of participants and that each age group included 40 participants with gender and educational level (college and noncollege) equally represented. Kuhn individually interviewed each participant twice for 45 and 90 minutes each time. The participants were asked to explain how they came to hold a view and to justify their position with supporting evidence. In addition, the participants produced opposing views, provided rebuttal to that view, and then offered a remedy for the problem. Lastly, the participants were asked to reflect on the reasoning presented. The model she proposed from this study closely corresponds to the epistemological models developed by Perry (1970), and King and Kitchener (2002). In Kuhn's model (1991, 2000; Kuhn & Weinstock, 2002), learners shift from a realist to an absolutist to a multiplist, then to an evaluativist belief of knowledge and knowing.

The realist level is characterized by assertions are copies of an external reality, reality is directly knowable, knowledge comes from an external source and is certain, and critical thinking is unnecessary. This level is consistent with Perry's early dualism (1), Belenky's level of silence (1), and King and Kitchener's early pre-reflective thinking stage (1-2).

According to the absolutist belief, knowledge is absolute, certain, non-problematic, right or wrong, and does not need to be justified since it originates from authority. This belief depicts epistemological thinking in childhood, and it can appear at later ages. At the level of absolutist assertions are facts that are correct or incorrect, critical thinking is a vehicle for comparing assertions to reality and determining their truth or falsehood, while the dimensions reality and knowledge remain unaltered. This pattern is consistent with Perry's late dualism (1), Belenky's level of received knowledge (2), King and Kitchener's late pre-reflective thinking stage (2-3), and Baxter Magolda's absolute knowing(1).

The third level, the multiplist, views assertions as opinions freely chosen by and accountable only to their owners, reality is not directly knowable, knowledge is generated by human minds and is uncertain, and critical thinking is irrelevant. From the multiplist view knowledge is regarded as unclear and distinctive, since each learner has his or her own views and truth. This view is typical of adolescence. This pattern is consistent with Perry's multiplicity (3-4), Belenky's level of subjective knowledge (3), King and Kitchener's quasi reflective thinking stage (4-5), and Baxter Magolda's transitional knowing (2).

The final level, the evaluativist, considers assertions as judgments that can be evaluated and compared according to criteria of argument and evidence, critical thinking is valued as a vehicle that promotes sound assertions and enhances understanding, while the dimensions reality and knowledge remain unchanged. An evaluativist position incorporates and organizes both the objective and subjective aspects of knowing. A learner with an evaluativist view believes that two individuals may hold viewpoints that are both "right," but one viewpoint can be "more right" than the other in that it is better supported. This more sophisticated point of view develops well into adulthood leading to a mature understanding of the nature and justification of knowledge that involves active processes of reflection and thinking (Mason, 2003). This pattern is consistent with Perry's relativism, portions of commitment within relativism (5-7), Belenky's level of procedural, portions of connected knowledge (4-5), King and Kitchener's late quasi reflective thinking, portions of reflective thinking (5-7), and Baxter Magolda's independent knowing as well as portions of contextual knowing (3-4).

Multidimensional Models of Epistemological Beliefs

Epistemological Beliefs

Current epistemological beliefs research (Hofer and Pintrich, 1997; Schommer, 1990) has challenged portions of the aforementioned models for their stage-like, unidimensional characteristics. The proposed multidimensional models suggest that personal epistemology is a collection of beliefs about knowing and learning, and may be more independent, rather than progressing in a developmental sequence. The central alternative models of epistemological beliefs independent epistemological beliefs (Schommer, 1990; Schommer-Aikins, 2002) and epistemological theories (Hofer & Pintrich, 1997; Hofer, 2000) are outlined below.

Schommer-Aikins System of Independent Beliefs

A second approach to understanding personal epistemology was pioneered by Schommer (1990) using a more quantitative methodology than that of her colleagues. Schommer's (1990) interest in how learners' beliefs about nature and the acquisition of knowledge impacted their approach to learning led her to dispute the one-dimensional conception of beliefs. Instead she held that learners' epistemological beliefs are a multilayered system of beliefs composed of separate dimensions or elements. Schommer proposed a model of five different epistemological elements related to certainty, source, and structure of knowledge, as well as control and speed in the acquisition of knowledge (Schommer, 1990). The first three elements (i.e., certainty, source, and structure) evolved from Perry's model, whereas control and speed of knowledge acquisition were drawn from Dweck's and Legget's, (1988) work on beliefs about intelligence and Schoenfeld's (1983) work on the learners' beliefs about mathematical learning.

To assess these multiple elements, Schommer (1990) developed a written (paper and pencil) quantitative measure, the Schommer Epistemological Questionnaire (SEQ). The SEQ consisted of 63 short statements that characterized epistemological beliefs. that uses a five-point Likert scale. In 1990, a total of 263 college students responded to the SEQ using a five-point Likert scale. Three educational psychologists reviewed and categorized the statements into 12 subsets reflective of the five elements proposed by Schommer. A factor analysis indicated that the 12 subsets loaded onto four independent factors, reflective of four of the five proposed elements, excluding knowledge. The first factor, Innate or Fixed Ability, characterized the learners' control over knowledge acquisition with positions ranging from being fixed at birth to a skill that can be learned. The second factor, Simple Knowledge, characterized the structure of knowledge, from knowledge being isolated to being interrelated. The third factor, Quick Learning, characterized the speed at which acquisition of knowledge occurs, quickly, gradually or not at all. Finally, the fourth factor, Certain Knowledge, characterized beliefs on a continuum that knowledge is absolute to that knowledge is tentative and evolving.

Schommer verified the factors in succeeding studies with large samples of high school and college students (Schommer, 1993; Schommer, et al., 1992). As did Perry, Schommer found evidence of developmental trends in learners' beliefs. For instance, in a cross-sectional study, first year high school students believed more in the simplicity an certainty of knowledge, the innateness of ability, and the quickness of learning than did high school seniors (Schommer, 1993). Therefore the younger learners held less sophisticated and more naïve views than the older learners.

In an earlier study Schommer, et al., (1992) explored the relationship between epistemological beliefs and comprehension, specifically focusing on how beliefs about the structure of knowledge related to the comprehension of integrated text material. Primarily freshman and sophomore college students read a highly integrated text from a statistics book. Measures assessing mastery of the material, prior knowledge, and use of study strategies were administered as well as the learners' confidence in understanding the passage. A regression analysis revealed that learners who believed that learning occurs quickly or not at all tend to draw oversimplified conclusions from the text and performed poorly on the mastery test due to an overestimation of their comprehension (Schommer, 1990).

Subsequent factor analyses have replicated the four factors (Schommer. Crouse, & Rhodes, 1992). Schommer's quantitative approach to the study of personal epistemology may have contributed to the increase in research of personal epistemology. The SEQ has allowed researchers to measure and identify more distinctly the relation between epistemology and learning.

Hofer and Pintrich's Epistemological Theories Model

Challenges exist to some of the views in both the developmental models and independent beliefs model. Hofer and Pintrich's (1997) model of epistemological theories consists of elements of both the developmental models and independent beliefs model. Hofer and Pintrich (1997) proposed that a learner's beliefs about knowledge and knowing are organized into personal theories as structures of interrelated propositions that are interconnected and logical. This view preserves the multidimensionality of epistemological beliefs but implies more integration among a learner's perspectives. Hofer and Pintrich (2002) view the nature of personal epistemology as including the learners' cognition and beliefs about the nature of learning, intelligence, instruction, classrooms, domain-specific beliefs about disciplines, and beliefs about the self.

Hofer and Pintrich (1997) at length reviewed the research related to epistemological beliefs. The review describes three key areas of research, which included investigations regarding how learners interpret their learning experiences (Belenky et al., 1986; Perry, 1970); the influence of epistemological beliefs on reasoning (King & Kitchener, 1994; Kuhn, 1991); and the idea of multidimensional beliefs (Schommer, 1994). In this review Hofer and Pintrich (1997) questioned Schommer's characterization of factors related to speed and the control of knowledge. Hofer and Pintrich believe the factors related to the dimensions Quick Learning and Innate Ability were reflective of learners' beliefs about intelligence. As an alternative, Hofer and Pintrich (1997) categorized learner's epistemological beliefs into four dimensions. This model includes dimensions related to the nature of knowledge (what learner believes knowing is) and the nature of knowing (how learner comes to know). Within the area nature of knowledge Hofer (2000a) identifies the dimensions certainty of knowledge and simplicity of knowledge, and within the nature of knowing the dimensions source of knowledge and justification for knowledge.

The least developed epistemological dimension certainty of knowledge is the degree that learners believe that knowledge is fixed (low level), while other learners believe that knowledge is fluid (high level). Belief that knowledge is fluid and open to interpretation is a key factor of King and Kitchener's (1994) reflective thinking stage (6-7) and Kuhn's (1991) evaluativist level.

Simplicity of knowledge is the degree that learners believe that knowledge consists of an accumulation of facts (low level), while other learners believe that knowledge is a system of related constructs (high level). According to Hofer (2000a) the lower level view of knowing is seen as concrete, discrete, and knowable facts while at the higher level learners see knowing as contextual, contingent, and relative. This dimension is reflective of Schommer's (1990) model that knowing is viewed on a continuum as an accumulation of facts (naïve) or as highly interrelated concepts (sophisticated).

The first dimension of the nature of knowledge, source of knowledge considers the degree learners belief that knowledge is transmitted from external sources (low level) while other learners believe that knowledge is internally constructed. At the lower levels of other epistemological models (Baxter Magolda, 1992; Belenky et al., 1986; King and Kitchener, 1994; Kuhn, 1991; Perry, 1970) knowing originates outside the self and resides in external authority. The developmental turning point is the ability of the self to construct knowledge.

The most developed epistemological dimension justification for knowledge is the degree that learners rely upon external authority while other learners believe that knowledge relies on personal evaluation and integration. This dimension considers how learners evaluate knowledge claims, use evidence, use authority and expertise, and their evaluation of experts (Hofer, 2000a). At the higher levels within the models learners use rules of inquiry and begin to evaluate and integrate the views of experts.

Hofer's (2000) study had two purposes: (1) to assess the dimensions of personal epistemology across models, through the development of a new instrument; and (2) to examine whether learners recognize disciplinary in differences in epistemological beliefs. Additional research questions were explored such as, the extent to which choice of academic major related to discipline-specific epistemological beliefs, gender differences, and the relation between grades and general and discipline-specific epistemological beliefs.

A total of 326 first-year college students enrolled in an introductory psychology course participated. Each participant was given a shortened version of the Schommer general epistemological beliefs questionnaire and two identical forms of a newly developed epistemological beliefs instrument to assess the four dimensions the Discipline-Focused Epistemological Beliefs Questionnaire (DEBQ) one labeled "Psychology" and one "Science" (Hofer, 2000). The new measure consisted of 27 items referring to the discipline as the frame of reference that learners responded to using a 5-point Likert scale.

In order to examine the dimensionality of epistemological theories exploratory factor analyses of the psychology and science DEBQ data were conducted revealing four similar factors for both disciplines. In this factoring, certainty of knowledge and simplicity of knowledge did not emerge as separate dimensions and instead are representative of one cluster of beliefs about knowing (Hofer, 2000). Justification for knowledge and source of knowledge did appear as factors and appear to represent two distinct positions but not the range Hofer (2000) had expected. Finally an additional unexpected factor emerged related to the "attainment of truth."

With respect to the discipline differences research question the study indicated significant differences in learners' beliefs about psychology and science. In other words, learners considered science knowledge to be more certain and unchanging and suggests that first-year college students are capable of making epistemological distinctions. Additionally, for science, authority and expertise were viewed as the source of knowledge and truth was perceived as being more attainable than for psychology (Hofer, 2000).

Hofer's (2004) qualitative, exploratory case study focused on the epistemology of instructional practices as interpreted by students in two versions of college chemistry, general and organic chemistry each with different underlying, epistemological assumptions. Her study combined observations of classes and interviews with students in order to provide several sources of evidence and contribute to triangulation of the data. Hofer's qualitative study addressed epistemological issues using four dimensions within two clustered central areas: the nature of knowledge (what one believes knowledge is) and the nature of knowing (how one comes to know). The nature of knowledge cluster area included the dimensions certainty of knowledge and simplicity of knowledge. The nature of knowing cluster area included the dimensions of source of knowledge and justification for knowing. The four dimensions as described by Hofer (2004) are discussed in the following paragraphs.

The dimension certainty of knowledge is the degree to which one views knowledge as certain (fixed or more fluid. At lower levels, absolute truth exists with certainty, while at higher levels knowledge is tentative, evolving, and modified in interchange with peers. The simplicity of knowledge at the lower levels, is knowledge viewed as discrete, knowable facts, and at higher levels, students see knowledge as contextual, contingent, and relative. This dimension describes a range of beliefs that move from viewing knowledge as an accumulation of facts to seeing knowledge as highly inter-related concepts (Schommer, 1994; 1990). Source of knowledge refers to the locus of knowledge, perceived as originating outside the self and residing in external authority or, as actively constructed by students in interaction with the learning environment, and peers (Baxter Magolda, 1992; Belenky et al., 1986). The dimension justification of knowledge involves how students evaluate knowledge claims, including use of evidence, the use of authority and expertise, and their evaluation of experts. Students may justify their beliefs through authority, observation, on the basis of what feel's right, or through the evaluation of authority, evidence, and expertise with the assessment and integration of the views of experts (King & Kitchener, 1994). At lower levels students justify beliefs through observation or authority.

Nature of Science

Defining the Nature of Science

In the past, the debates about the definition of the NOS have centered on epistemological and sociological questions. However, over the past ten years researchers have studied the aspects of the nature of science, and recently agreed on the elements of the nature of science (McComas et. al., 1998; Driver et al., 1996). The literature identifies several issues that characterize the NOS that defines science as a discipline: 1) scientific knowledge is durable, yet tentative, 2) empirical evidence is used to support ideas in science, 3) social and historical factors play a role in the construction of scientific knowledge, 4) laws and theories play a central role in developing scientific knowledge, yet they have different functions, 5) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, 6) science is a creative endeavor, and 7) science and technology are not the same, but they impact each other (McComas, 2004; Lederman, 2004; Leach, et al., 1996).

Students' Images of Science

Influences upon students' actions and learning during laboratory investigations include their personal images of science and of learning. Leach et al., (1998) use the phrase "images of science" to refer to the descriptions of the epistemology and sociology of science used by learners in specific contexts for specific purposes. Leach and colleagues laboratory instruction study found that learners draw upon images of science to explain the purposes of empirical investigation, relationships between data and knowledge claims, and relationships between knowledge claims and experimental design, analysis and interpretation of data. Three categories of learners' images of science were determined. The first image of science classifies learners with a data-focused view, in which learners appear to view the process of data collection as a simple one of the description of the real world. The second image used by other learners involves a radical relativist view, in which learners appear to view the process of drawing conclusions as so problematic that it is never possible to select one explanation as being better than another one. The final image used by some learners is a theory and data linked view in which data, theory, and methodological aspects of laboratory instruction are viewed as inter-related, each being able to influence the other. Other research supports the aforementioned view that learners develop a range of images about science rather than a cohesive view (Linn & Hsi, 2000; Bell & Linn, 2002). This perspective echoes with Strike and Posner's (1992) belief that learners have complex cognitive images about science based on their varied experiences and sources of knowledge.

Student Understanding of the Nature of Science

Studies into learner understanding of the NOS tend to arrive at the same basic finding that learners need to experience cognitive dissonance in order to eliminate ancient conceptions of the NOS. When learners were presented with discrepant events their notions of the NOS began to conform to professional scientists' understanding of the nature of science (Clough, 1997). Hogan (2000) suggests that researchers can gain a better understanding of how learners view the nature of science by dividing up their knowledge into two categories: distal knowledge, how students understand formal scientific knowledge, and proximal knowledge, how learners understand their own personal beliefs and commitments in terms of science. In another study of learner understanding of the NOS, it was found that a learner's views depended greatly on moral and ethical issues, rather than in newly presented material (Zeidler, Walker, Ackett

& Simmons, 2002). Instead of changing their ancient notions of the nature of science, learners tended to hang on to their prior understandings even when presented with conflicting information. Undergraduate science majors were found to change their conceptions of the NOS during a study that offered the learners many opportunities to discover conflicting information (Ryder, et al., 1999). Therefore, it appears from the research that learners will change their conceptions of the NOS from naive to more sophisticated through exposure to discrepant information.

Measuring the Understanding of the Nature of Science

According to Lederman (1992), early research into learner's conceptions of the NOS consisted of forced-choice instruments that provided little insight into the conceptions underlying learners' responses. Many of these instruments used in the studies regarding the NOS tended to be objective, pencil and paper assessments which subsequently changed into more descriptive instruments.

There are several studies of learners' images of science in the literature that are based upon the use of pencil and paper assessments and closed-response questions. In a recent study reported by Leach et al., (1998) the focus was upon the images of science that influence a students' learning during laboratory activities. The implications from the study were that many learners do not recognize the epistemological basis of routine algorithmic procedures used for data analysis and this can lead learners to taking inappropriate actions; that learners are likely to view knowledge claims as emerging directly from the logical analysis of data and not how particular theories and models assist in shaping scientists' ways of evaluating and interpreting data; and that some learners draw strong conclusions from empirical investigations, based on inconclusive evidence.

According to a study by Lederman and Zeidler (1987) the NOS refers to the values and assumptions inherent to the development of scientific knowledge. In the study these values and assumptions were identified with Rubba's (1977) six categories of nature of scientific knowledge explained in his nature of scientific knowledge scale. According to these categories, scientific knowledge is amoral, creative, developmental, parsimonious, testable and unified. Learners' beliefs about how scientific knowledge fits into these categories reflect their understanding of the NOS.

In the 1990's researchers argued that traditional paper and pencil assessments would not be adequate enough to fully explain what needs to be known about learner conceptions of the NOS (Carey et al., 1989, Carey & Smith, 1993; Lederman, Wade & Bell, 1998; Smith, et al., 2000). Researchers responded by conducting interviews along with the questionnaires or by including several open-ended questions on the questionnaires in order to obtain more descriptive data. Another approach to probing learners' images of science reported by Carey et al., (1989) is to pose questions about particular laboratory activities that the learners are carrying out. To assess learners' understanding of the NOS Carey and colleagues (1989) developed the "Nature of Science" interview to probe for an abstract definitional understanding of the key elements of the process of scientific inquiry. This instrument assesses learners' understanding of the nature of the following: science, scientific ideas, a hypothesis (prediction), and an experiment. Several versions of an instrument originally developed by Lederman, the Views of Nature of Science (VNOS), have been used mostly by the researchers who focus on preservice teachers. Other instruments have been developed to be more descriptive in explaining learner achievement in the nature of science such as Scientific Inquiry Capabilities and Scientific Discovery (Zachos, Hick, Doane & Sargent, 2000). Although the objective, pencil and paper assessments have been altered to include more description of mechanisms, there is still a need for improved assessments regarding the nature of science.

Connections Between the Nature of Science and Epistemology

Hofer (2002) explains personal epistemology as dealing with questions such as “how do we know,” as well as an individual’s personal beliefs about the nature of knowledge. In similar fashion, NOS knowledge deals with learners’ epistemological “values and beliefs inherent to scientific knowledge and its development” (Ad-El-Khalick, et al., 2002). With the similarities in these two constructs it is easy to accept that a relationship must exist between them. As both constructs deal with the beliefs about knowledge, then one can place NOS as the science subcomponent of personal epistemology. Exposure to the features of the NOS can be useful in helping learners to think about their epistemology. Examining the nature of science can supply characteristics that distinguish science from other ways of knowing and explicitly help learners examine their rationale in forming ideas.

Eliciting and Developing Students’ Understanding of NOS

Instructors, often overlook the importance of NOS instruction (Abd-El-Khalick et al. 1998; Bell, et al. 2000). Recent thinking in NOS instruction is that it has to be targeted rather than relied on as a by-product of general science learning.

Abd-El-Khalick and Khishfe (2002) categorize the methods to enhance learners’ images of science into the following three categories: 1) historical, 2) implicit, and 3) explicit-reflective. Learners, like scientists interpret new science experiences from a framework consisting of their experiences and prior knowledge.

The historical method, suggests incorporating the history of science into science instruction to augment learners’ views of the NOS. Contextualizing the NOS means Integrating historical science examples that are tied to the fundamental concepts taught in the science discipline. Using historical examples illustrate the challenges and complexities scientists and the scientific community experience (Clough, 2006). However, according to Abd-El-Khalick and Khishfe (2002), two national studies produced conflicting results of the effectiveness of this method.

The implicit method suggests that learners will develop NOS conceptions simply by participating in inquiry-based activities (Lederman & Abd-El-Khalick, 1998; Abd-El-Khalick & Khishfe, 2002). This pedagogical approach relies on implicit NOS messages embedded within the activities. Research does not support the instructor view that planning inquiry laboratory activities that reflect NOS will result in students' noting the implicit messages (Lederman, 1992; Moss, et al., 2001; Khishfe & Abd-El-Khalick, 2000).

The explicit method is needed to directly target NOS, while providing for reflective activities to enhance learners' understandings in an effort to develop coherent overarching NOS frameworks (Abd-El-Khalick, et al., 2000; Southerland, et al., 2003). The essential role of explicit NOS instruction that draws learners' attention to specific NOS ideas is clearly identified in the literature (Bell, et al., 1998; Lederman, 1998; Abd-El-Khalick & Lederman, 2000a; Clough, 2006) Explicit instruction is not didactic instruction, but a thoughtful process resulting in learners reflecting on NOS phenomena through class discussion embedded with instruction (Abd-El-Khalick, 2000). According to several studies, the best way to instruct NOS concepts is through the use of an explicit, reflective instructional approach (Akerson, et al., 2000; Lederman & Abd-El-Khalick, 2000; Khishfe & Lederman, 2005). In order for the instruction to be explicit the instructor cannot rely on learners picking up the ideas on their own. Learners are dependent on the explicit means of targeting NOS through activities, discussion, and writing. In order for instruction to be reflective, learners need to consider what they know about a topic in order to change their minds and continue learning. These instructional methods require that the learners be made aware of how their conceptions vary from that of the scientific way of knowing (Settlage, et al., 2003).

Research Methodology Issues

Even today, researchers struggle to find a means to assess NOS and personal epistemological beliefs. Most of the NOS and epistemological beliefs instruments (Duell and Schommer-Aikins, 2001) that exist were developed from studies done in the 1950s and 1960s. In the process of studying models aimed at mapping the structure and the development of NOS and epistemological beliefs, researchers have created qualitative and quantitative measurement instruments, which range from interviews to task performances, to paper and pencil questionnaires. The validity of the instrument used is an important consideration for weighing the results yielded by the studies, as the instruments themselves necessarily reflect a particular conceptualization of the construct, which consequently constrains the particular dimensions which emerge.

Researchers must follow the basics of assessment administration. The researcher should take great care giving instructions to avoid influencing participants. If the initial instrument is presented with other instruments counterbalance the order of assessments. Any form of assessment, whether qualitative or quantitative, can be rendered invalid if it is not properly carried out or properly analyzed.

The measuring instruments associated with general personal epistemological beliefs, generally fall into two categories: uni- and multidimensional. The difference between the instruments is the relationship among the different theories of epistemological beliefs. Unidimensional theories consider that epistemological beliefs are mutually correlated, while multidimensional theories consider that epistemological beliefs are independent of one another, and thus free to vary. According to Schraw

(2001) no attempt has been made to justify whether uni- or multidimensional theories are more accurate, although empirical findings currently provide more support for the multidimensional viewpoint. However, most researchers agree that using a variety of research methods and instruments in a fruitful and positive manner may further clarify and validate the measures.

The history of the development of assessments associated with NOS began in the early 1960s. The first assessments emphasized a quantitative approach (Lederman, et al., 1998). With few exceptions, prior to 1980 the instruments developed allowed for easy grading and a quantified measure of learners' understanding.

Empirical studies of learners' beliefs about the nature and validation of knowledge, can present particular barriers to researchers as most NOS and personal epistemological beliefs are not directly apparent but suppressed from view. For instance, most learners do not discuss NOS and personal epistemological questions about knowledge and may have conflicting beliefs about knowledge and knowing making it difficult to ask direct NOS or epistemological questions.

The following sections present a general overview of several instruments used over the past 30 years in assessing general personal epistemological beliefs, science epistemological beliefs, and NOS beliefs.

Personal Epistemological Beliefs Assessments

Perry and his colleagues created the Checklist of Educational Views (CLEV) to identify students on a continuum as dualistic or relativistic thinkers. The CLEV was administered to a random sample of 313 freshmen in 1954 and again to these same students a year and a half later. Subsequently, Perry and his colleagues conducted 366 interviews which included 67 four-year recordings. Perry provided evidence for inter-rater reliability of the interviews as well as validity of the CLEV to assess students' beliefs about knowledge (Perry, 1968/1999). Criticisms of Perry’s work include that he worked with a male sample of students and his sample was limited to an elite, private institution. Variability in school setting and subject gender would help to determine the degree to which instruction drives or hinders epistemological development.

Belenky et al. (1986) utilized the phenomenological approach with long, open-ended interviews that allowed the interviewer and participant to openly reflect upon their beliefs. This qualitative approach differed greatly from Perry’s in that the technique developed into the theory, rather than the hypothesis driving the methodological approach. Interviews were conducted of 135 women from nine institutions ranging from coed adult education programs to private liberal arts colleges. Interviews were 2-5 hours in length and all were recorded and transcribed into a 5000 page report. The interviews took the form of a case study that allowed the subjects to “tell their whole story” without the researcher imposing any preconceived hypothesis onto the subject. Interview questions were broad in nature and open-ended, and subjects were encouraged to respond based upon their own points of view. Specific questions to assess Perry’s nine positions also were embedded into the interviews.

Results from the interviews were coded by blind reviewers who attempted to classify the data into Perry’s nine positions. It was found that this data, from women and more specifically women from diverse backgrounds, did not fit neatly into the Perry Scheme (Duell & Schommer- Aikins, 2001). This led to the Women’s Ways of Knowing model put forth by Belenky et al. The methods employed provide great insight into an individual’s beliefs about knowledge and the social construct of those beliefs. However, conducting this type of interview is a long and arduous process that requires a skilled interviewer and ample time. Belenky et al. do not report evidence for reliability and validity of the interview as a research instrument for assessing epistemological development (Duell & Schommer-Aikins, 2001).

Baxter Magolda developed the Measure of Epistemological Reflection (MER) to conduct her research. This instrument consists of a standardized, open-ended questionnaire interview and a standardized rating protocol. Questions in the instrument focus on beliefs as well as justifications for beliefs, specifically beliefs about the certainty of knowledge as well as the implications these beliefs have for decision making, what the role of the learner should be, what the role of peers should be in the learning process, what the role of instructor should be and what role evaluation plays in the learning process. The drawback to using this instrument is that interpretation is time consuming and requires a knowledgeable rater.

King developed the Reflective Judgment interview to assess student beliefs about what can and cannot be known, how people come to know something and the certainty of knowledge. Specifically, the interview identifies into which of the seven previously discussed stages an individual falls. The interview is comprised of four ill-structured problems in the areas of physical science, social science, history and biology that illustrate alternative or opposing conceptions of the dilemma. Each problem is based on an area of current interest with which the sample is likely to be familiar. For each problem, the subjects are asked probing questions that elicit an explanation and defense of their judgment about the issue. They also are asked to explain in what way they know their opinion is true. Subjects are encouraged to expand fully on their responses (Duell & Schommer-Aikins, 2001).

Inter-rater reliability of this instrument ranges from moderate to high and is also ensured by training and certification of the interviewers and scorers. The interview also has fared well on validity measures. However, King and Kitchener caution that since no contextual support is offered to the participants during the interview, it may be actually measuring the individual's functional level, defined by Fisher and Pipp (1984) as a person's cognitive capacity when there is no available support, and thus may underestimate his or her ability to think reflectively. When contextual support is provided, individuals are able to perform closer to their upper limit, which is referred to as their optimal level. Fischer and Pipp (1984) refer to the space between the functional level and the optimal level as the developmental range (King & Kitchener, 2004).

Due to limitations of the Reflective Judgment interview, Kitchener, Wood, & Jensen (1999) developed a paper-and-pencil measure for the Reflective Judgment Model. This measure is comprised of two components. The first focuses on the student's ability to differentiate between more or less sophisticated approaches to a dilemma. The second aspect addresses the level of sophistication of approaches that individuals see as similar to their own. Current reliability and validity measures appear to be similar to those of the Reflective Judgment interview (Duell & Schommer-Aikins, 2001).

Schommer developed a questionnaire to assess the five belief dimensions discussed in her theory. Subsets of items were created to assess beliefs in multiple ways and were written in a positive and negative valence for the following aspects: the certainty of knowledge, the relationship between hard work and success, the ability of individuals to learn how to learn, the innateness of learning ability, the speed in which learning takes place, the importance of effort, the value of multidisciplinary approaches and the role of authority figures. The instrument is comprised of 63 items that subjects respond to on a 5-point Likert scale. There is evidence to support the reliability, content validity and predictive validity of the instrument. Schommer cautions while this instrument is useful for identifying strengths in an individual's epistemology, additional instruments may be needed for a more penetrating view into specific dimensions of interest to the researcher (Duell & Schommer-Aikins, 2001).

Kuhn and her colleagues created a 15-item questionnaire to evaluate the Argumentative Reasoning Model. While acknowledging the value of qualitatively rich responses from long interviews, they believe this instrument to be practical for assessing epistemology across judgment domains and age groups. At the writing of this review, there is evidence of concurrent validity, but nothing reported on issues of reliability. This instrument is still a work in progress (Duell & Schommer-Aikins, 2001).

Personal Epistemological Beliefs in Science Assessments

If we want to understand whether our students are learning both process and scientific thinking, we need to find some way to probe the state of their personal epistemological beliefs about science. More important to the study of personal epistemological beliefs however, there is evidence that learners' beliefs about the value of knowledge in a particular academic domain, is related to their decision to pursue courses in that domain (Buehl & Alexander, 2004; Schommer, et al., 2003). Early epistemological beliefs studies were guided by the assumption that beliefs were domain general. Domain specific epistemological beliefs have become the focus in a emerging line of research.

In 1995, Schommer and Walker addressed domain specificity by testing the domain generality of personal epistemological beliefs across two academic domains: mathematics and social sciences. With the use of an instrument developed by Schommer (1990) two experiments were performed. In experiment one, participants were asked to complete a survey about personal epistemological beliefs while either thinking about mathematics (e.g., algebra and geometry) or social sciences (e.g.; psychology and sociology). In the second experiment two design changes were made one to the survey involving the addition of domain reminders and the addition of a control group. Results indicated that the participants were able to keep a specific domain in mind while completing the survey. The majority of the participants demonstrated a consistent level of epistemological sophistication.

Epistemological assessments geared toward the domain of science include the Maryland Physics Expectation (MPEX), the Views about Science Survey (VASS), the Colorado Learning Attitudes about Science Survey, and the Epistemological Beliefs about the Physical Sciences (EBAPS). Development of the aforementioned instruments include aspects of the personal epistemological belief theories developed by Schommer (1990), using multiple dimensions and Hofer and Pintrich (2002) views that personal epistemology includes the learners' cognition and beliefs about the nature of learning, classrooms, domain-specific beliefs about disciplines, and beliefs about the self.

The Maryland Physics Expectation (MPEX) survey was developed by Redish, Saul, and Steinberg in the 1990s by the Maryland Physics Education Research Group (PERG) as part of a project to study the attitudes, beliefs, and expectations of students that have an effect on what they learn in an introductory calculus-based physics course. Students are asked to agree or disagree on a five-point Likert-scale from strongly agree to strongly disagree with 34 statements about how they view physics and how they think about their work in their physics course. The focus of the survey was not on students' attitudes in general, such as their epistemologies or beliefs about the nature of science and scientific knowledge, but rather on their expectations. By expectations the authors mean to ask the students to ask themselves: “What do I expect to have to do in order to succeed in this class?”

The MPEX items were validated with hours of interviews, listening to students talk about each item, how they interpreted it, and why they chose the answer they did. In addition, the uniformity of the favorable MPEX responses was validated by offering it to a series of expert physics instructors and asking what answers they would want their students to give on each item (Redish, 1998).

A second survey on student beliefs toward science was developed by Ibrahim Halloun and David Hestenes ([Halloun, 1996). The Views about Science Survey (VASS) comes in four forms: biology, chemistry, mathematics, and physics. The physics survey has 30 items while the chemistry survey has 50 items. Each item offers two responses, and students respond to each item on an eight-point Likert-scale. This eight-point scale has been found to confuse students thereby influencing the reliability and validity of the instrument.   In addition to items that probe expectations, the survey includes items that attempt to probe a student's epistemological stance toward science. The VASS is designed to probe student characteristics on six attitudinal dimensions: three scientific (structure of scientific knowledge, methodology of science, & approximate validity of scientific results) and three cognitive (learnability, reflective thinking, & personal relevance).

According to (Redish, 2003), both the MPEX and the VASS suffer from the problem of probing what learners think they think rather than how they function. In addition, they have the problem that for many items, the "answer the instructor wants" is reasonably clear, and learners might choose those answers even if that's not what they believe. In the Epistemological Beliefs Assessment for Physical Science (EBAPS), (Elby, et al., 1999; Redish, 2003) attempt to overcome the aforementioned problems by presenting several formats, including Likert-scale items, multiple-choice items, and "debate" items. Many EBAPS items attempt to provide context-based questions that ask students what they would do rather than what they think. The design of the EBAPS is similar to the multi-dimensional models of Schommer and Hofer discussed earlier. The

EBAPS contains 17 agree-disagree items on a five-point scale, six multiple-choice items, and seven debate items for a total of 30. The EBAPS examines epistemological beliefs along the following five axes: (1) Structure of knowledge, (2) Nature of learning, (3) Real-life applicability, (4) Evolving Knowledge, and (5) Source of ability to learn. The statistics of the EBAPS chosen as the personal epistemological beliefs assessment instrument for this study is discussed further in chapter three.

Another way in which EBAPS differs from MPEX is by construction, MPEX probes a combination of students' epistemological beliefs about knowledge and students' expectations about their physics course. Redish et al. (1998) designed MPEX to probe both epistemology and expectations. The EBAPS was constructed to probe epistemology alone, to the extent that it can be teased apart from expectations.

The dimensions of the EBAPS are similar to those discussed by Schommer (1990) and Hofer (2004) when describing their multi-dimensional beliefs theories. For instance, the first dimension structure of knowledge on the EBAPS probes students' beliefs concerning whether science is a coherent body of knowledge or a loose collection of perceived facts parallels both Hofer's and Schommer's epistemological dimension of the simplicity of knowledge. By their definition simple knowledge suggests a range of beliefs from that of knowledge as isolated, unambiguous bits to a view of knowledge as highly interrelated concepts (Hofer & Pintrich, 1997).

The second dimension of the EBAPS, nature of knowing and learning probes learners' views on whether learning science is propagated from authority or self constructed. This dimension is similar to Hofer and Schommer's dimension source of knowledge. This dimension is further described as the locus of knowledge ranging from knowledge acquired from authority figures versus knowledge derived from empirical evidence and reason.

The third dimension of the EBAPS, real life applicability probes learners' beliefs concerning whether science is relevant to everyone's life or if it an exclusive concern of scientists. This dimension considers learners' views of the applicability of scientific knowledge as distinct from the learners' own desire to apply science to real life. Hofer's dimension justification for knowing considers how individuals justify what they know and whether it is relevant.

The fourth dimension of the EBAPS, evolving knowledge probes the extent to which learners' beliefs navigate between absolutism, thinking all scientific knowledge is set in stone and extreme relativism, making no distinctions between reasoning and mere opinion.   In this dimension the approximate validity of scientific results is probed by determining if learners view scientific knowledge as approximate, tentative, and refutable rather than absolute, exact, and final. This dimension correlates with the certainty of knowledge dimension discussed by Hofer and Schommer involving the aspects of absolute versus continually dynamic.

The final EBAPS dimension, source of ability to learn probes learners' epistemological beliefs about the efficacy of hard work and good study strategies in learning science, as distinct form their self-confidence and other beliefs about themselves. In other words, science is learnable by anyone willing to make the effort, not just by a few talented individuals.   Schommer refers to this dimension as innate ability.

Nature of Science Assessments

In general, NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). NOS traditionally has been treated as declarative knowledge outcomes and measured by objective instruments as discussed earlier. Although the validity of the assessment instruments described below has been criticized they are presented here as being the most valid attempts to assess understandings of the NOS (Lederman, et al., 2002; Lederman, et al., 1998).

Cooley and Klopfer's (1961) Test on Understanding Science (TOUS) is used as one of a series of tests. Some researchers criticize TOUS with one of the criticisms of TOUS being that a few of the TOUS items do not relate to a learners' conception of scientific knowledge and are more relevant to the institution of science and the profession of scientists (Lederman, et al., 1998). In addition, some argue that the TOUS loads strongly on a verbal factor and the difficulty of some items in the TOUS decrease the meaning for students. Lederman, et al., (1998) suggest that TOUS is an excellent initial assessment tool for those interested in assessing understandings of the NOS.

The Nature of Science Scale (NOSS) developed by Kimball (1967-1968) is used to determine whether or not science instructors have the same view of science as scientists. Kimball's validation samples included scientists, science teachers, philosophy majors, and science majors. A criticism of the NOSS is that its development and validation using a sample of college graduates make it inappropriate for high school populations.

The Science Understanding Measure (SUM) based on the TOUS was developed by Coxhead and Whitefield (1975). The purpose of SUM is the informative and diagnostic analysis of groups of students in the 11 to 14 age range. The SUM involves five areas: scientists as people, science and society, the role and nature of experiments, theories and models in science, and the unity and interrelatedness of the sciences.

Rubba and Anderson (1978) developed the Nature of Scientific Knowledge Scale (NSKS) to assess secondary students' understanding of the nature of scientific knowledge in relation to their science epistemological beliefs. The NSKS's six subscales are amoral, creative, developmental, parsimonious, testable, and unified. Even with the NSKS obtaining weak criticism from other researchers, it does possess potentially significant wording problems (Lederman, 1998). For example, there are some pairs of statements that differ only in that one is stated in the positive and the other in the negative. This redundancy could encourage participants to check their answers on previous items when they read similarly-worded items later in the questionnaire. This could affect reliability estimates. However, it is considered to be a valid and reliable measure of NOS by virtue of its focus on one or more ideas that have been traditionally considered under the label of NOS (Lederman, et al., 1998). This instrument was used in this study to assess further students epistemological beliefs concerning the nature of scientific knowledge. The statistics of the NSKS will be discussed in further detail in chapter three.

The Views on Science-Technology-Society (VOSTS) was developed by Aikenhead and Ryan (1992) and is an instrument dealing with STS topics. The content of VOSTS statements is defined by the domain of STS content appropriate for high school students. The VOSTS conceptual scheme included science and technology, influence of society on science/technology, influence of science/technology on society, influence of school science on society, characteristics of scientists, social construction of scientific knowledge, social construction of technology, and nature of scientific knowledge. For the past decade, interviews and other qualitative methodologies have been more widely used to assess students' knowledge about NOS. Some researchers become aware of the importance of using qualitative methodologies to determine how students interpret the language of items as well as how researchers interpret students' written language (Lederman & O'Malley, 1990).

Lederman, et al., (2002) developed a new open-ended instrument, the Views of Nature of Science Questionnaire (VNOS), which in combination with individual semi-structured interviews seeks to provide a meaningful assessment of learners' NOS views. The VNOS has three versions, all of which are open-ended. The most frequently used versions are the VNOS–B with seven items and the VNOS–C with ten items. Each instrument aims to elucidate students' views about several aspects of "nature of science" (NOS). These NOS aspects include the following: (1) Empirical NOS; (2) Tentative NOS; (3) Inferential NOS; (4) Creative NOS; (5) Theory-laden NOS; (6) Social and cultural NOS; (7) Myth of the "Scientific Method"; and (8) Nature and distinction between scientific theories and laws.

Lederman, et al., (2002) suggest that the VNOS–B and the VNOS–C be administered under controlled conditions (e.g. classroom setting) and with sufficient time. The authors suggest that the instruments not be used for summative assessments (i.e., final determination of student conceptions or views) and that the users inform the students that there is no right or wrong answers. The researchers strongly recommend that administration of the VNOS be followed with individual interviews to insure the validity of the instrument. The VNOS–B was tested for construct validity. The VNOS–B was administered to two groups of nine participants each: a novice group and an expert group. Analysis of the interviews identified clear differences in the expert vs. novice responses regarding NOS. The instrument was further modified and expanded for the VNOS–C. A panel of five experts examined the items for content validity and the items were modified accordingly. Profile comparisons indicated that interpretations of participants' views as explained on the VNOS–C were similar to those expressed by participants during individual interviews (Lederman, et. al., 2002).

Many researchers focus on assessment of students’ conceptions of the NOS. The question is how knowledge about NOS helps students learn science and why NOS should be as a goal of science instruction. Driver, et al., (1996) answered this question by suggesting five arguments supporting the inclusion of the NOS in science curriculum. These five arguments include: understanding the NOS will help students make sense of the science, manage technological objects and processes they encounter, make sense of socio-scientific issues, participate in decision-making processes, appreciate science as a major element of contemporary culture, help students understand norms of scientific community embodying moral commitment, and support successful learning of science content.

However, evidence suggests that knowledge of the NOS assists students in learning science content, enhances understanding of science, enhances interest in science, enhances decision making, and enhances instructional delivery (McComas, Almazroa, & Clougii, 1998). For example, Songer and Linn (1991) found that students with dynamic views of science acquired a more integrated understanding of thermodynamics than those with static views. The dynamic view of science means that scientific knowledge is tentative, whereas the static view means that science is a group of facts that are best memorized.

Applicability to College Science Education

Epistemological Orientations in the Sciences

As the learner goes through college, he or she undergoes developmental progression in their attitudes toward knowing, learning, and teaching. The *seven* epistemological models described in this paper, developed by Perry (1970), Belenky et al. (1986), King & Kitchener (2002), Baxter Magolda (2002), Kuhn (1991), Schommer-Aikins (1990), and Hofer & Pintrich (1997) outline the course of this progression. The models differ some, but paint a more or less coherent image of epistemological progression. Doing science depends on mature habits of mind, such as questioning assumptions and not taking information at face value. A learner with developed epistemological beliefs in science knows how to evaluate controversies and the existence of uncertainty

Real science is all about testing accepted knowledge and challenging authority, accepting the inescapability of uncertainty and vagueness. Then in due course committing to theories and models based on the best available evidence while acknowledging that the theories and models will eventually have to be revised or rejected as better evidence emerges. Unfortunately despite significant progress in science curriculum reform in recent years, many courses are still taught in what some identify as a “dualistic mode,” emphasizing facts and well-established principles and procedures and not introducing multiplicity until the learner’s junior or senior year with the use of case studies, or involving the learner in research or design experiences.

Many learners enter college at the level of absolute knowing (Baxter Magolda, 1992), believing that knowledge is certain, authorities have the knowledge, and the responsibility to communicate it, and the learners’ job is to absorb it and repeat it. As they experience their college courses and extracurricular activities, the learners may progress through some or all of several successive stages in which they gradually relinquish their belief in the certainty of knowledge and the all of knowing of authorities. They recognize the need of making judgments based on evidence, and become increasingly skilled at gathering and analyzing the evidence. Science majors at the level of absolute knowing view science as a collection of known facts. According to Palmer and Marra (2004), these students have trouble understanding the instructor's use of evidence as the basis of judgments or decisions and are essentially incapable of gathering and using evidence for their own judgments.

An extensive research base supports the reflective judgment model (King & Kitchener 2002, 2004) and records the progression in levels of college students from freshman to senior years. The data closely match the previously cited studies of science and engineering students based on the Perry model. On average, the learner enters college at the level of pre-reflective thinking (dualism), basing their judgments on unconfirmed beliefs and the declaration of authorities, and leave at the quasi-reflective thinking level (multiplicity), beginning to seek, and use evidence to support their judgments. Studies indicate very few graduates reach the level of reflective thinking (contextual relativism). Research using the King-Kitchener model found that only advanced doctoral students were consistently able to reason reflectively (Felder & Brent, 2004).

Later studies of epistemological development on the Perry scale have reached less gratifying conclusions. In particular, most learners majoring in science are found to be in the 2.5–3.5 level and less than one-third make it as far as Level 5 (Pavelich & Moore, 1996; Wise, Lee, Litzinger, Marra, & Palmer, 2004). Studies by Jehng, Johnson, & Anderson (1993) and Paulsen and Wells (1998) show that learners in science are more likely than learners in social sciences and humanities to believe in the certainty of knowledge and in authority as its source. However those it the field of science would view those beliefs as mistaken.

Science majors at the level of transitional knowing have begun to view science as a set of theories and facts with exceptions (Palmer & Marra, 2004). Learners in the impersonal pattern take comfort in the objective nature of science and are bewildered if this view is contradicted by their instructor. Many learners in the interpersonal pattern turn away from science switching to the arts or humanities because they begin to view as cold, inhuman, dogmatic, manipulative, and the enemy of subjective knowing (Felder & Brent, 2005).

There are two patterns of development described in the epistemological models, one characteristic of more female than male and the other of more male than female, but contextual knowing, is the endpoint of both patterns. The contextual mindset of learners at the stage of contextual knowing influences how these individuals view science. At Baxter Magolda's (1992) earlier levels, science is seen as a collection of objective facts that are either known and understood now or will be known and understood eventually if the correct investigation procedures are followed (Palmer & Marra, 2004). Contextual knowers exhibit correctly viewing science as a collection of approximate models of reality that the scientist must play a part in constructing. These learners' skepticism and willingness to challenge what is currently known and to question the assumptions core to all claims, their tolerance of vagueness, their receptiveness to use both logic and intuition in their investigations, and their unwillingness to transfer judgments made in one context to another context without critical evaluation, could define a first-rate scientists.

It is clear that instructional programs wishing to prepare graduates to be expert scientists should be designed to promote the epistemological development of their students. Unfortunately, many science courses emphasize facts and well-established procedures and do not routinely call on learners to confront the uncertainty of knowledge and the need to make evidence-based judgments in the face of that uncertainty. The result is that most learners graduating from college do not progress much beyond the epistemological level at which they entered.

Assessing Epistemological Levels in the Classroom

Numerous instruments have been developed to measure epistemological beliefs. These instruments as discussed earlier fall into two types: uni- and multidimensional. Educators may want to consider the following questions in order to select the measurement tool most appropriate for evaluating their own learners in a classroom setting. First, consider the issues of age, ethnicity, and gender of the participants to be assessed. According to Duell & Schommer-Aikins, (2001) four conceptual issues the educator may want to take into account as they chose an instrument include: (1) Is the theory behind the instrument credible? (2) Does this instrument measure the epistemological dimension(s) relevant to the educator's goals? (3) Is the educator comfortable with the format of the instrument? and (4) Among the instruments which one has the strongest evidence of reliability and validity?

Initial epistemological beliefs measurement methods involved conducting and transcribing open-ended interviews and using trained raters to assign levels to the interviewees. Interview transcription and analysis remains the most reliable and valid approach to assessment, but the difficulty and expense of this approach has motivated efforts to design questionnaires and multiple choice instruments that can inexpensively administered to large numbers of learners.

Alternative measurements to interviews in which learners write essays on topics derived form the interview protocols include the Measure of Intellectual Development (MID) for the Perry model (Pavelich & Moore, 1996), and the Measure of

Epistemological Reflection (MER) for the Baxter Magolda model (Baxter Magolda, 1992). Likert-scale instruments that assess learner levels on the Perry and the King and Kitchener models respectively include the Learning Environment Preferences (LEP) questionnaire and Reflective Thinking Appraisal (Felder & Brent, 2004). Although these assessments have the desired advantages of low cost and ease of administration the ratings obtained using them tend to be one or two lower than those obtained with interviews and correlate moderately at best with the latter levels.

The instrument used to collect the data should be reliable (consistent results are obtained in repeated assessments) and valid (the instrument measures what it is intended to measure). The validity and reliability of epistemological development assessment is critically important if the results are to be used to design balanced instruction to address the needs of all the learners. Reliability and validity data are readily available for some instruments discussed, while for others they are difficult to find (Felder and Brent, 2005).

Promoting Epistemological Growth

Promoting epistemological intellectual growth requires challenging learners' beliefs about the nature of knowledge, the role of authorities, and the procedures that should be used to make judgments. This requirement poses a problem for instructors. In most college, science classes, learners are likely to be found at all levels of epistemological development from absolute knowing through contextual knowing. Instruction that might be ideally suited to learners at one level could be ineffective or counterproductive for learners at another.

One of the key principles to promoting epistemological growth is effective instruction. The instructor needs to consider the learner's epistemological beliefs and how he or she learns. Some instructors teach without having much formal knowledge of how learners learn. The instructor's role is primarily that of a facilitator or coach, encouraging the learners to achieve the target attitudes and skills and providing constructive feedback.

It may not be adequate enough to just help learners to reflect on their epistemological beliefs. The learning environment may also need to be changed so that learners are required to engage in constructivist learning behaviors that may then influence their epistemological beliefs In particular, assessment is a key factor in determining an individuals' learning behavior and beliefs about learning in particular contexts. Assessments need to focus on the development of understanding and the application of theory to personal situations and experiences rather than a reproductive focus on gaining facts. However over-assessment can reduce the motivation for learners to understand concepts, and encourage them to rote-learn material.

Instructional conditions should provide the student with the challenge, reflection, and support needed to promote epistemological development. Recommendations for classroom environments that enhance development across epistemological positions have included encouraging learner questions and comments, instructor recognition of learner reactions, and increased emphasis on learner participation (Baxter Magolda, 1987). This development may be fostered by curricular methods that validate the learner as a knower, situate learning within the learners' experience, and create chances for learners to construct meaning with others (Hofer, 2001). King and Kitchener (2002) suggest providing opportunities for learners to discuss and analyze ill-structured problems, the skills of gathering and evaluating data, engaging learners in the discussion of controversial issues, and assisting them in examining their assumptions about knowledge and how it is gained. In addition, instructors need to show respect for learners' beliefs in spite of developmental level, and to provide feedback and support both on a cognitive and affective level.

Many learners have difficulties learning within the conventional structure of a general chemistry course. Chemistry is traditionally taught in two specific settings, the lecture hall and the laboratory. Traditional pedagogy leaves little room for doing anything but moving quickly digested information from textbooks to testing. There are few protective measures in traditional pedagogy to examine whether actual learning takes place, unless one assume that correct responses to exam questions indicate learner understanding (Coppola & Jacobs, 2001). Furthermore, traditional laboratory activities are not actual inquiry experiments, instead they very observations that have been known and repeated hundreds of times. Although many instructors have experimented with promising pedagogical techniques in the classroom or laboratory, few have treated this work with the same level of respect that they treat their research.

Literature from studies concerning pedagogical instruction in science suggest six pedagogical applications that may provide the balance of challenge, reflection and support needed to promote epistemological growth and promote a deep approach to learning (Bruning, et al., 2004; Felder & Brent, 2004; Louca, Elby, Hammer, & Kagey, 2004; NRC, 1999; NRC, 1997; Palmer & Marra, 2004; Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005). The pedagogical applications are listed in Table 2. Figure 3 provides a general overview of the pedagogical applications that facilitate epistemological growth in the classroom. The remainder of the review discusses these applications and offers suggestions for implementing them.

Table 2 Pedagogical Applications that Facilitate Epistemological Growth

1. Learning Tasks - Variety and Choice
2. Expectations – Communicating and Explaining
3. Modeling and Practice
4. Constructive Feedback
5. Learner-Centered Environment
6. Respect for Student Development

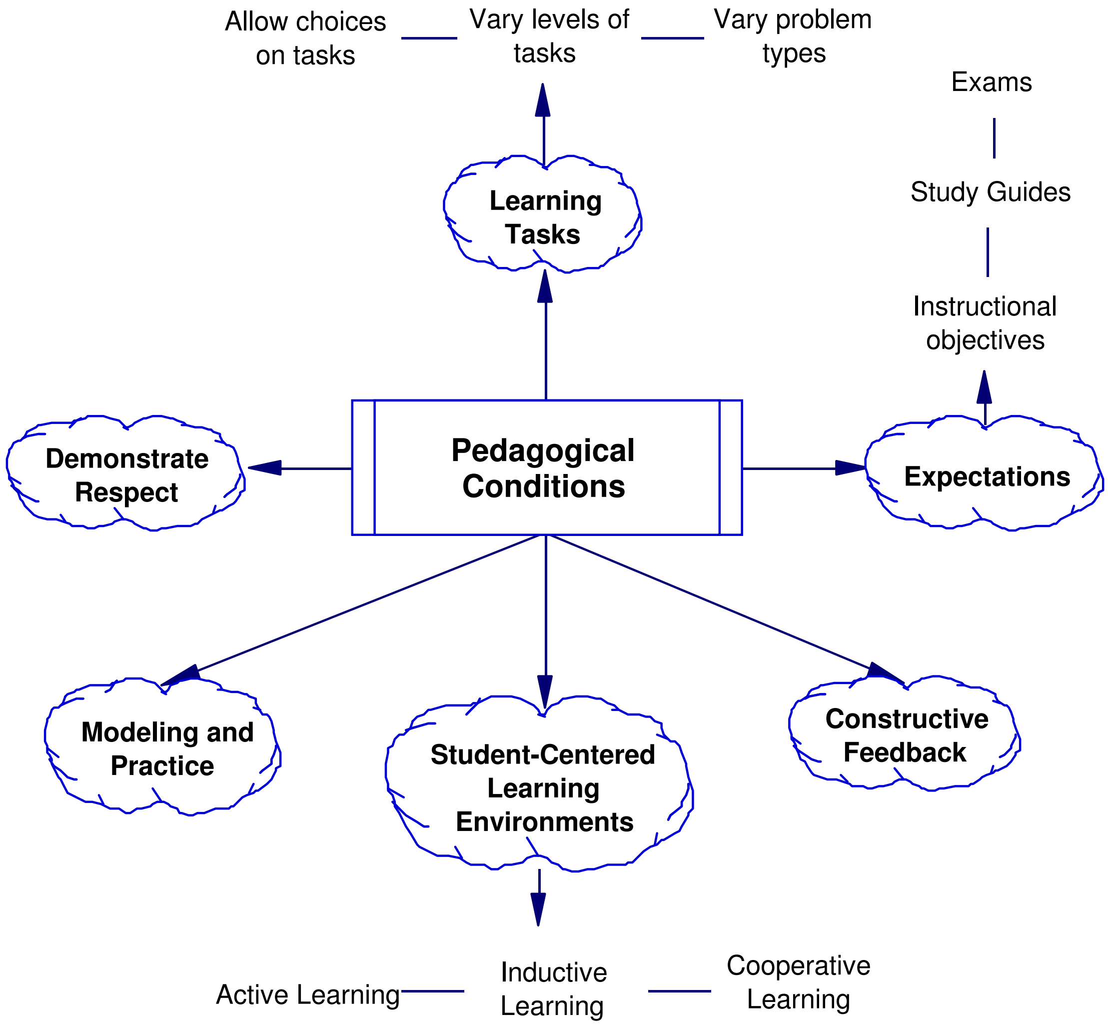


Figure 3 Summary of pedagogical applications that facilitate epistemological growth

Learning Tasks – Variety and Choice

The use of a variety of instructional tasks is the key to promoting learning. Assigning a variety of learning tasks is the only way to assure that all learners are confronted with tasks enough above their current development level to challenge them but not too far above to discourage them. Variety and choice enable instructors both to challenge the learners' epistemological beliefs and to ensure that learners are confronted with tasks that require a deep approach to learning (Chin & Brown, 2000, Clow, 1998).

In selecting a task which encourages learners to employ a deep approach to learning, a number of factors should be considered. According to Clow, (1998) several studies identified the following key factors that facilitate a deep approach:

1. The activity should be perceived by the learners as interesting and relevant.
2. Learners should have autonomy over learning and study methods.
3. If the workload is too excessive learners will resort to a surface approach.
4. The task should not increase the anxiety of the learner.
5. Learners should not feel threatened by the task in anyway.
6. Learners should be actively involved in the task.
7. Learners should interact with each other as peer learning can be very powerful.
8. Learners should have and take time to reflect on the task afterwards. They need to consider what they have learned, how they learned it, and how it fits with their prior knowledge.
9. The context of the task should be similar to the relevancy of the subject material.
10. Provide some choice over learning tasks, and how the task is assessed.

There are several ways to provide variety and choice in learning tasks. The first way is to offer a variety of high-level problems. Science problems come in a wide range of types such as closed-ended with one correct solution, open-ended with multiple solutions, theoretical problems, applied problems, while others call for library research, problem formulation, and critical thinking. For example, provide learners with data from a real or hypothetical experiment such as salt on a roadway retarding ice formation and call on learners to explain the results in terms of the course concepts. Other tasks (Garratt, 1998) might be based on the interpretation of a graph or figure, the creation of a concept map, or a short thought provoking question such as: "Consider several beakers of tap or pure water at different temperatures. How do their pH values compare? Explain."

In order to promote a deep approach to learning assign high-level problems that the learner perceives as relevant to the subject matter. In addition, have some of the problems relate to the learners' backgrounds, career goals, concerns, and interests by using socioscientific issues such as environmental science, genome project, and alterative fuels (Sadler, Chamber, & Zeidler, 2002; Zeidler, 1984).

Provide learners with some choices over the task by allowing them to select from alternative tasks, alternative problems on homework and exams, and deciding how some tasks will be graded. Providing some choice helps minimize the incidence at which learners are forced to work at levels too high or low for their level of development (Felder & Brent, 2005).

Expectations – Communicating and Explaining

There are numerous reasons for learners finding chemistry difficult to learn. For instance when we instruct we make assumptions about what our students know (Garratt, 1998), but we rarely analyze them in detail for ourselves. Often the assumptions we make are wrong as we may not know what the students were suppose to learn from their previous courses and students may think they know more than they do. Learners are helped to overcome their problems with learning (misconceptions) if they have a clear understanding of what is expected of them, what goals we set for them, and what goals they set for themselves.

Course objectives are broad statements reflecting general course goals and outcomes, while learning objectives are targeted statements about expected learner performance. Usually, learning objectives are competency-based as the they designate exactly what learners need to do to demonstrate mastery of course material. Therefore, learning objectives should be stated in terms of learner outcomes. Instructional objectives should be brief, clear, specific statements of what learners will be able to perform at the conclusion of the task.

According to Felder and Brent (2004), instructional objectives are statements of observable behaviors that demonstrate learners' abilities, attitudes, knowledge, and understanding. Instructional objectives have two parts: an action verb and a content area. Utilize the action verb to specify the desired learner performance followed by a specific description of the course specific goal. For instance, instructional objectives assist in maintaining a learner-centered emphasis and usually take one of the following forms: "The learner will be able to...." or "On the next exam, the learner may be called upon to…" The action verb may involve a range of skills or cognitive processes at various levels of thinking such as define, calculate, outline, list, predict, compare and contrast, design and model. It is important to examine various levels of cognitive understanding. Bloom's (1956) taxonomy of educational objectives breaks down the cognitive domain into six levels. Levels 1-3, known as lower-level skills include knowledge, comprehension, application, while levels 4-6 identified as higher-level skills are analysis, synthesis, and evaluation. The best way to promote the development of higher-level skills is to include high-level tasks in the instructional objectives.

Learners learn more effectively when they know what they are working towards. Learners value and expect transparency in the way their knowledge will be assessed. Therefore, write instructional objectives that include both knowledge of content and mastery of the skills you wish the learners to develop. Felder and Brent (2005) suggest including some higher-level problem-solving skills (e.g. analysis, critical thinking) and the process skills (e.g. oral communication, teamwork). Make the objectives as detailed and specific as possible, list all the different tasks the learner will be expected to do, and make course tasks, homework, and exams consistent with objectives. Students wish to see clear relationships between lectures, laboratory activities, and learning tasks and what they are expected to demonstrate they know and can do. The instructional objectives can be valuable if they are shared with the learners in the form of study guides as they reveal to the learner what they are responsible for on the exam. When learners have a clearer understanding of what is expected of them, the clarity leads to a greater chance of better learner performance (NRC, 1999).

Modeling and Practice

Learners acquire skills most effectively through practice and modeling. No matter how often learners see a skill demonstrated, they rarely master it until they have practiced it repeatedly and received feedback on how to improve. In other words, the only way a skill is developed is by trying something, seeing how well or poorly it works, reflecting on how to do it differently, then trying it again and seeing if it works better. Effective modeling and practice in instruction can challenge the learner’s beliefs and promote epistemological growth.

One of the least effective methods of modeling, thinking, and problem solving used in traditional instruction is to transcribe fully worked-out problems on the board, projector, or in a PowerPoint show. Give students incompletely specified problems and have the students itemize what they know, what they need to know, and then determine how they will determine the unknowns. Ask students to make up problems having to do with the course content that require high-level skills.

Reform movements in chemistry education have sought to engage learners by promoting active learning and providing contemporary situations that illustrate abstract concepts inside and outside the classroom. Introducing computers to a course can often result in a boost to students' learning. Interactive technologies (e.g., Blackboard, Web CT, and World Wide Web) remotely deliver animations, on-line quizzes, simulations, tutorials at a time and pace dictated by the learner. More significantly, the learners can have these experiences whenever and wherever they wish (Clow, 1998).

Give the learners something to do in class instead of passively listening. For instance, in a 50-minute class at several points during the class, ask the students to answer a problem, sketch a concept map, solve part of a problem, or interpret an observation first individually, then in groups of three or four for 30 seconds to two minutes. After the activity, call on a few individuals for response before opening the floor to volunteers.

Problem-solving skills and speed in problem solving are developed through practice and feedback. Learners need to be given sufficient experience working with mathematical and scientific models. According to Taber (2000) this means that the problem sets have to be structured to ensure that the learner is both able to achieve success, and to develop their skills by applying the scientific principles in higher-level tasks and contexts.

King and Kitchener (2002) describe an ill-defined problem (e.g., global warming, ozone layer) as one that has more than one acceptable solution, while a well-defined problem has only one correct answer (e.g., solving quadratic equation). To understand science as it is practiced, rather than solving problems from a textbook the learner needs to engage in problem-posing. After posing a problem, learners need to experience open-ended problem solving in the classroom or laboratory setting. Real scientific problems do not have answers in the back of the textbook.

Research on problem-solving has received a great deal of attention. Although, several models have emerged, most are quite similar and can be summarized into a five-stage sequence: (1) identifying the problem, (2) representing the problem, (3) selecting an appropriate strategy, (4) implementing the strategy, and (5) evaluating the solutions (Bruning, et al., 2004).

Obstacles to effective problem-solving can be eliminated by enhancing the occurrence of this type of learning through practice. Learners who persist in trying different approaches, even those that do not result in a final solution are practicing problem-solving. Five conditions discussed by Farmer, Farrell, and Lehman (1991) that enhance problem solving include: (1) the problem must be a problem to the learner, an obstacle, (2) the learner must have a clearly defined attainable goal, (3) the relevant prerequisite rules and concepts must be recalled by the learner, (4) there must be cues to help the learner recall rules and approaches, and (5) the instructor must stress the nature and expectations of the task.

Perform demonstrations and have the learners predict the outcomes prior. The best demonstrations generate incorrect predictions resulting from misconceptions. Once the learners are given evidence that their mental pictures may be wrong can promote cognitive dissonance, demystify authority leading to epistemological change (Felder and Brent, 2005).

Provide visual illustrations as most learners get a great deal more out of visual information than verbal information. Show pictures, sketches, concept maps, and computer simulations of course-related material. Take the class to the local wastewater treatment plant and point out the chemistry of the system (e.g., acidity, alkalinity, chlorine chemistry, pH levels, and stoichiometry). Instructors should give repeated practice in high-level tasks in class and as homework before including these tasks on assessments such as exams. The more we challenge learners to assess their own knowledge and skills accurately, the more confident they will become as learners.

However, challenge alone is not sufficient. Without providing appropriate support to help learners deal with the changes they are being called upon to make, they may decide to stay at their current level or even retreat to a lower developmental level. Letting go of fundamental and firmly held beliefs even in learning is one of the hardest tasks faced by students. Science college instructors frequently adopt a sink or swim mentality, teaching at a high level and forcing the learners to either adapt or drop out. However, a more able approach is to include modeling in the epistemological ways of thinking.

Modeling, also referred to as monitoring is the metacognitive process of keeping track of, regulating, and controlling a mental process, considering past, present, and planned mental actions. Ask learners to pause and reflect on present learning (e.g. Why am I doing this?) and past learning (e.g. What did you learn?) to deepen their problem-solving approach and improve understanding.

Therefore, it is essential that learners develop self-reflection skills and suitable beliefs about learning and knowledge not only for their own sake but because these skills and views may be related to improvements in their conceptual understanding. Tremendous growth has occurred in research about learning and the role that epistemological reflection has on the learner constructing knowledge and beliefs. Researchers recognize that learners' beliefs about the nature of knowledge and learning play an important role in their success as well as their ability to reflect on how they learn.

Reflection promotes knowledge integration and refers to both metacognition and sense making. Reflection provides a method for fostering knowledge integration by helping learners to expand their repertoire of ideas, differentiate, and make connections between them. The process of reflection may help the learner identify weaknesses with their current understanding and thus motivate them to revisit, test, and reformulate the links and connections among their ideas, leading to more coherent, robust, and integrated understanding.

Constructive Feedback

Learners in any classroom cover a range of levels of epistemological development. Studies have shown that learners' intellectual development can be strongly influenced by their affective states. Zusho, Pintrich, and Coppola (2003) believe emotion drives a learners' attention, which in turn drives learning and memory. Learners who are depressed or angry may not take in and process information effectively. Furthermore, an accepting and supportive classroom atmosphere has been found to enhance both academic and intellectual development. Studies that support findings related to social and cultural influences have been important in offering instructors pedagogical recommendations to facilitate epistemological growth in their students (Felder & Brent, 2004; Wolters & Pintrich, 1998).

Providing appropriate feedback is essential if learners are to remain motivated. A feature of effective feedback is that it will improve the learner's confidence not only in the quality of work being produced but also in their ability to progress. Instructors should seek to respond positively to learner answers to questions or contributions to discussion by picking out those aspects which can be treated as partially correct and leading the discussion towards a better response. For example, when learners share uninformed opinions during class discussions, the instructor can demonstrate effective and respectful ways to challenge erroneous assumptions or misconceptions. The important benefit of using positive feedback is that it often leads to deeper learning.

Learner-Centered Environment

According to constructivist models learning is not a spectator sport. Researchers believe the most identifiable goal of epistemological growth is a decreasing reliance on authority for all the answers. To promote epistemological growth numerous studies suggest that using a learner-centered environment can accomplish the goal (Hammer, & Elby, 2003; Herron & Nurrenbern, 1999; Hogan, 1999; NRC, 1999). This is achieved by involving learners in learning tasks individually and in groups that require learners to take more responsibility for their learning than the traditional approach requires.

Studies from the National Research Council (NRC, 1997) have reported that learner-centered environments are an essential element for a quality learning experience. Learning-centered environments are defined by the NRC as “environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting.” The learner-centered approach places more responsibility on the learner by expecting her or him to come to class prepared and ready to work at the challenging task of refining conceptual understanding and problem-solving skills. In a study performed by Nolen (2003) classroom learning environment was a significant predictor of both satisfaction and achievement in science.

Currently the most relevant instructional implication of constructivist epistemology is that pedagogical strategies that facilitate the construction of knowledge and are learner-centered should be favored over those that do not (Smith, Sheppard, Johnson, & Johnson, 2005). Students learn by using auditory, kinesthetic and visual approaches (Bunce, 2001). Many pedagogical strategies that foster, encourage, and facilitate the construction of knowledge using these approaches have emerged over the years such as active learning, case-based learning, cooperative or collaborative learning, hands-on learning, and inductive learning. All of these strategies attempt to create an environment where learners are actively thinking and applying knowledge, as opposed to passively listening to an instructor present the material.

J. W. Layman (1996) explains how classroom instruction can change as the instructor and learner move from instructor- centered pedagogy to learner-centered pedagogy:

> "The previously dominant view of instruction as direct transfer of knowledge from instructor to student does not fit the current perspective… The present view places the learner's constructive mental activity at the heart of all instructional exchanges… This does not mean that students are left to discover everything for themselves, nor that what they discover and how they choose to describe and account for it are left solely to them. Instruction must provide experiences and information from which learners can build new knowledge. Instruction helps to focus those processes so that the resulting knowledge is both valid and powerful. Valid in the sense of describing the world well … and powerful in the sense of being useful and reliable for those students in many diverse setting."

Inductive learning is based on the claim that knowledge is built primarily from a learner's prior learning experiences and interactions. Inductive learning is an effective method to motivate desire in students to learn a topic and for addressing the instructional expectations (Felder & Brent, 2004). Inductive learning approaches such as guided inquiry, problem-based learning and case study method learning have learners confront problems before they are given all the concepts needed to solve them (Bruning, et al., 2004; DiPasquale, Mason, & Kolkhorst, 2003; O'Sullivan & Copper, 2003; Leonard, 2000).

The instructor using the inductive learning approach begins by exposing learners to concrete instances of a concept. An effective way to motivate learners when using this method is for the instructor to inform the learner up front what the material has to do with their everyday life. Subsequently learners are encouraged to observe patterns, raise questions, and make generalizations from their observations. This approach can push the learner toward the independence and ability to relinquishing their misconceptions.

Active learning is instruction that engages learners in any course-related activity other than passively watching and listening to a lecture. This in-class instruction involves learners working individually or in small groups on tasks related to the instructional objectives such as answering questions, brainstorming, formulating questions, solving short problems, or troubleshooting (Felder & Brent, 2004). The idea behind active learning is that learners acquire skills through active practice and feedback. Therefore, the more practice they get at engaging in an activity, the better they are likely to understand the concepts associated with the activity. Numerous studies support the positive effects on knowledge and skill acquisition of interspersing active learning in a lecture class (NRC, 1999; Leonard*,* 2000*;* Olmstead, 1999; O'Sullivan & Copper, 2003)

Cooperative learning is one of the widely used and researched pedagogical methods (NRC, 1997). Hofer (2001) suggests one way to promote critical thinking skills and conceptual change is to encourage learners to work together in cooperative settings in which they discuss and evaluate their own beliefs and how their beliefs affect learning. A number of studies have found that cooperative learning environments help learners develop the skills and beliefs needed to think critically (Lord, 1994; Schraw, 2001). Macgregor, Cooper, Smith, and Robinson (2000) performed a synthesis of forty-eight interviews with instructors teaching undergraduate classes across the United States who incorporated small-group activities into their large classes. The instructors incorporating small-group learning activities in their large classes provided extensive empirical evidence and theoretical rationale for cooperative learning. For instance the studies suggested that cooperative learning promotes cognitive elaboration, enhances critical thinking, provides feedback, and promotes social and emotional development.

In cooperative groups, learners work with peers to help incorporate new knowledge. Some instructors use this approach in laboratory settings, lecture, or recitation sessions. In general cooperative learning requires certain characteristics of team members: individual accountability, individual responsibility, interpersonal skills, and positive interdependence. The important aspects of these learning groups are they are designed to challenge learners' current knowledge and require learners to seek knew knowledge, compare and contrast prior knowledge or apply knowledge that has just been presented (Bunce, 2001). The questions posed by team members reflect where the learners are in the learning process, rather than where the instructor assumes they are. In a cooperative activity learners can compare and contrast concepts such as heat and temperature in discussing the gas laws. Discussion among the team members helps learners confront their own understanding or lack of it. After the discussion, presentations of each team's rationale assists learners in expressing the concepts, practice with the concepts, a chance to critique presentations, and time to assimilate the new knowledge (Bunce, 2001).

The project titled The National Survey of Student Engagement (NSSE, 2004) strengthens educators and researchers understanding of how learners perceive classroom-based learning as an element in the larger issue of learner engagement in their college education. Smith, et al., (2005) suggest that NSSE findings are a valuable tool for colleges to track how successful their academic practices are in engaging their student bodies. The NSSE project is based on the premise that learner engagement, the frequency with which learners participate in activities that represent effective educational practice is meaningful and necessary for the quality of education. The annual survey of freshman and seniors asks learners how often they have, for instance, participated in projects that require integrating ideas form various sources, used e-mail to communicate with classmates and instructors, asked questions in class or contributed to class discussions, or tutored other classmates. Learner responses are organized around five benchmarks: (1) Level of academic challenge, (2) Active and collaborative learning, (3) Student-faculty interaction, (4) Enriching educational experiences, and (5) supportive campus environment.

One of the pleasing revelations of the NSSE findings was the significant number of learners engaged in various forms of active and collaborative learning activities. The shift form passive, instructor-dominated pedagogy to active, learner-centered environments promises to have desirable effects on learning. Student-centered learning environments take learners to deeper levels of understanding and meaning, encouraging them to apply what they are learning to real life. Regression analyses of responses from 61,000 students across 459 colleges indicate that learners who scored higher on the deep learning scale were more satisfied with their overall educational experience. According to the latest findings seniors, full-time students, and students at liberal arts colleges scored higher on the deep learning scale. However, learners majoring in the physical sciences and engineering scored lowest, due primarily to relatively low integrative and reflective learning scores (NSSE, 2004). To some degree, the findings from the NSSE corroborates previous research showing that learners majoring in the physical sciences and engineering use deep approaches to learning less often than learners from other fields (Felder & Brent, 2005; Zeegers, 2001).

Respecting Student Development Levels

The social environment in a classroom can have a profound effect on the quality of learning that takes place. If learners believe that an instructor is concerned about them and has a strong desire for them to learn the concepts, the effects on their attitudes and motivation to learn can be intense. Learners in any classroom cover a range of levels of epistemological development. The instructor should not only respect and be sensitive to all learners but also encourage learners to use their skills and talents. Presentation of course content in a non-biased manner, a willingness to entertain competing viewpoints, a reflective and composed response to confrontation and controversy, and sensitivity to learners with different needs and from varying backgrounds encourages the learner and improves the quality of instruction.

Asking learners to change their epistemological beliefs is asking a lot of them. Instructors must enhance their challenges to learners’ beliefs with measures that convey they care about the learners and are willing to help them. Ways of establishing an atmosphere of respect and caring include learning students' names, being available, when using student-centered learning methods, explain how, and what they are doing.

To foster the developmental level of each learner carefully consider the learning activities to be performed in and out of class. For instance, learners at Perry's Level 5, Belenky's level of procedural knowing, and Hofer and Pintrich's level source of knowledge might thrive in a classroom environment based on cooperative and inquiry-based learning, in which the learners are faced with high-level open-ended problems and are given guidance by the instructor when it is needed but are left to find their own way. Level 4 learners might do well in this environment even if they feel uncomfortable at first eventually promoting their progression to Level 5. However, Level 2 learners and Level 3 learners might find such an environment uncomfortable enough to derail their learning. For example, open-ended questions that do no have unique well-defined solutions may present a major challenge to learners at the lower belief levels of epistemological development. These problems usually require a higher epistemological belief level and deep approach to learning.

Nevertheless, the answer is not to instruct completely in a manner that learners at Level 2 would find comfortable such as presenting facts and formulas in lectures, assigning only single-answer problems involving those facts and formulas, and putting similar problems on the exams. Level 2 and Level 3 learners would not experience any epistemological growth because of it, and learners at the higher levels would be bored. The solution is to provide an appropriate selection of challenges to learners at all levels.

The Laboratory in Chemistry Education

Introduction

For years, the science laboratory has been thought of as the best place for the building and articulation of students' images and understanding of the nature of science (Vhurumuku, et al., 2004). The fundamental assumption has been that by students being involved in laboratory work they would come to develop and assimilate the implied images of the nature of science resulting in meaningful learning. According to Markow and Lonning (1998) meaningful learning in the college chemistry laboratory is based on the notion that laboratory instruction should lead to an understanding of concepts rather than rote learning and fact verification. Students need to view the laboratory as a place to construct new knowledge and not simply as a place to verify the textbook.

There are several pedagogical models to support meaningful learning in chemistry such as laboratory instruction. Research on the role of the laboratory in science teaching is based on more than 30 years of experience with all facets of the chemistry curriculum (Lazarowitz & Tamir, 1994; Bell, 2004; Hofstein, 2004). Numerous studies have been reported on laboratory instruction and its effectiveness for acquiring scientific knowledge, scientific skills, and motivating students (Tiberghien, et al., 2001; Hofstein, et al., 2005). Over the years an attempt has been made to evaluate the domains that characterize laboratory work with studies focusing on the following features: (1) modes of learning, instruction, and assessment in the chemistry laboratory, (2) modes of assessing students' performance in the chemistry laboratory, (3) assessing students' attitudes towards chemistry laboratory work, and (4) assessing students' perceptions of the laboratory classroom learning environment (Hofstein, 2004).

The Nature of Laboratory Instruction

Numerous studies suggest that laboratory instruction is an effective and efficient teaching strategy to attain some chemistry learning goals. According to Hofstein (2004) effective laboratory activities help students (1) construct their chemistry knowledge, (2) develop communication, cooperation, psychomotor, and thinking skills, (3) promote positive attitudes, and 4) encourages students to “think scientifically.”

For students to become successful in scientific inquiry, their direct experience with laboratory apparatus and materials may be a necessary precursor (Millar, 2004). Practical laboratory work helps provide students with experience with chemical phenomena giving concrete meaning to, for example, ideas of chemical reactions by performing real reactions with laboratory tools. Too often, however students find chemistry difficult when in the laboratory they make observations at the macroscopic level, but the instructors expect them to interpret their findings at the microscopic level (Gabel, 1999; Newton, 2000).

The laboratory is a complex learning environment in which students interact with each other, the lab activity, with the laboratory equipment or instruments, and with the instructor. The interactions include affective, cognitive, and psychomotor components. Often students do not have time to think about and reflect on their observations during laboratory instruction (Domin, 1999). However, a critical component of the laboratory instructional environment is encouraging students to reflect on concepts in chemistry that can guide their inquiry.

The effectiveness of laboratory investigations can be seen as an ideal environment for meaningful learning when appropriate instructional techniques are implemented into the curriculum design. For example, the use of cooperative learning techniques, active learning techniques, such as pre-preparation and post-laboratory small group discussions, peer evaluations, and concept mapping could promote higher order thinking and positive attitudes (Cooper, 1995, NRC, 1996). With laboratory investigations discussions play a meaningful role in developing students' understanding of scientific ideas (Driver, et al., 1994; Millar, 2004)

Developmental Positioning in Chemistry Laboratory Instruction

According to several of the epistemological models (e.g. Perry, King-Kitchener, Baxter Magolda) the needs for experiential learning and concrete examples are important support elements for learners at the dualist level. The laboratory can provide learners the opportunity to make connections between abstract ideas from lecture and the world of atoms, measurement, molecules and solutions. While, highly structured traditional lab activities support dualists, these activities can be mere methods of "verifying the truth." Nonetheless, lab activities that are more challenging such as discovery, inquiry, or problem-based may appear too unstructured to the dualists and present more risk of accidents (Finster, 1989, 1991).

According to Finster (1989, 1991), if most general chemistry students are at a late dualist-absolute knowing level then the most productive instruction will occur at the early multiplicity-transitional knowing level. Learners with a dualist perspective may have difficulty in the laboratory environment unless they know exactly what they are suppose to do, why they are there, and what data they are suppose to collect. Progressing from a more structured laboratory environment (dualist-absolute knowing) to one of less structure (late multiplist-early relativist) can encourage personal epistemological growth. Table 3 summarizes how the learner at different epistemological levels views aspects of the educational process.

Table 3 Learner Epistemological Views of Educational Characteristics (Adapted from Finster, 1991, p. 753)

Level – Position	Dualism-Absolute Knowing	Multiplicity-Transitional Knowing	Early Relativism Independent Knowing	Contextual Relativism Contextual Knowing
Issues-Assumptions				
Nature of Knowledge	Knowledge is known; right and wrong answer; collection of facts; quantitative	Much knowledge is known; but uncertainty exists in some areas; knowledge is contextual	All opinions are equal; knowledge is contextual; authority guides	Knowledge complex-contextual; no absolute truth; right - wrong can exist; Quality important over quantity
Role of Instructor	Source of knowledge; absolute authority Role is to dispense knowledge	Source of the right way to find truth; viewed as dogmatic; model process towards truth	Model the way they want us to think; use evidence	Source of expertise; guide or consultant; Mutuality of learning is desired
Role of Learner	Receives information; demonstrates information on assessments; work hard	To learn how to learn truth; express oneself	To learn how they want us to think	Exercise the intellect; apply "rules of adequacy" to information, judgments, and perspectives
Role of Peers	Not legitimate sources of knowledge	Not authorities; can assist in helping or be ignored as all opinions are equal	Sources of diversity; thought and perspective	Sources for learning and diversity
Evaluation Issues	Right is good; wrong is bad; Assessments should be clear-cut and objective	Is the assessment fair and how to answer if no "right" answer?; hard work not standard	Show independent or relativistic thought	Evaluation of self-work separate; Assessments offer feedback for improvement; Quality of answer is important
Intellectual Tasks	Learn basic information; distinguish right from wrong; provide explanations	Compare and contrast; distinguish content from process; improved analysis	use supporting evidence in analysis; examine assumptions and processes; relate to real life	Relate learning between different contexts; consider relationships and complexity; conceptual change
Sources of Challenge and Frustration	Ambiguity, multiple perspectives, uncertainty; dispute between authorities	Recognize that uncertainty is not temporary; Qualitative; Which answer "really right"	accepting learning responsibility; think independently; listen to authority	Choice or commitment; choose between alternatives; scholarly work
Sources of External Support	High degree of structure; concrete examples; experiential learning; Presence of authority for truth	Decreased structure; diversity; clear assignments involving process; access of authority to help	open class atmosphere; prefers diversity; Presence of authority to help evaluate	Diversity of options; Comfortable moving across contexts; intellectual mastery

Laboratory Instructional Methods

Throughout the history of chemistry education, four different methods of laboratory instruction (table 4) have been established. Domin (1999) identifies four the different instructional methods as: (1) Expository (traditional-verification), (2) inquiry, (3) discovery, and (4) problem-based. These methods are distinguished according to three descriptors: approach (deductive or inductive), procedure (given or student generated), and outcome (predetermined or undetermined).

Table 4 Descriptors of Laboratory Instructional Methods (Domin, 1999, p. 543).

Method	Outcome	Approach	Procedure
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student generated
Discovery	Predetermined	Inductive	Given
Problem-based	Pre-determined	Deductive	Student Generated

Expository instruction, also termed traditional or verification is the most common and heavily criticized laboratory instructional method (Domin, 1999; Berg, 2005). Within this learning environment the instructor defines the topic to be investigated, relates the outcome, and directs the actions of the students. The predominant feature of this method is its “cookbook” nature where the students repeat the instructor’s directions or follow the procedure in a course lab manual and are aware of the outcome. The students then compare their results against the expected. This approach has been criticized for placing little emphasis on thinking, being an ineffective means of conceptual change, and unrealistic in its portrayal of the nature of science.

Studies suggest that two reasons exist for the inability of traditional laboratory instruction to result in minimal meaningful learning (Hodson, 1996; Domin, 1999;

Shiland, 1999; Berg, 2005). First, in traditional laboratory instruction the students spend more time determining if they obtained the correct results than they spend thinking, planning, and organizing the experiment. Second, traditional laboratory activities are designed to facilitate the development of the lower-order cognitive skills of Bloom's taxonomy of educational objectives; knowledge, comprehension, and application (Domin, 1999; Berg, 2005).

An alternative to traditional laboratory instruction is an open-inquiry approach. In this inductive method of instruction the students formulate the problem within a given area, and the outcome is undetermined (Domin, 1999; Berg, 2005). This gives the students ownership of the activity while requiring them to relate the investigation to previous work, state the purpose, predict the results, generate the experimental procedure, and perform the investigation. This laboratory instructional method is designed to improve a students' ability to utilize formal thought, improve their attitudes toward science, and to give the student the opportunity to engage in an authentic investigation process. Inquiry laboratory activities when properly designed facilitate the development of the higher-order cognitive skills of Bloom's taxonomy of educational objectives; analysis, synthesis, and evaluation (Domin, 1999; Berg, 2005).
However, the inquiry method has been criticized for placing too much emphasis on the scientific process at the cost of content, and for being time consuming.

The discovery or guided-inquiry approach is inductive with the instructor guiding the student towards discovering a desired outcome. In discovery learning students are given a general outline of possible procedures or perhaps no more than a statement of goals. This laboratory instructional method has been criticized for sharing some of the weaknesses of the traditional method and for being time consuming. Discovery laboratory activities when properly designed facilitate the development of the lower-order cognitive skill of application and higher-order cognitive skills of Bloom's taxonomy of educational objectives; analysis, synthesis, and evaluation (Domin, 1999; Berg, 2005).

In the problem-based instruction, the instructor provides a problem and the required reference material while guiding the students toward a solution. Using a deductive approach, students working in this instructional environment must apply their understanding of a relevant concept to devise an experimental pathway to the solution. Therefore this requires the student to think about what they are doing and why they are doing it. This instructional method is time consuming and poses high demands on both students and instructors. Problem-based laboratory activities when properly designed facilitate the development of higher-order cognitive skills of Bloom's taxonomy of educational objectives; analysis, synthesis, and evaluation (Domin, 1999; Berg, 2005).

Laboratory Pedagogical Approaches

The latest trend in pedagogical techniques in the chemistry laboratory is to demand more work from the learners before the laboratory by developing a prepared mind. The pedagogical emphasis on mental preparation and how the mind can improve the acquisition of motor skills in the laboratory can possibly be achieved with the use of a pre- or post laboratory discussion or assignment or both. Mental preparation administered in the form of pre-lab or post-lab questions, summaries or imaginary practice is learning effective and places minimal demands on the instructor (DeMeo, 2001). All too often learners view laboratory work as unconnected and it is here pre- and post-lab assignments or discussions can be particularly useful, both to identify and subsequently to merge the links to what they already know (Bodner, 1986; Byers, 2002).

Pre-Laboratory

The implementation of pre-laboratory pedagogy has undergone some changes over the years however the thought is still that it prepares the learner's mind for learning and applying new concepts and physical skills (DeMeo, 2001). According to Johnstone & Al-Shuaili, (2001) learner pre-laboratory preparation should not be just "read the lab manual before you come to the laboratory." Some learners ignore preparing for laboratory because they belief they can survive without doing it. The idea of preparing the learner for laboratory with a pre-lab session may encourage deeper thinking about the experiments before they are carried out. The pre-laboratory should prepare the learner to be an active participant in the laboratory.

Personal Response System

The Personal Response System (PRS), unofficially known as "the clicker," is technology that allows for electronic interactions and real-time student feedback (Burnstein, & Lederman, 2001). This portable remote-control device allows students to register their answers to multiple choice questions anonymously; the system tallies the responses and shows a histogram of responses. Faculty can use this data in any number of ways to adjust their classroom teaching based on student responses to significant. The benefits to both faculty and students can be great.

The PRS can benefit faculty in three areas: teaching, research, and service (Fitch, 2004). The most commonly stated goal of student response systems is to improve student learning in the following areas: (1) improved class attendance and preparation, (2) clearer comprehension, (3) more active participation during class, (4) increased peer or collaborative learning, (5) better learning and enrollment retention, and (6) greater student satisfaction. A second basic goal is to improve teaching effectiveness. With PRS, immediate feedback is easily available from all students on the pace, content, interest, and comprehension of the activity, lecture, or discussion. The PRS allows the instructor to view immediately how the whole class collectively responds to the questions thereby allowing the instructor to adjust the class activities and discussions based on what is clear and what is not clear to the students,

The student benefits include allowing students: (1) to respond to questions in private with no pressure to get the right answer, (2) to view immediately how the whole class collectively responds to the questions, and (3) to discuss the question and responses with classmates who can sometimes articulate new material in a way that the expert (i.e. instructor) might not be thinking.

Laboratory Work

Any piece of laboratory work requires students to employ procedures. However, instructors cannot expect students to use procedures effectively if these are not taught explicitly, explained and used in a variety of contexts. Once the procedures are understood, students' have powerful tools to be used in designing experiments. Experimental design is a particularly effective context for teaching epistemological knowledge (Tiberghien, et al., 1998).

During laboratory work there should be a constant interaction between the collection of data (i.e. measurements, observations) and theory. Laboratory notebooks are often used as a formative assessment tool. The use of laboratory notebooks as a part of instruction is supported by many researchers who advocate writing in science to enhance learner understanding of scientific content and processes as well as general writing (Keys, et. al., 1999; Shepardson & Britsch, 2000; Bass, et. al., 2001). The laboratory notebook trains learners to fulfill another scientific requirement, the provision of a clear and accurate written record of procedures, results and discussion. The particularly common and egregious habit of recording results and performing calculations on scraps of paper or paper towels is actively discouraged. Instead, learners should be instructed to treat the laboratory notebook as an integral part of each laboratory exercise in which the pre-lab write up prepares them for the exercise, and where results are entered during each laboratory session. Laboratory notebooks at a minimum should consist of the elements listed in Table 5. The conclusion and discussion should be based on the laboratory results and accompanied by a brief discussion of their chemical significance. Learners are encouraged to record any problems encountered during the procedure and comment on their effect on the results with recommendations for avoiding similar problems in future laboratory exercises.

Table 5 Basic Elements of the Laboratory Notebook

1. General-Introduction-Purpose
2. Predictions
3. Procedural
4. Results-Calculations
5. Discussion-Conclusion
6. References

Microcomputer-Based Laboratory Instruction

Microcomputer-based Laboratory (MBL) instruction has been used in chemistry laboratory education since early 1980 (Barton, 2005; Pienta, & Amend, 2004; 2002; Nakhleh, 1994; Friedler & Tamir, 1984). MBL are tools that use microcomputers for analysis, data acquisition, and display. Students use probes and software to direct the computer to collect, record, and graph scientific data similar to research scientists (Pienta, & Amend, 2004; Newton, 2000).

MBLs can support and enhance meaningful learning in scientific inquiry. They assist in a learners' knowledge construction, and help develop concepts and skills such as graphing, collaboration, and scientific reasoning (Pienta, & Amend, 2004; Nachmias & Linn, 1990). The value of the MBL learning environment lies in increasing the student’s ability to analyze and interpret data. Students can repeat experiments thereby generating more data for analysis, manipulate the parameters of investigations, and study graphs by using MBL modeling tools (Pienta, & Amend, 2004; Newton, 1997; Settlage, 1995; Lazarowitz, & Tamir, 1994).

MBLs allow students to devote more time to observation, reflection, and discussion. Students performing a traditional bench laboratory investigation can require twice as much time as those performing the investigation with a MBL system. Therefore, the MBL instruction allows students more time to discuss, plan, and take responsibility for their study processes (Pienta, & Amend, 2004; Domin, 1999). However, according to Pienta and Amend (2004) students without an appropriate conceptual understanding of chemistry may fail to observe the phenomenon under investigation. Therefore, MBLs may not promote learning for all students (Atar, 2002).

The instructional effectiveness of MBL is connected to the pedagogical method employed. The design of the activities with the MBL must be carefully structured. Learners spending time doing little more than looking at the MBL hardware log data and prepare graphs can hinder learning outcomes (Malina & Nakhleh, 2001; Newton, 1997; Linn, 1995). In addition, learners need time to become familiar and confident in using the probes and software.

Learners’ interactions with the instructor are important in maximizing potential benefits from MBL use (Pienta, & Amend, 2004; Barton, 1997; Newton, 1997). The instructor should engage learners in discussions of the meaning of their data and graphs with their peers. This encourages learners to reflect on their meaning and improve their ability to think more deeply (Barton, 1997). In addition, asking learners prompting questions such as: a) How do you know when the reaction has finished, or b) If you dilute the solution, how does this affect the reaction time? can significantly affect their interpretations of the data (Pienta, & Amend, 2004; Rogers, 1997).

Post Laboratory

Data processing and the development of conclusions provide students opportunities to develop conceptual and epistemological understanding. Data processing can be treated as an algorithm, or as an epistemological opportunity for students to develop the confidence that can be attributed to data and the uses to which data can be put (Tiberghien, et al., 1998). The use of post-laboratory discussions to facilitate reflection and promote the consolidation of learning appears to be consistent with current learning theories. The facilitation of post-lab discussions in peer groups encourages deeper reflection about the results (Byers, 2002). The post-laboratory tasks or discussions should deal with applications, extensions, implications, and possible connections with other areas of chemistry.

Laboratory reports need to be more than filling in blanks in an established pattern. While most learners initially need guidance formatting a laboratory report, the challenge is in forcing the learner to examine chemistry from more than a “body of knowledge” approach. Constantly addressing the issues such as experimental limitations and that science does not always present a clear, single answer can promote analysis by the learner in the form of “thinking about thinking.” The technical writing experience for science majors can be helpful as they will probably be writing scientific articles in the future (Wimpfheimer, 2004).

Summary

Researchers exploring learners’ personal epistemological development and images of the nature of science have identified several individual constructs, instructional factors, and social factors that may influence whether positive learning changes will occur. There is a great deal of research available on the topic of the nature of science and epistemological beliefs in the classroom. However, much of the research is very limited in scope, looking at preservice teachers, and students in K-12. There is limited research on the connections between NOS and personal epistemological belief development of college science students in a laboratory environment.

The purpose of this chapter was to describe the theoretical and conceptual frameworks, and describe the empirical research pertinent to student images of science and epistemological beliefs development. Research literature regarding the following variables was presented: (1) models of epistemological development; (2) multidimensional models of epistemological development; (3) nature of science; (4) the applicability to college science education; and (5) the laboratory in chemistry education was examined to gain an understanding of previous studies.

Sections one and two, the scope of the review, described related theories including Perry's Scheme of Intellectual and Ethical Development, Baxter-Magolda's Epistemological Reflection Model, King and Kitchener's Reflective Judgment Model, and Hofer and Pintrich's Epistemological Theories Model. It has also provided information on assumptions, and validity and reliability issues of the theories. In addition, it reviews literature studies related to these theories.

Section three reviewed literature of studies related to the Nature of Science, also referred to as students' images of science. The review discusses the controversy over the definition of the NOS, describes the images of science that students draw upon during laboratory activities, the need for students' to experience cognitive dissonance to change their NOS beliefs, the instruments used to measure understanding of the NOS, thoughts on the connections between NOS and epistemology, and how to elicit and develop students' understanding of NOS in the classroom.

Section four discussed the research methodology issues with the major focus being on the potential assessment tools used in studying NOS and personal epistemological beliefs. It provides an overview of a few of the instruments used to assess the aforementioned beliefs.

Section five discussed the literature surrounding how the constructs in sections one, two and three apply to college science education. It provides an overview of studies that describe epistemological orientations in learning science as well as how to assess students' epistemological levels in a classroom setting. In addition, it has reviewed literature concerning pedagogical applications that can be used in the classroom in order to promote epistemological growth.

The final section of this chapter presented an overview of the laboratory in chemistry education. This section of the literature review elaborated on the nature of laboratory instruction, epistemological development in laboratory instruction, and the history of laboratory instructional methods. The review ended with an overview of potential laboratory pedagogical approaches used in laboratory instruction.

Chapter three describes in six sections the design and methodology of the research study. Section one restates the purpose of the study, elaborates on the rationale behind the research questions, and presents an overview of the analysis, design, and methodology. Section two describes the context and participants of the setting. Section three discusses the research instruments, measures, and techniques which include the: (1) Chemical Concepts Inventory (CCI), (2) Epistemological Beliefs Assessment for the Physical Sciences (EBAPS), (3) Nature of Scientific Knowledge Scale (NSKS), (4) Students' Reflective Assessment of Laboratory Methods, and (5) In-depth semi-structured interviews. Section four identifies the forms of pedagogical treatment involved in the laboratory instruction. This section offers an overview of the laboratory environment and pedagogy. Included is a discussion of the three general instructional features under consideration for this study, pre-laboratory, laboratory work, and post-laboratory. Section five summarizes data collection giving a general overview of the phases of data collection and the researcher's role during the study. Section six summarizes the how the data is analyzed by describing the potential quantitative and qualitative analysis methods implemented for the study. The last section discusses aspects used in monitoring the reliability and validity of the data collection and analysis.

Chapter Three: Methods

Introduction

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research. The primary focus of this mixed methods study was two-fold: (1) to determine if college science students' NOS and personal epistemological beliefs change as a result of the completion of a general chemistry laboratory course and (2) to explore the possible influences of laboratory classroom instructional practices on the aforementioned changes in beliefs. This chapter is divided into five sections. The first addresses the general research design such as the research instruments, data collection procedures, and data scoring procedures. Following this are sections discussing the recruitment and characteristics of the study's participants. The chapter will then conclude with the procedures for analyzing and informing the data. The procedures will be described as they pertain to the research questions in the present study. Figure 4 presents an overview of the organization of chapter three.

Due to the differing research methods used by science educators studying images of science and instructional strategies and educational psychologists studying personal epistemological beliefs, a semi-naturalistic mixed-methods triangulation embedded approach was employed in this study. This approach represents one of the traditional models of a mixed-methods triangulation design. The researcher collects and analyzes the different data sets separately and then the qualitative data provides a supportive, secondary role (Creswell, 1999; Carcelli & Greene, 1997). The qualitative results are embedded within the quantitative data to better interpret the findings serving a supportive secondary role. This model is used to compare and inform quantitative results with qualitative findings.

Reliability usually measures the extent to which the results of an instrument or study would be replicated given the same sample. Reliability is an important pre-condition for establishing validity (Lincoln & Guba, 1985). However, the qualitative research tradition recognizes that participants and their interpretations of research instruments are dynamic. Therefore, exact replication of results is not an assumption of this study. Initial and final interviews were implemented to assist in checking the validity of the participants' scores on the EBAPS and NSKS. The initial scores of the interview participants were compared to their initial interview responses. This method was repeated with the final scores and interviews. The Cronbach alpha coefficient as well as Pearson correlations are reported and used as indicators of internal consistency and to describe the strength and direction of the linear relationship between the dimensions of each instrument.

A combination of assessment tools developed and validated in previous studies within the two different disciplines was used to determine if students' NOS and personal epistemological beliefs change following the completion of a general chemistry laboratory course and the possible influences of laboratory classroom instructional practices on the aforementioned changes in beliefs.

Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants' responses to the pre-post assessments. A paired-samples t-test (repeated measures) was used to compare the pre-post mean scores for the participants. The variability for the paired-samples t-test was calculated by calculating the eta squared. The effect size (d) was interpreted using the guidelines from Cohen (1998). In this dissertation, effect sizes were calculated from the mean gain score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. To interpret the effect size values the following guidelines from Cohen (1998) were used: 0.20 = small effect, 0.50 = moderate effect, and 0.80 = large effect. Pearson product-moment correlation was used to determine the degree that quantitative variables were linearly related. To compare individual student performance on the pre- and post-assessment the normalized (Hake) gain factor was calculated.

The variability for the paired-samples t-test was calculated using the formula for eta squared. Eta squared can range from 0 to 1 and represents the proportion of variance in the dependent variable that is explained by the independent variable. To interpret the eta squared values the following guidelines from Cohen (1998) can be used: 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect. Variability is defined here as t^2 divided by t^2 plus sample size minus 1 (eta squared = t^2 / t^2 + N-1). The data analysis is discussed further in chapters three and four. The remainder of this chapter discusses the research design. Figure 5 presents an overview of the general context and measures that were applied in this study.

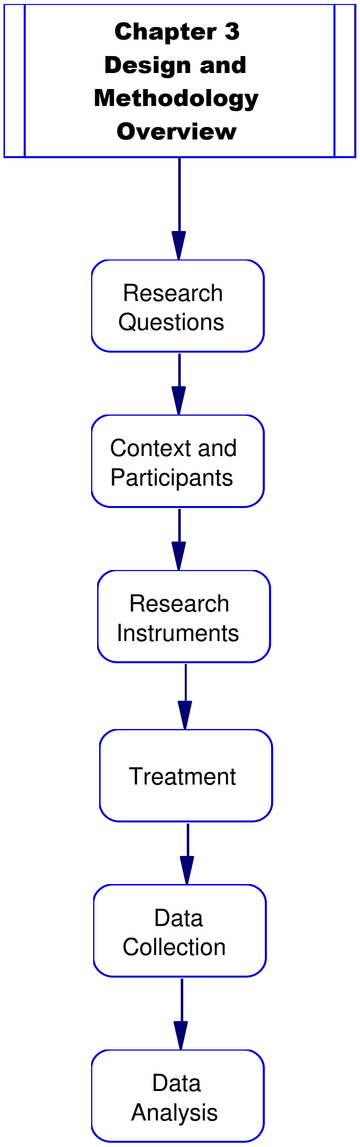


Figure 4 Overview of the organization of chapter three

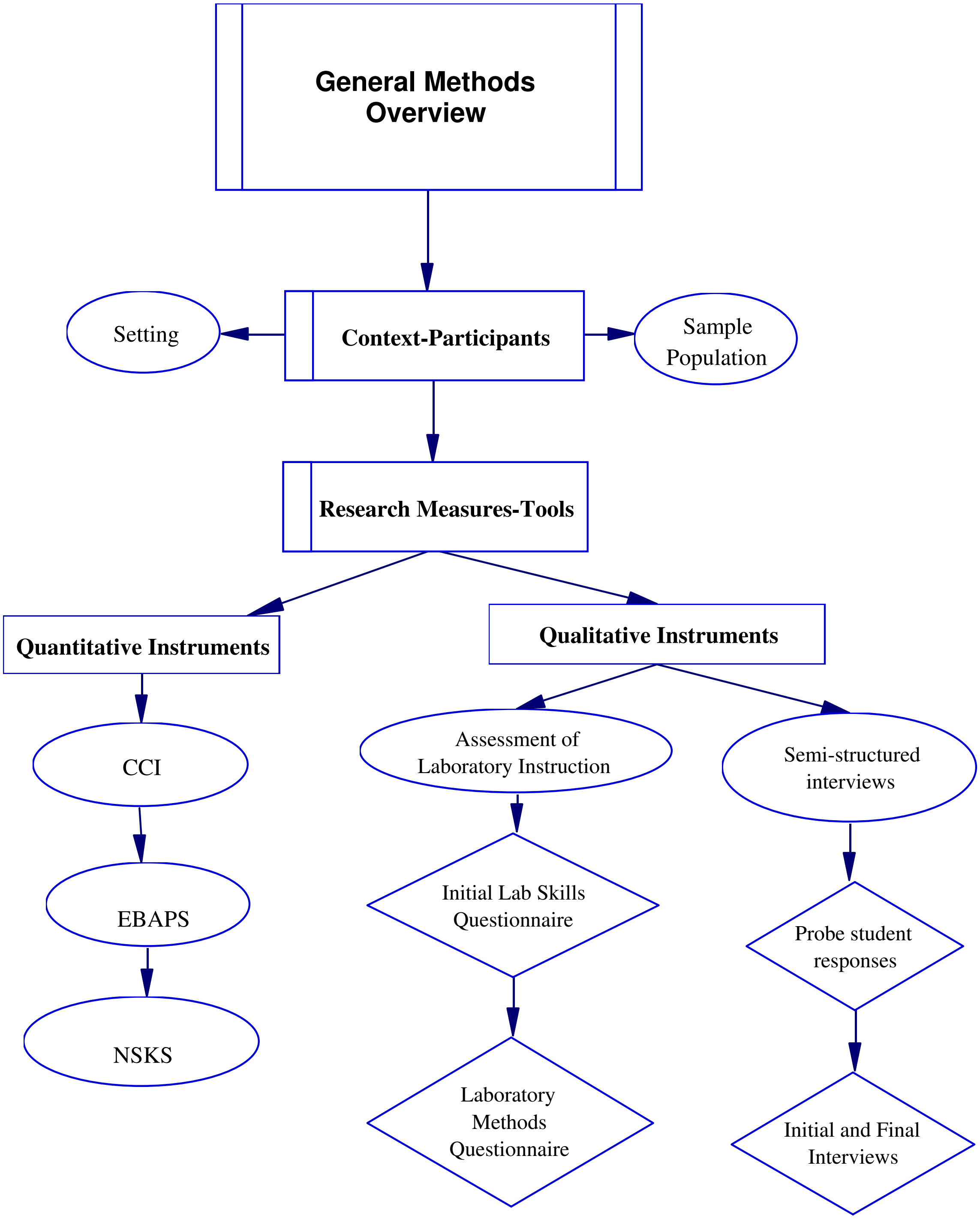


Figure 5 General context and measures overview

Research Questions

RQ1. What range of personal epistemological and NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

RQ1a. Do students' images of the nature of chemistry (NOS) change by the completion of a semester general chemistry laboratory course?

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

RQ2. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

RQ2a. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their personal epistemological beliefs about science (chemistry) during the semester general chemistry laboratory course?

RQ2b. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

Elaboration of Research Questions

The questions that guided this study deal with students' personal epistemological beliefs of science, students' images of science (NOS), and laboratory pedagogical practices as discussed in the literature review (Chapter 2). The construct of personal epistemology involves the nature of knowledge and knowing. The NOS refers to the epistemology of science, science as a way of knowing, and the beliefs and values inherent to the development of scientific knowledge. Laboratory science experiences are where students interact with materials to observe phenomena. Certain laboratory pedagogical practices might improve both students' images of science and their epistemological beliefs. Together the research questions prescribe an investigation that explores if students' NOS and personal epistemological beliefs about science (chemistry) change by the completion of a semester chemistry laboratory course and how, what laboratory instructional strategies students' believe influenced their understanding of the material and changed their NOS and personal epistemological beliefs. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research.

Research question 1 focused on students' current NOS and personal epistemological beliefs. Leach, et al., (1998) indicate there is a good deal of evidence that the images of science and epistemological beliefs that students hold can hinder performance during laboratory work (Sere, et al., 1993; Ryder, et al., 1997). Research question 1's associated sub-questions consider if at all, students' current NOS and epistemological beliefs change following the completion of the semester course. There are a number of studies of students' images of science and epistemological beliefs in the literature; however few of these relate to high school or college students or the images of science or epistemological beliefs that students might draw upon during laboratory work (Leach, et al., 1998).

As discussed in chapter two studies have been conducted to examine personal epistemological beliefs of both instructors and students in domain specific areas such as history, mathematics, and science. However, there seems to be a lack of agreement in its definition even when one refers to personal epistemological beliefs in a particular subject (Elder, 1999; Paulsen & Wells, 1998). Currently, a point of understanding is that beliefs are more multi-dimensional rather than uni-dimensional in nature (Schommer, 1994; Hofer, 2001). In this study NOS and personal epistemological beliefs about science and learning science were examined with the use of the EBAPS and NSKS discussed in chapter two and later in this chapter. The EBAPS assesses student's beliefs concerning the learning and nature of scientific knowledge. For the purpose of this study the science epistemological beliefs also includes or refers to beliefs about the nature of scientific knowledge as proposed in the model developed by Rubba and Anderson (1978). Therefore, the NSKS will be used to supplement the NOS beliefs assessed in the NOS portion of the EBAPS. The present study examined if students' NOS and personal epistemological beliefs change by the completion of the course with the use of pre- and post surveys and interviews.

Research question 2 explored what laboratory pedagogical practices (e.g. pre-laboratory activities, laboratory work, post-laboratory activities), as discussed in chapter two, students believe influenced their understanding of the material during the semester laboratory course. Heavy attrition within science can restrict the flow of students pursuing careers in the STEM (science, technology, engineering and mathematics) fields, because academic performance in courses such as chemistry and physics is interpreted by students and advisors alike as a reliable predictor for ultimate success as a science major. Therefore, pedagogical instructional strategies are critical so that students with a desire to succeed can achieve their educational goals. The chemistry curriculum is influenced by the accreditation criteria developed by the American Chemical Society. These reform movements in chemistry have sought to engage students by promoting active learning and providing contemporary situations that illustrate abstract concepts (American Chemical Society, 1999). Effective instruction usually integrates several instructional pedagogies in order to motivate and facilitate learning at the individual level (Smith, et al., 2005; Prince, 2004). In science laboratories students carry out experiments which are often intended as either an activity in doing experimental research, or support for understanding the theory discussed in lecture. Both purposes require the learner to make links between scientific theories and the scientific phenomena and equipment. However, often students in science laboratory courses only manipulate equipment and do not manipulate the ideas (Gunstone, 1996). Therefore, in laboratory instruction it is imperative to include pre- and post-laboratory activities requiring students to make predictions and give explanations (Hofstein & Lunetta, 1982). Research question 2's associated sub-questions considered if students believe any of the laboratory pedagogical practices influenced their NOS or personal epistemological beliefs about chemistry. According to Rollnick, et al., (2001), university chemistry departments rarely question the importance of laboratory work as an essential component of the experiences of undergraduate science students. However, research in the relationship of NOS and personal epistemological beliefs to laboratory pedagogical practices has been rarely addressed (Leach, et al., 1998; Sere, et al., 1998; Tiberghien, et al., 1998; Sere, et al., 1998; Sere, 2002; Wickman, 2003). In chapter two laboratory pedagogical practices are discussed in relation to learning in a laboratory environment. The present study examined with the use of semi-structured interviews and a laboratory pedagogical questionnaire what laboratory pedagogical practices students believe influenced their understanding of the material or changed their NOS or personal epistemological beliefs.

Context and Participants

Setting

The setting for the study is a rapidly growing, fiscally autonomous, urban campus of a major university in Florida with approximately 5000 students enrolled in 45 undergraduate and graduate degree programs through the Colleges of Arts & Sciences, Business, and Education.   Participants in this study were registered for General Chemistry 2045 Laboratory, a one-semester course at the University. The 16-week semester general chemistry course included a separate 3-hour lecture and 3-hour laboratory section each week with a maximum number of twenty students per laboratory section. The prerequisites for the course are high school chemistry or physical science, and college algebra. The lecture sections were taught by two different professors; laboratory sections are taught by the researcher and several other graduate teaching assistants. The study was conducted in the campus general chemistry laboratories during the Fall semester of 2006.

Population Sample

Fifty-six undergraduate students, between the ages of 18 and 45 representing five intact chemistry laboratory sections in the Fall semester of 2006 participated in this study. The course participants represented freshman, sophomores, juniors, and seniors from different study programs (majoring in environmental science, biology, chemistry, marine science, nursing, and teacher education).

Overall, the mean age of the participants was 21 years, with a range of 18 to 45 years of age. Approximately 64% of the participants were female and 36% were male. Overall 46% of the participants were freshman, 21% sophomores, 18% juniors, 9% seniors, and 7% with no college rank. All but five of the 56 participants had taken a high school chemistry and biology course. Seventy-seven percent of the participants were majoring in science with 13% undecided.

A sample of 20 participants from the total sample of 56 volunteered and participated in the initial and final interviews. Overall, the mean age of the interviewed participants was 22 years, with a range of 18 to 45 years of age. Approximately 85% of the participants were female and 15% were male. Overall 40% of the participants were freshman, 25% sophomores, 25% juniors, and 10% with no college rank. All of the 20 participants had taken a high school chemistry and biology course. Ninety percent of the participants were majoring in science with 10% undecided.

Research Instruments – Measures

Chemical Concepts Inventory

The Chemical Concepts Inventory (CCI) is the label given to an assessment that explores learners' mental models, their qualitative images, understanding of concepts related to how chemistry works (see Appendix A). Research supports the inclination that learners can often solve mathematical problems in chemistry but have poor or incorrect mental models about the fundamental concepts behind the mathematics (Pavelich, et. al., 2004). The design of the CCI was modeled after Treagust (1988) and Odom and Barrow (1995). College level general chemistry courses cover many concept areas in a semester therefore the CCI was designed to cover a wide sampling of concepts from general chemistry. The content validity was checked using the Context Matrix used by the American Chemical Society test development team (Russell & Hill, 1989).

The CCI has shown statistically significant ($p < 0.001$) correlations between students' scores on the inventory prior to a course of instruction and their performance on labs, quizzes, and exams in the course as well as a statistically significant correlation with students' final performance. These correlations range from 0.144 to 0.165 with all values significant at the $p < 0.001$ level. The CCI's overall Cronbach alpha reliability coefficient ranges from 0.75 to 0.86 for high school and college science students (Russell & Hill, 1989).

The CCI was used to better understand the chemistry background (prior knowledge) of the participants. This assessment of a learner's current chemical concept knowledge was given at the beginning of the study as a pre-assessment of students' images of chemistry concepts (i.e. determine prior knowledge). The CCI is comprised of 22 multiple choice questions, with several paired questions. The first question asks about a chemical or physical effect while the second asks for the learners reasoning about the observed effect. A second type of question asks students to explain more completely why they had chosen a particular response as well as why they had discarded the remaining responses. The final common form of question asks the students to define a basic chemical concept such as boiling or evaporation.

Descriptive statistics of the CCI such as frequencies, means, and standard deviations were computed to summarize the participants' level of prior knowledge about chemistry. Interview participants were selected on a volunteer basis.

Personal Epistemological Beliefs Assessment

Personal epistemological beliefs in science refer to students' understanding of how scientific ideas are built up, including their knowledge about the process of knowing-about scientific knowledge (Songer & Linn, 1991). Students' personal epistemology and their understanding of how chemical ideas are built do influence their learning. Studies have shown that learners' prior knowledge does influence their ideas and that learners generally do hold a surprisingly wide range of ideas that are resistant to change (Taber, 2002; Gabel 1998; Fensham, 1994).

The personal nature of learners' epistemologies has a significant impact on their learning. In a study by Carey, et al. (1989), learners' understanding of the NOS was challenged and improved through experiments designed to encourage the learners to build, reflect, and test their own scientific theories, resulting in significant improvement to the learners' level of understanding. Gobert and Discenna (1997) identified a statistically significant correlation between each learner's epistemology and his or her use of models in making inferences abut scientific phenomena.

In order to probe the epistemological beliefs of learners taking a physical science (i.e., chemistry, physical science, or physics) the multi-dimensional Epistemological Beliefs Assessment for the Physical Sciences (EBAPS) was administered at the beginning and end of the study (Elby et. al., 1999). The EBAPS discussed in chapter two (see Appendix B) is designed to assess personal epistemological beliefs of learning science and the nature of scientific knowledge in five dimensions: the structure of knowledge, the nature of learning, real-life applicability, evolving knowledge, and the source of ability to learn (Elby, 2001). Each item was scored on a scale of 0 (least sophisticated) to 4 (more sophisticated). Table 6 identifies the score range for each epistemological sophistication level which was used to classify each participant's initial and final level of belief. The EBAPS items are a mix of Likert-type ratings of agreement or disagreement, as well as hypothetical conversations to which students respond using multiple choice answers to indicate how closely their own views match those of the conversation participants. Table 7 identifies each dimension and describes the reasoning behind each as is discussed in chapter two. EBAPS's overall Cronbach alpha reliability coefficient for high school and advanced chemistry and physics students ranges between 0.73 and 0.83.

Table 6 Epistemological Beliefs Assessment for Physical Sciences Scale

Sophistication Level	Score Range	Scaled Score Range
Extremely Sophisticated	3.5 – 4.0	87 - 100
Highly Sophisticated	3.4 – 3.0	86 – 75
Moderately Sophisticated	2.9 – 2.4	74 - 60
Poorly Sophisticated	2.3 – 1.6	59 - 40
Unsophisticated	1.5 – 0	39 - 0

Potential epistemological beliefs instruments were eliminated as they were specifically aimed at physics not chemistry students were Halloun & Hestene’s (1998) Views About Science Survey (VASS), and the Maryland Physics Expectation survey (MPEX) by Redish et al., (1998).   Another instrument that was eliminated was Schommer’s (1990) Epistemological Questionnaire (EQ) which probes learners’ epistemological stances toward physical science only to the extent that epistemological stances are stable beliefs or theories that don’t depend heavily on disciplinary context (Elby & Hammer, 2001, 2002). Some of the instruments mentioned above are discussed in more detail in chapter two. This instrument was used to answer research question #1 concerning students personal epistemological beliefs about science at the beginning and end of the semester course.

Table 7 EBAPS Instrument Variables (adapted from Elby, et al., 1999).

Dimension	Reasoning
Structure of scientific knowledge	Is physics and chemistry knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas? Or is it a coherent, conceptual, highly-structured, unified whole?
Nature of knowing and learning	Does learning science consist mainly of absorbing information? Or, does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding?
Real-life applicability	Are scientific knowledge and scientific ways of thinking applicable only in restricted spheres, such as a classroom or laboratory? Or, does science apply more generally to real life? These items tease out learners' views of the applicability of scientific knowledge *as* distinct from the learner's own desire to apply science to real life, which depends on the learner's interests, goals, and other non-epistemological factors.
Evolving knowledge	This dimension probes the extent to which learners navigate between the twin perils of absolutism (thinking all scientific knowledge is set in stone) and extreme relativism (making no distinctions between evidence-based reasoning and mere opinion).
Source of ability to learn	Is being good at science mostly a matter of fixed natural ability? Or, can most people become better at learning (and doing) science? As much as possible, these items probe students' epistemological views about the efficacy of hard work and good study strategies, as distinct from their self-confidence and other beliefs about themselves.

Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants’ responses to the pre-post assessment. To compare individual student performance on the pre- and post-assessment the normalized (Hake) gain factor was calculated. A paired-samples t-test (repeated measures) was used to compare the pre-post mean scores for the participants. The variability for the paired-samples t-test was calculated using eta squared (Appendix B). The effect size (d) was interpreted using the guidelines from Cohen (1998). Pearson product-moment correlation was used to determine the degree that quantitative variables were linearly related. This correlation analyses helped address the first research question. The data analysis is discussed in more detail later in this chapter as well as chapters 4-7.

Nature of Scientific Knowledge Scale

To assess learners' initial and final images of science, Rubba and Anderson's (1978) *Nature of Scientific Knowledge Scale* (NSKS) was administered (see Appendix C). In addition, the NSKS was used to supplement and support the portions of the EBAPS that dealt with the nature of scientific knowledge related to personal epistemological beliefs. This instrument discussed in chapter two is a 48-item Likert scale forced-response format consisting of five choices (strongly disagree, disagree, neutral, agree, and strongly agree). The NSKS's six subscales are amoral, creative, developmental, parsimonious, testable, and unified (see Table 8). The NSKS is considered to be a reliable and valid pencil and paper measure of the NOS as it focuses on one or more of the characteristics of the NOS. When the NSKS was administered to high school and college students, the reliability ranged from .65 to .89. The construct validity of the NSKS was examined by testing an anticipated difference in understanding of the nature of scientific knowledge between two groups of college freshmen with different educational backgrounds (Rubba, 1977). For reliability, NSKS's overall Cronbach alpha reliability coefficient for biology and chemistry students (grades 9, 10, 11), and Cronbach alpha reliability coefficient is 0.89 for advanced chemistry students (grade 12).

Even though the NSKS has received little criticism from other researchers, according to Lederman (1998) it does possess significant wording problems. For instance, there are some statement pairs that differ only in that one is stated in the positive and the other in the negative. This redundancy could encourage participants to check their answers on previous items when they read similarly worded items later in the questionnaire, and could inflate reliability estimates and misplace confidence in the validity of the questionnaire. The scores of the negatively worded items in the NSKS were reversed so that all items have the same response scale.

The range of scores for each dimension is 8 to 40 points. For each dimension, a score of 24 points indicates a neutral (N) position or combination of realist and instrumentalist views on NOS while a score between 25 and 40 is within the accepted view of the nature of science (Instrumentalist-I), and a score between 8 and 23 is within the unaccepted NOS view (Realist-R). The overall score for all six dimensions ranges from 48 to 240 points. A score of 144 (141-147) on the overall scale score is considered neutral (N) while scores ranging from 145 and 240 (148-240) are within the accepted view of the nature of science (instrumentalist), and scores ranging from 143 and 48 (48-140) are within the unaccepted view (realist).

Initial research into learners' images of science (i.e. NOS) consisted of forced-choice survey responses that provide little insight into the conceptions underlying learners' responses (Lederman, 1992). Lately researchers have turned to semi-structured interview assessments to probe students' images of science. To further assess students' images of science adapted versions of interview protocols such as the "Nature of Science" interview developed by Carey et al. (1989) will be used during interviews (see Appendix F). The adapted versions will be adjusted based on the student responses to the NSKS. The original interview by Carey et al. (1989) is composed of 21 questions with the following themes: the goals of science; the types of questions that scientists ask; the nature of experiments, hypotheses, and theories; the influence of theories and ideas on experiments; and processes of theory change (Thoermer & Sodian, 2002; Sandoval & Morrison, 2003). This assessment was used to answer research question one concerning students' NOS beliefs and as additional support for the NOS aspects of the EBAPS.

Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants' responses to the pre-post assessment. The scores of the negatively worded items in the NSKS were first reversed so that all items have the same response scale. To compare individual student performance on the pre- and post-assessment the normalized (Hake) gain factor was calculated. A paired-samples t-test (repeated measures) was used to compare the pre-post mean scores for the participants. The variability for the paired-samples t-test was calculated using eta squared. The effect size was interpreted using the guidelines from Cohen (1998). Pearson product-moment correlation was performed to determine the degree that quantitative variables were linearly related. This correlation analyses helped address the first research question. The data analysis is discussed in more detail later in this chapter as well as chapters 4-7.

Table 8 Nature of Scientific Knowledge Scale (Rubba & Anderson, 1978)

Amoral - Scientific knowledge provides man with many capabilities, but does not instruct him on how to use them. Moral judgment can be passed only on man's application of scientific knowledge, not the knowledge itself.
Creative **-** Scientific knowledge is a product of the human intellect. Its invention requires as much Creative imagination as does the work of an artist, a poet or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.
Developmental - Scientific knowledge is never "proven" in an absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be judged in their historical context.
Parsimonious **-** Scientific knowledge tends toward simplicity, but not to the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort in science to develop minimum number of concepts to explain the greatest possible number of observations.
Testable **-** Scientific knowledge is capable of public empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.
Unified **-** Scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contributes to a network of laws, theories and concepts. This systematized body gives science its explanatory and predictive power.

Students' Reflective Assessment of Laboratory Methods

An initial survey (see Appendix D) adapted from the *Curriculum Innovation Fund of the University of Manchester* (2002) to gauge what participants believed about laboratory practical work and how they rated their current laboratory skills was administered during the first laboratory session.

The second student questionnaire (see Appendix E) adapted from several sources (Byers, 2002; Berg, 2003; Jalil, 2006) was used to assess a learner's reaction to the three broads areas of instructional methods associated with each laboratory activity (e.g., pre-laboratory activities, laboratory work, and post-laboratory activities). The students were probed further on their comments during the interviews (see Appendix F). The comments were compared and further evaluated with their responses on the EBAPS and NSKS and interview sessions.

The questions covered three broad areas:

1. The learner's general evaluation of laboratory instruction in the three broad areas of instructional methods associated with each laboratory activity (e.g., pre-laboratory activities, laboratory work, and post-laboratory activities).
2. The learner's perceptions of the pre- and post laboratory activities in relation to laboratory work.
3. A cognitive domain self-assessment (reflection) of their learning outcomes from the laboratory activity.

The first area of the questionnaire probed the pedagogical features of laboratory instruction. The students were asked to evaluate how helpful they found each of the pedagogical features with respect to understanding and necessity of the laboratory learning experience. The pedagogical features are defined in the following three categories: (1) pre-laboratory activities, (2) laboratory work, and (3) post laboratory activities. This section of the questionnaire was used to assist in answering research question two. The overall frequencies of responses were calculated and reported.

The second area of the questionnaire probed students' perceptions regarding the following four aspects of laboratory work: (1) understanding the laboratory work, (2) enjoyment in performing the laboratory work, (3) achievement in conducting the laboratory work, and (4) difficulty in doing the laboratory work. Students were asked to choose one statement for each aspect that best describes their own position regarding the aspect. This section was used to assist in answering research question 2 clarifying which laboratory instructional strategy (pre- or post-lab) the students found most beneficial. The overall frequencies of responses were calculated and reported.

The third area of the questionnaire was formulated using Bloom categories in the cognitive domain (Berg, 2003). The learner was asked to describe the kind of learning they believed they gained in a particular laboratory activity. The participants evaluated their own learning outcomes on the scale: very much, a lot, some, a little or nothing for each of the Bloomian categories. This area of the questionnaire was used in assisting with answering research question 2 concerning students' understanding of the laboratory material. The overall frequencies of responses were calculated and reported.

The goal of the questionnaires was to elicit general information on students' views of the three laboratory pedagogical features (pre-laboratory, Labwork, post-laboratory) used during the semester course. Section one of the questionnaire related to students' preferences for instructional tools within the three pedagogical features was transformed into a quantitative form. Based on students' responses, five levels will be used in this study as follows: level 1: least essential; level 2: somewhat essential; level 3: essential; level 4: very essential; and level 5: extremely essential. Level 1 will be represented by 1 point, and level 5 by 5 points. The goal of the open-ended questions, questions 7 and 8 on the questionnaire is to elicit additional information on the instructional methods and their NOS and personal epistemological beliefs. The responses to these questions along with the interviews were compiled and organized to address the second research question.

Chemistry Laboratory Course Description

Introduction

The core ideals and pedagogy for the course laboratory outcomes are identified and discussed in the following section. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research.

The instructor acted as a facilitator during the laboratory sessions. The tone of the session was set for active student learning with the use of a student-centered pre-laboratory discussion. The instructor relinquished control of the laboratory session, quite often to the students. The instructor moved from group to group interacting with the students several times during the laboratory work session. The instructor asked guiding questions and redirected students to interact with other student laboratory pairs in their laboratory groups during the laboratory work.

All the students participated in the nine laboratory activities during the semester of the study. The exercises are presented in chronological order in Table 9. The instructor facilitated the laboratory sessions as in previous semesters with no changes made to the original presentation or format. None of the pedagogical techniques were designed or changed in order to elicit changes in NOS or personal epistemological beliefs. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research.

The laboratory activities occurred once a week during a three-hour lab period, with Lab 7 conducted as a dry lab. The chemistry department CHM 2045 laboratory manual was be used in this study. Examples of portions of the pre-laboratory, laboratory work, and post-laboratory activities are located in Appendices G-K. The manual combines several versions of instruction, expository instruction where the entire experiment is described with explicit instructions enabling participants to carry out an exercise after it is explained or demonstrated and modified inquiry instruction where the experiment is less structured enabling the student an opportunity to participate in the investigative plan. All the required chemicals and equipment not located in assigned laboratory drawers were made available for the participants.

Table 9 Topics of Laboratory Exercises

Chemistry 2045 Laboratory Experiments
1. Laboratory Orientation (LO)
2. Data Analysis & Physical Properties (DP*)
3. Matter Lab (ML)
4. Chemical Reactions-Stoichiometry (CRS*)
5. Activity Series - Redox (ASR*)
6. Atomic Fingerprints (AF)
7. Molecular Shapes (MS)
8. Thermodynamics – Enthalpy (TE*)
9. Molar Volume – (MV)

Organization of Course Laboratory Instruction

Introduction

The anticipated laboratory course outcomes are identified in Table 10. However, the anticipated outcomes were not specifically identified or predicted at the beginning of the study as possibly influencing the NOS or personal epistemological reasoning changes. The outcomes are based on normal laboratory objectives as well as standard laboratory activities. Whether the outcomes influenced the participants' beliefs is only considered during the post-interviews. The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs in light of specific science laboratory instructional features for future research.

An overview of the organization of laboratory instruction is presented in Table 11. Student centered pre- and post-laboratory assignments and discussions were introduced into the laboratory experiments. In this study, the instructional categories with specific pedagogical methods used in laboratory instruction that were compared are: (1) pre-laboratory activities (i.e. quiz, procedural flowcharts, interactive introductory PowerPoint, and predictions) and group discussion, (2) laboratory work activities (i.e. microcomputer techniques, traditional bench techniques, laboratory notebook recording, reflective questioning, and peer interaction), and (3) post-lab activities (i.e. analyzing qualitative and quantitative data, post-laboratory discussion, and writing a laboratory report).

Table 10 Anticipated Laboratory Course Outcomes

Anticipated Laboratory Course Outcomes
Conceptual and theoretical knowledge
Clarifying and illustrating scientific theory
Arouse curiosity and stimulate interest
Connect chemistry to real world
Generic skills
Academic culture
Computer skills
Cooperative learning
Critical analysis
Ethical behavior
Knowledge skills
Leadership
Problem solving
Proper use of references
Self-regulation
Team work
Time management
Practical and scientific skills
Apply statistical tests
Deductive reasoning
Develop manipulative skills
Develop safe laboratory skills
Error analysis
Form predictions
Interpret findings
Make observations
Proper use of equipment/instruments
Properly present data
Record and report observations
Test predictions experimentally
Trouble-shoot laboratory procedures

Table 11 Organization of Laboratory Instruction

Treatment	Potential Activities
Pre-laboratory	
Prior to Class	Blackboard Online Quizzes Pre-laboratory Questions Laboratory Notebook
In-class	PRS – PowerPoint Pre-laboratory Discussion
Laboratory Work	1) Traditional Bench Work or microcomputer-based techniques or combination 2) Recording of qualitative and quantitative data in laboratory notebook 3) Interact-reflect-discuss with lab partner(s)
Post-laboratory	1) Post-lab discussion in class or online 2) Written analysis of activity with results 3) Student Reflective Assessment of Laboratory

Learners participated in pre-lab assignments to be done prior to the lab meeting, then a pre-lab in-class discussion with their laboratory peer groups guided by the instructor, followed by the instructor clarifying experimental equipment and procedures, a brief overview by the instructor of any new equipment if necessary, and concluding with the learner performing the experiment. During the laboratory work the participants recorded data, reflected on the data at the end of class if time permitted. If time did not permit a post-lab discussion at the end of the session the participants, met outside the normal classroom time with laboratory peer groups or during a scheduled chat session on the course website guided by the instructor, and wrote a final report.

Students worked in pairs and teams of 2-4 pairs per group. For laboratory activities, 2 and 5 a Basic Lab Report (BLR) was written by each student or group of students. Each individual student wrote a Formal Lab Report (FLR) for Labs 4 and 8. For the remaining laboratory activities the students completed their analysis directly in their laboratory notebook as per the laboratory notebook guidelines (see Appendix I). The relationship of data collection to instruction is described in Table 12.

Pre-Laboratory Course Activities

The necessity for some form of pre-laboratory preparation is patently obvious. Pre-laboratory activities were used as a means to decrease the information overload on students. A learner entering a laboratory environment without some form of preparation is likely to spend excessive time in fruitless frustration routine, and non-learning (Johnstone & Al-Shuaili, 2001). For this course the pre-laboratory activities were two-fold. The participants performed out of class pre-laboratory activities prior to class which was followed by 15-45 minute in class pre-laboratory activities.

For each laboratory topic, students performed pre-laboratory activities located in the lab manual or on the course website and turned in at the beginning of the laboratory period. Examples of portions of the pre-laboratory activities are located in Appendices H and J. The pre-lab prepared students through a series of online and pencil-and-paper exercises from the laboratory manual introducing and assessing prior knowledge of concepts, terms, and laboratory procedures.

The on-line activities designed for the laboratory portion of the course involve pre-laboratory activities. Each week, before entering the laboratory class, the students went on-line using the *Blackboard* course site and viewed a pre-laboratory presentation (see Appendix J) and took an on-line pre-laboratory quiz (Appendix H). The major advantage to the on-line pre-laboratory preparation of the student is the consistency of laboratory preparation. Every student viewed the same presentation for a particular laboratory experiment. Therefore, the variability of the quality of pre-laboratory presentation is removed.

In the pre-lab work students were asked to complete the online pre-lab practice quiz and pre-lab questions prior to the laboratory meeting. The pre-laboratory quiz and questions consist of a number of exercises of several types. Some focused on a particular type of calculation important in the experiment or the safety considerations such as whether to wear goggles and gloves. Some focused on an important organizational or laboratory technique used in the experiment while others introduced important terms, concepts or nomenclature needed in the experiment. The week prior to the laboratory activity the students met in laboratory peer groups to discuss the factors they believed influenced the parameters they measured or observed via e-mail, course web-site chat, or by holding a group discussion.

The pre-lab discussion was normally held during the first 15-45 minutes of the laboratory session and included a short PowerPoint interactive quiz using the PRS clicker during laboratory activities 2, 4, 5, and 8. The pre-lab discussion consisted of the students cooperatively engaging in peer laboratory group discussions, demonstrations, and activities on procedural as well as conceptual issues including use of available classroom technology (e. g. MBL computer probes, Interactive PowerPoint introduction using PRS clickers). For laboratory activities 3, 6, 7, and 9 the students were given a brief overview of the procedure and safety concerns the first 5-10 minutes of the course with further lab discussion occurring during and after the laboratory work. This was done to assist in determining whether the students preferred a detailed pre-lab discussion prior to the laboratory work or after the completion of the laboratory work. This assisted in assessing student’s reflections on section two of the laboratory reflective questionnaire.

The on-line activities designed for the laboratory portion of the course involved pre-laboratory activities. Each week, before entering the laboratory class, the students go on-line using the *Blackboard* course site and view a pre-laboratory presentation and take an on-line pre-laboratory quiz. One of the major advantages to the on-line pre-laboratory preparation of the student is the consistency of laboratory preparation. Every student views the same presentation for a particular laboratory experiment. Therefore, the variability of the quality of pre-laboratory presentation is removed.

The following is a list of portions of the course pre-laboratory discussion. The discussion was guided, but not explicitly directed, by the instructor.

- Discuss pre-laboratory questions as a class
- Discuss safety and procedural concerns as a class
- Decide what data to gather and how to accomplish it with their partner and laboratory groups
- The groups collaboratively prepare a class data table on the front board.
- Determine who should be responsible for individual tasks such as; collecting original data, performing replications, etc.

The students discussed their pre-laboratory questions at the start of class. After completing the assigned reading for the laboratory experiment, each student came to the laboratory with the pre-laboratory questions from the laboratory manual completed and a list of any other questions they may want to discuss. The instructor allowed the students the opportunity and the time to discuss these questions with each other. The students formed groups and decided on a specific question they would like answered. For instance: How does the limiting reagent affect the percent yield? Other questions often presented for consideration included: (1) Are there any other safety considerations? (2) What procedures will be followed or changed? and (3) What information will need to be gathered? These questions set the stage for the laboratory work interactions that took place during the experiment. The instructor used these questions to set up the framework for the experiment.

Laboratory Work Course Activities

During the laboratory work student laboratory pairs and groups organized themselves and worked together to collect experimental information in a collaborative manner. The instructor moved among the laboratory groups keeping the students on task, asking guiding questions, and redirecting student questions to other laboratory pairs in their groups, such as: (1) How do we measure a certain variable and (2) What is your goal in performing this step? As each laboratory pair generated data the information was recorded on the class data table on the front board as well as in their laboratory notebooks. During the laboratory work the instructor attempted to guide the students in making meaning by examining patterns or trends occurring during the experiment. For instance questions were asked that encouraged reasoning, such as:

- What did you find when you did this earlier?
- What will happen if you increase the amount of this substance?
- How does this relate to the group data?

Once or twice during the laboratory work the instructor stopped the activity to go over questions concerning the concepts, data, and procedures. This was due to the fact that some students had the same questions or problems. The students were asked during the course of the laboratory session how the laboratory activity related back to the concepts in order to help them connect theory with process. The students studied their results as well as the class results to determine whether they need to repeat steps to replace inconsistent data. The class data was pre-analyzed and discussed as a group prior to the end of the laboratory session or outside during online chats.

During laboratory work the students engaged in activities that solely implement traditional bench methods, some that combine traditional bench methods with microcomputer-based technology, and those that relied heavily on microcomputer-based technology (see Table 12). Laboratory activity 1 (LO) introduced the students to the equipment, safety regulations, and basic scientific format of laboratory science. The format for the physical property portion of Lab 2 (DP) was more structured as this was many of the students' first experience with the Vernier Microcomputer (MBL) and sensors. Students were provided a basic outline of the microcomputer-based program (Vernier), sample data and calculations for a similar situation followed by an overview of what they might observe. The students were then guided through on how to perform an analysis and interpretation with a typical MBL system using sample data. The measurement activity engaged students in collecting and analyzing quantitative data. Labs 3 and 4 (ML-CRS) are progressively less structured, providing students with general traditional bench procedural options, a statement of objectives, safety considerations, and a review of the basic concepts related to the lab. The fifth lab (ASR) called on students to perform traditional bench chemistry in the form of an analysis of chemical reactivity. Lab 6 (AF) presents in part real-life chemistry with the learners engaged in traditional methods to study the concepts surrounding the electromagnetic spectrum and the atom. The only activity performed that used neither traditional bench or MBL methods is lab 7 (MG) which dealt with molecular geometry. Labs 8-9 (TE-MV) both involved student use of the MBL.

In this course a learner's laboratory notebook, discussed in chapter two is defined as a set of entries written by the learner that reflect investigative experiences within the chemistry laboratory. Thus the laboratory notebooks reflect both learning and instruction as it occurs. Students followed the general laboratory notebook guidelines located in the laboratory manual (see Appendix I). Students were taught proper notebook organization, and also how to record their procedures and observations as they performed their laboratory work and ideas that they had related to the work. In this course students collected records of their laboratory investigation in their laboratory notebooks and later transformed these data into figures, graphs, tables and schemas, interpreted their results and made knowledge claims.

During this portion of instruction the students were expected to interact with their assigned lab partner, as well as the other members of their laboratory team at their assigned laboratory station. (see Appendix J). Laboratory work provided students opportunities to learn from their mistakes, problem solve in an experimental environment, and improve their laboratory skills. Performing more than 1 trial, collecting class data, and interacting with their laboratory team can introduce important aspects of real science, such as, collaboration of a community of scientists.

Post-laboratory Course Activities

The class data was pre-analyzed and discussed as a group prior to the end of the laboratory session or outside during online chats. The post-lab discussion was held during the last 15-45 minutes of the laboratory session, or during a set time scheduled by the students at a location on campus, or during the week online at a set scheduled time prior to the next laboratory session. This discussion consisted of the students cooperatively engaging in peer laboratory group discussions of their results, class data and discussing procedural as well as conceptual issues that may have related to their final analysis. The students examined the pooled data and looked for trends.

The discussions conducted included some of the following elements depending on whether the discussion was held during the laboratory session or outside later in the week: (1) Warming up – Planning the discussion: The participants evaluate the purpose of the discussion, the duration, technical details etc. The participants decided how they wished to proceed; (2) Discussion: Free discussion within the laboratory group. The instructor, if present only intervened if the group seemed to need help; and (3) Summaries: From time to time during the discussion the participants summarized certain points. This brought more clarity to the discussion and more validity to the data. This gave students the chance to clarify misunderstandings.

The structure of the discussions was seldom so rigid that there were clear lines between the aforementioned elements. The discussions did not consist of specific questions. It was rather a collection of some possible questions for the students to consider (Appendix H). During this portion of the laboratory instruction participants were asked to reflect on what they could claim, evidence of the claim, how their results compared to others, and what connections could be made between lecture and lab based on their results. The students were encouraged to make explicit associations among claims, data, evidence, and observations.

After each laboratory the students assessed the laboratory instructional methods using the Student Reflective Assessment of Laboratory Methods Questionnaire (see Appendix F). The students were required to write four laboratory reports using the laboratory report guidelines located in the laboratory manual. For laboratory activities, 2 and 5 the students wrote a report using the BLR format and a FLR for labs 4 and 8. (Appendix K) For the remaining laboratory activities the students performed a brief analysis in their laboratory notebooks.

Table 12 Relationship of Data Collection to Instruction

Week(s)	Data Collection	Instruction (per week)	Instructional Method(s)
1-3	Chemical Concepts Inventory Pre-Assessment (CCI) Epistemological Beliefs Pre-Assessment for Physical Sciences (EBAPS) *Nature of Scientific Knowledge Scale* (NSKS)	Lab-1 Laboratory Introduction Lab Notebook (LNB) (TB-MBL)	Expository & Discovery
2-6	Initial Interviews Student Assessments of Laboratory Methods	Lab-2 Data Analysis and Physical Properties (TB-MBL) BLR-1	Discovery
4	Student Assessments of Laboratory Methods	Lab-3 Matter Lab (TB) LNB	Discovery
5	Student Assessments of Laboratory Methods	Lab-4 Chemical Reactions-Stoichiometry FL-1 (TB)	Expository & Discovery
8	Student Assessments of Laboratory Methods	Lab-5 Activity Series - Redox (TB) BLR-2	Discovery & Inquiry
9	Student Assessments of Laboratory Methods	Lab-6 Atomic Fingerprints (TB) LNB	Expository & Discovery
10	Student Assessments of Laboratory Methods	Lab-7 Molecular Shapes (MS) Dry Lab LNB	Expository
11-12	Student Assessments of Laboratory Methods EBAPS (post)	Lab-8 Thermodynamics (TB-MBL) FL-2	Discovery & Inquiry
12-13	Student Assessments of Laboratory Methods NSKS (post)	Lab-9 Molar Volume (MBL) LNB	Discovery
13	Final Interviews	Lab Review	
14 -16	Final Interviews	Lab Practical	

Data Collection

The data collection process in this study occurred in three phases. During the first phase data was collected regarding students' initial NOS and personal epistemological beliefs as well as their prior skills and knowledge related to chemistry. During phase two initial interviews were performed with the twenty volunteers from the population sample (n=56) students concerning their NOS and personal epistemological beliefs about science. In addition, during this phase student laboratory instruction reflections were collected (n=56). Phase three involved post-administration of the NOS and personal epistemological beliefs assessments (repeated measure) as well as final interviews with the twenty volunteers concerning what laboratory instructional strategies students' believed influenced their understanding of the laboratory material, as well as their NOS and personal epistemological beliefs about chemistry. Each phase is described briefly in the following section and in greater detail later in the chapter in regards to the setting and sample, context, materials used, as well as the procedures for the measures. The quantitative phase will include a discussion of the survey instruments that will be utilized for this study. The qualitative phase will describe the interview process and what questions were asked. A data collection timeline is described in Table 13.

Researcher's Role

There is a certain element of bias that this researcher brings to the study as the major laboratory instructor. Threats to the validity and integrity of the data were minimized as described below and at the end of this chapter. The course was presented and taught in the same manner it has been taught during the prior two years by the researcher. The instructor facilitated the laboratory sessions as in previous semesters with no changes made to the original presentation or format

The initial assessments (CCI, EBAPS, NSKS, laboratory skills questionnaire) were administered and collected by the researcher and a graduate student teaching within the department. The aforementioned method of instrument administration was repeated with the post-administration of the EBAPS and NSKS at the end of the semester study. The laboratory instruction questionnaires were collected each week from the students after each laboratory session. The participants placed the questionnaires in a labeled envelope out of the view of the researcher to avoid any conflict of interest with the researcher's role as the instructor. Analysis (coding) of the questionnaires occurred after the completion of the semester when grades had been assigned and entered. The interviews were performed by a trained outside interviewer (graduate student) within the education department to avoid interference with data collection and interpretation. The reliability and validity issues are discussed further at the end of this chapter.

Table 13 Data Collection Timeline

Week(s)	Data Collection	Sample Size
1-3	Chemical Concepts Inventory Pre-Assessment (CCI) Epistemological Beliefs Pre-Assessment for Physical Sciences (EBAPS) *Nature of Scientific Knowledge Scale* (NSKS)	56
2-3	Initial Interviews	20
2-14	Student Assessments of Laboratory Methods	56
14-15	EBAPS and NSKS (post)	56
15-16	Final Interviews	20

Phase One: Quantitative

During the first phase the researcher presented a general orientation of the study during the introductory session of the first week of the laboratory course. The *Chemical Concepts Inventory* (CCI), the *Epistemological Beliefs Assessment for the Physical Sciences* (EBAPS), the *Nature of Scientific Knowledge Scale* (NSKS), and a laboratory skills questionnaire were prepared as a survey package to be completed by all participants and administered by a graduate student teaching within the department (see Appendix A-D).

The *Epistemological Beliefs Assessment for the Physical Sciences* (EBAPS) and the *Nature of Scientific Knowledge Scale* (NSKS) were administered as a pre and post assessment to all participants. In addition to these instruments, the package contained an invitational letter describing the study, a participant consent form with a page requesting demographic information (see Appendix L). The CCI was used to examine the participants' prior knowledge in chemistry.

The EBAPS was used to examine the participants' initial beliefs at the beginning of the semester course and their final personal epistemological beliefs about the physical sciences upon completion of the course. The NSKS was used to examine the participants' initial NOS beliefs at the beginning of the semester course and their final NOS beliefs upon completion of the course as well as supplemental support for their epistemological beliefs. The laboratory skills questionnaire was used to examine the participants' views and skills concerning laboratory work.

Phase Two: Qualitative

The survey results were compared and contrasted with the results of the second phase of the data collection process, which included qualitative data collection with initial semi-structured interviews of the participant volunteers (Appendix F), to further assess students' initial NOS and personal epistemological beliefs. During the course of laboratory instruction data concerning laboratory instructional strategies were collected and analyzed with the use of the Student Evaluation of Laboratory Instruction Questionnaire.

The type of interview used in this study was a semi-structured interview. Interview participants were selected on a volunteer basis. This interview was structured because it was planned, taped, and the interview was driven by some guidelines. On the other hand, they were semi-structured because the interviewer used probes and follow-up questions based on the responses of the interviewee. The participants entered into a dialogue with the interviewer, allowing one to listen to the data for clues about students' beliefs, experiences, and perceptions that provided data to address the problem and research questions (Hatch, 2002).

Phase Three: Quantitative and Qualitative

The final phase involved participants retaking the EBAPS and NSKS surveys in order to determine if there was a change in their beliefs by the completion of the semester course. In addition, those participating in the initial interviews participated in a final end of the semester interview. During this interview the interviewer collected data to assess further whether the participants' NOS or personal epistemological beliefs changed and what role the laboratory instructional strategies played in those belief changes.

In-Depth Semi-structured Interviews

The primary purpose of the interviews was to clarify the epistemological and NOS beliefs held by the participants so that these beliefs could be compared to the assessment instruments. Rather than being bounded by only measuring instruments, the interview enabled me to gain a clearer understanding of the participants' beliefs and thoughts. Participants were interviewed by an outside interviewer at two points during the semester: before the end of the first month of the semester and during the final month. The interviews were guided by an interest in hearing individuals use their own words to express their personal views. The interviews were semi-structured (Appendix F) with the primary questions pre-planned and standardized to minimize the interviewer effects. The questions were presented in the same general sequence, but the interviews varied slightly depending on the student responses. In addition, the probe questions varied depending on student responses.

The participants were interviewed in a university office by an outside interviewer. The initial interviews lasted between 15-20 minutes and were audio-taped for transcription purposes. The final interviews lasted between 30-45 minutes and were also audio-taped. Interview times were extended as needed to allow the participants to express their ideas.

The initial interview protocols (Appendix F) included general questions and/or statements exploring participants' initial NOS and personal epistemological beliefs. The interviewer presented the participant with a particular question and asked the participant to offer a position. For instance, one question related to personal epistemological beliefs involved the participant reacting to the following: "Science is a weakly connected subject consisting mainly of facts and formulas without much structure versus being a strongly connected and highly structured subject." Another question related to participants' NOS beliefs was "Scientific knowledge is a changing and evolving body of concepts and theories." A full account of these questions is provided in Appendix F. These questions were open-ended to encourage the participants to explain their beliefs.

The probe questions used during the initial interviews by the interviewer included those listed in Tables 14 and 15 (Appendix F). The probe questions were adapted from

King and Kitchener (1994) and Carey et al., (1989). The probe questions were designed in order to elicit ratable data from the student to explain more completely why they have chosen a particular response as well as why they had discarded remaining responses.

The final interview protocols (Appendix F) included questions and/or statements exploring participants' NOS and personal epistemological beliefs by the end of the course as well as questions pertinent to instructional practices as experienced by the students. Once again the interviewer presented each interview participant with questions such as "What instructional feature (pre-lab, laboratory work, or post-lab) was the most effective in promoting your learning in this course?", "How would you rank the following aspects of each instructional feature (least essential to extremely essential)?", and "What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the evolving knowledge science in this course?"

For the final interviews similar probes were used for select questions (Appendix F) related to the initial and final EBAPS, and the NSKS survey results, along with comments from the students' reflective laboratory assessment questionnaires in an attempt to see if participants could explain in some cases why they might have changed their answer(s) from the beginning of the semester for those questions to which they responded differently during the initial assessment(s) or interview.

In addition to audio-taping and transcribing during each interview notes and observations were taken during the interviews by the outside interviewer. Short summaries of each interview were composed in order to provide a contextual background for each interview.

Grounded theory analytical procedures were used to inductively analyze the participants' interview responses. These procedures involved (1) the simultaneous collection and analysis of interview data, (2) comparative methods of analysis whereby participants' responses were compared among one another and within each participant, and (3) the integration of a theoretical framework. The data analysis is discussed in more detail later in this chapter.

Table 14 Interview Probe Questions (King & Kitchener, 1994, p. 1020)

Probe Questions
1. What do you think about this statement?
2. How did you come to hold that point of view or answer?
3. On what do you base that point of view or answer?
4. Can you ever know for sure that your position on this issue is correct? How or why not?
5. When two people differ about matters such as this, is it the case that one opinion is right and one is wrong? If yes, what do you mean by "right"? If no, can you say that one opinion is in some way better than the other? What do you mean by "better"?
6. How is it that people have such different point of view about his subject?
7. How is it possible that experts in the field disagree about this subject?

Table 15 Probe Questions – Unpacking Interview Terms (Carey, et al., 1989)

What do you mean by ________?		
Answer	Helps	Theory
Conclusion	Learn	Truth
Discover	Procedure	Try again
Equipment	Proof	Try Out
Explanation	Test	Understand

Summary of Data Collection

Introduction

Qualitative and quantitative data collection mixed-measures were employed in three phases during this study of fifty-six students in 3 sections of a first semester general chemistry laboratory class taught by the researcher and other graduate students. A consent form (Appendix L) was signed and collected from each participant before the administration of the instruments. The students were guaranteed that all the data they provided would be kept strictly confidential, so that only the researcher(s) would have access to the personal data.

The data gathered during the study were analyzed to determine the answers to the two main research questions and their sub-questions. The questions in general focused on the initial and final personal epistemological and NOS beliefs held by the participants as well as the role that the instructional features (pre-lab, laboratory work, or post-lab) played in their learning and beliefs. The major sources of data gathered throughout the study included:

- Participants' pre- and post-responses to the EBAPS and NSKS;
- Participants' responses to open-ended laboratory questionnaire; and
- Transcriptions from initial and final semi-structured interviews with the participants.

Grounded theory analytical procedures were used to inductively analyze the participants' interview responses. These procedures involved (1) the simultaneous collection and analysis of interview data and (2) comparative methods of analysis whereby participants' responses were compared among one another and within each participant,

Instruments

The researcher and a department graduate student administered to each class at a prearranged time the initial study instruments (CCI, EBAPS, NSKS, and initial lab questionnaire) during the first laboratory session. The participants were informed by the researcher the purpose of instruments and provided instructions about how to answer the instruments. The researcher informed the students they needed to give honest responses. After the students completed the instruments, their answers were collected by the researcher and graduate student to be analyzed at a later date. The data of cases that dropped the course or that failed to complete a majority of the components of the study were discarded prior to further analysis. During the last two laboratory activities the EBAPS and NSKS were re-administered to all remaining participants. The relationship of data collection to instruction was identified in Table 12.

Semi-Structured Interviews

Following completion of the initial surveys, students were selected from volunteers in the study sample to participate in the initial interviews in order to gain a deeper understanding of the patterns of student responses to certain assessment questions. Approximately 35 % of the students (N=20) from the participating general chemistry laboratory courses volunteered and participated in the interviews. The interviews were held on campus at scheduled times outside of the normal laboratory class period. The participants from the initial interview participated in the final interview to determine if their NOS or epistemological beliefs had changed and the extent to which, if at all, laboratory instruction influenced those changes. The interviews were audio-recorded for transcription and further analysis.

During the interviews, the interviewer presented the participant with particular question(s), pre-determined from the responses on the surveys and asked the participant to offer a position (Appendix F). For instance, some of the questions asked the participant if they could attempt to explain or expand their answer and why they might have changed their answer from the beginning of the semester for those questions to which they responded differently during the initial survey or interview. Following an articulation of a rationale, the participants were asked to explain more completely why he or she chose a particular response as well as why they had discarded the remaining responses. The participants were given a chance to reflect on their position, and clear up any misinterpretations. This method allowed for initial member checking.

In addition to audio-taping and transcribing during each interview notes and observations were taken during the interviews by the outside interviewer. Short summaries of each interview were composed in order to provide a contextual background for each interview. These summaries were used as member checks.

Data Analysis

Introduction

A mixed-methods descriptive approach to data analysis, using both quantitative and qualitative data was used to analyze and then compare the data in order to generate the most rigorous description of the participants' images of science and epistemological beliefs and the influence that laboratory instruction may have had on changing those images or beliefs. This approach necessitates when quantitative measures are employed (CCI, EBAPS, and NSKS). This allowed a numerical assessment of students' beliefs and understanding as opposed to making predictions or inferences.

The data analysis was performed with the Statistics Package for the Social Sciences (SPSS) software version 15. Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants' responses to the pre-post assessments. A paired-samples t-test (repeated measures) was used to compare the pre-post mean scores for the participants. The variability for the paired-samples t-test was calculated by calculating eta squared. The effect size (d) was interpreted using the guidelines from Cohen (1998). In this dissertation, effect sizes were calculated from the mean gain score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. To interpret the effect size values the following guidelines from Cohen (1998) were used: 0.20 = small effect, 0.50 = moderate effect, and 0.80 = large effect. Pearson product-moment correlations were used to determine the degree that quantitative variables were linearly related.

The variability for the paired-samples t-test was calculated using the formula for eta squared. Eta squared can range from 0 to 1 and represents the proportion of variance in the dependent variable that is explained by the independent variable. To interpret the eta squared values the following guidelines from Cohen (1998) were used: 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect. Variability is defined here as t^2 divided by t^2 plus sample size minus 1 (eta squared = t^2 / t^2 + N-1).

CCI Analysis

Quantitative. The CCI was administered to all participants, pre-instruction as a means of gauging the participants' prior chemistry knowledge. The data analysis was performed with the Statistics Package for the Social Sciences (SPSS) software through use of descriptive statistics (frequencies, means, and standard deviations) to summarize the participants' responses to all quantitative assessments The scantron forms were scanned using the CCI Key (see Appendix M), and the data stored on a CD in a locked filing cabinet.

EBAPS Analysis

Quantitative. The EBAPS was administered to all the participants both pre-instruction and post-instruction as a means of quantitatively gauging the individual and overall changes in personal epistemological beliefs concerning the learning of science and the nature of scientific knowledge during instruction. Each item on the EBAPS was scored on a scale of 0 (least sophisticated) to 4 (most sophisticated). (see Appendix N) The scoring scheme is non-linear to take into account question-by-question (see Tables 7, 8, & 16) variations in whether, for instance, neutrality is more or less sophisticated. A subscale score is the average of the learner's scores on every item in that subscale. When an item within a given subscale is left blank, the average is calculated without that item included. Multiplying through by 25 allows one to report subscale scores on a scale of 0 to 100. The total score is the average of students' scaled scores on all 30 items (Elby, et al., 1999). The data analysis will be performed with the Statistics Package for the Social Sciences (SPSS) software and Microsoft Excel. Further statistical analysis was performed as needed and discussed earlier in this chapter. Refer to Appendix N for the EBAPS Scoring with Excel Template (Elby, et al., 1999).

Table 16 EBAPS Coding - Subscales (adapted from Elby, et al., 1999)

EBAPS Subscales - Color Coding	Items
Structure of Knowledge (Red)	2, 8, 10, 15, 17, 19, 20, 23, 24, 28
Nature of Learning (orange)	1, 7, 11, 12, 13, 18, 26, 30
Real-life Applicability (green)	3, 14, 19, 27, 28
Evolving Knowledge (blue)	6, 29
Source of Ability to Learn (purple)	5, 9, 16, 22, 25
No subscale (black)	4, 21

Qualitative. The purpose of the EBAPS was to qualitatively gauge the interview participants' initial epistemological understanding and any changes in their epistemological development. Using the qualitative data transcribed from the interview sessions, and the results from the EBAPS, participants' epistemological beliefs level of development were tentatively identified and offered as support for initial and final beliefs with the Epistemological Beliefs Assessment for Physical Sciences Scale (Table 7).

NSKS Analysis

Quantitative. The NSKS was administered to all the participants both pre-instruction and post-instruction as a means of quantitatively gauging the individual and overall changes in NOS beliefs during instruction. Composite scores (i.e., addition of subscale scores) of learner change for the three NSKS subscales that distinguish between the instrumentalist and realist positions in learners' images of science will be used in the study (see Appendix O). Subscales are composed from the eight items, four positive and four negative, corresponding to each of the factors in a Model of the Nature of Scientific Knowledge, i.e., amoral, creative, developmental, parsimonious, testable and unified subscales. Subscale scores are calculated by summing the appropriate 8 items of a given subscale after reflecting the negative items of the scores. Following this scoring scheme, a maximum score of 40 points for each subscale and 240 points for the entire NSKS is possible. Further statistical analysis will performed as needed

The range of scores for each subscale is 8 to 40 points. For each subscale, a score of 24 points indicates a neutral position while a score between 25 and 40 is within the accepted view of the NOS or one of an instrumentalist, and a score between 8 and 23 is within the unaccepted view of science or one of a realist. The overall score for all six subscales ranges from 48 to 240 points. A score of 144 on the overall scale score is considered neutral while scores ranging from 145 to 240 are within the accepted view of the nature of science, moving towards instrumentalism, and scores ranging from 48 to 143 are within the unaccepted view, moving towards realism (see Appendix O)

Qualitative. The purpose of the NSKS was to qualitatively gauge the interview participants' initial understanding and any belief changes of NOS. Using the qualitative data transcribed from the interview sessions, and the results from the NSKS participants' NOS beliefs, along with the EBAPS the participants' level of development will be tentatively identified with the NSKS scale located in Appendix O

Semi-Structured Interviews

To ensure the reliability of the coding scheme, the coding scheme and data was given to other colleagues following complete coding by the principal researcher. Those researchers coded the data, and the results were compared to ensure that another person would code the data the same way. After the first repetition of the other researchers coding the data, the coding scheme was revised, simplified, and clarified.

Initial interviews were conducted after the administration of the CCI, EBAPS, and NSKS in order to gain a deeper understanding of the patterns of student responses to certain assessment questions. Initially the interview participants were to be selected on the basis of their scores (high, middle, low) on the CCI, the responses on the NSKS, and the EBPAS questionnaire, however due to participants busy schedules and a small sample size (N=56) volunteers were requested. Approximately 35 % of the students (N=20) from the participating general chemistry laboratory courses volunteered to participate in the interviews. Interview methods are discussed below, in this chapter section titled Data Collection and in Appendix F. Students were asked questions directly pertaining to their NOS and personal epistemological beliefs during the initial interview.

During the final interview they were asked to reflect on their beliefs as related to instruction. The interviewer probed the students' responses and comments concerning components of the laboratory questionnaire. The data obtained from the interviews were used to explore possible student experiences and beliefs that lead to specific responses and/or changes on the NSKS, EBPAS, and laboratory questionnaire.

Grounded theory analytical procedures were used to inductively analyze the participants' interview responses. These procedures involved (1) the simultaneous collection and analysis of interview data, (2) comparative methods of analysis whereby participants' responses were compared among one another and within each participant, and (3) the integration of a theoretical framework. To analyze the interviews, the researcher read through both sets of transcripts making preliminary notes regarding patterns that emerge from individual participants. The dimensions of the EBAPS and NSKS were used to develop the coding patterns. The data collected from the sets of interview responses were coded using the dimensions of the instruments (EBAPS and NSKS) discussed in chapters two and three. The transcribed interview data was read looking for patterns, relationships and other themes within the dimensions. Entries were coded according to patterning identified while keeping a record of what entries went with which element of the patterns. In other words the data was read and then chunked based on common language. The coding scheme will be discussed further in subsequent chapters.

Reliability and Validity in Qualitative Research

Introduction

The importance of providing checks and balances to maintain acceptable standards is a necessary component of any research inquiry. In effect, the need for rigorous data collection and analytic methods has to be addressed. The traditional method of judging the rigor of a research inquiry is by the use of several of the following six strategies: prolonged engagement, triangulation, peer debriefing and support, member checking, negative case analysis, or auditing (Padgett, 1998; Guba & Lincoln, 1989; Lincoln & Guba, 1985).

Trustworthiness

Researchers, who frame their studies in an interpretive model, think in terms of trustworthiness as opposed to the conventional, criteria of internal and external validity, reliability, and objectivity (Denzin & Lincoln, 1994; Lincoln & Guba, 1985; Padgett, 1998). Lincoln and Guba (1985) suggest that the "trustworthiness" of a qualitative study allows a researcher and audience to evaluate the value of the results. Denzin and Lincoln (1994) suggest that four factors be considered in establishing the trustworthiness of findings from qualitative research: credibility, transferability, dependability, and confirmability. An inter-rater or peer check on the coding of the interview responses by a minimum of two raters checked reliability.

Credibility

Credibility refers to the confidence one can have in the truth of the findings and can be established by various methods. Three credibility methods are triangulation, member checking and negative case analysis. With respect to triangulation, data from multiple sources through multiple methods (i.e. interviews, surveys, and reflective questions), non-participant observation, and document reviews will be employed. Triangulation is a way of corroboration that allows the researcher to be more confident of the study's conclusions. Triangulation of outcomes produced by the initial and final interviews and the Student Assessments of Laboratory Methods questionnaire were used to assess the influence of the laboratory instructional methods as well as the

EBAPS and NSKS pre-post assessments. This procedure was particularly important in addressing research sub-questions 1 and research question 2.

Prolonged engagement means being present at the site where the study is being done long enough to build trust with the participants, experience the scope of variation and to overcome distortions due to the presence of the investigator at the site. This may involve an entire year or longer or it could mean as little as a month or semester. If the investigator is on the site long enough to see the range of things to be expected, the results produced will be more credible. This study lasted for one semester.

Persistent observation is a practice that checks depth of experience and understanding. To be persistent, the investigator must explore details of the phenomena under study to a deep enough level that he or she can decide what is important and what is irrelevant and focus on the most relevant aspects.

In studies of this nature (involving repeated measures), completing the initial responses to an instrument could impact responses on the repeated measure of the instrument. A testing effect can occur when the pre-assessment itself influences the post-assessment. The reliability of the assessment instruments may change in human ability to measure differences (due to experience, fatigue, etc). Therefore, initial and final interviews were implemented to assist in checking the validity of the participants' scores on the EBAPS and NSKS. The initial scores of the interview participants were compared to their initial interview responses. This method was repeated with the final scores and interviews.

Interviews, observations and surveys are time-consuming, but will be the main data-gathering methods. During the field observations and interviews the researcher simply can not afford to rush through or skirt around the issues.

Member checking involves checking the accuracy of facts and observations, as data collection transitions into data analysis. Crosschecking will encourage self-awareness and self-correction. All interview participants were shown transcribed summaries of their initial and final interviews to verify the accuracy. After the initial analysis of the study, feedback on some of the findings was achieved from individuals in the field who did not participate through peer reviews. Individuals from the research site were asked to confirm the accuracy of the observations as well as comment on whether the interpretations ring true and are meaningful. This process provided participant validation of the findings.

Applicability

Applicability or transferability means, in essence, that other researchers can apply the findings of the study to their own. To provide for applicability the study presents the findings with “thick” descriptions of the participants, the data collection procedures, the analytic procedures, and the emergent patterns.

Dependability

According to Denzin & Lincoln, (1994) dependability refers to the stability of the findings over time and confirmability to the internal coherence of the data in relation to the findings, interpretations, and recommendations. The logic for selecting participants and events to observe, interview, and include in the study were clearly presented. A technique for assessing dependability is the dependability audit where an independent auditor reviews the activities of the investigator. Once again, this was accomplished with a peer review.

Confirmability

Confirmability refers to the quality of the results, in other words the degree to which qualitative data and their interpretations can be authenticated. The techniques to be used for establishing credibility such as data triangulation, investigator triangulation, and member-checking are important for building confirmability. An audit trail can be used to accomplish dependability and confirmability simultaneously (Lincoln & Guba, 1985; Padgett, 1998). The audit trail for this study includes detailed notes regarding data collection, data analysis, and any modifications made.

Summary

This chapter described the predicted design and methodology of the research study. The purpose of this study was to explore the theoretical and conceptual frameworks, and describe the empirical research pertinent to student images of science and epistemological beliefs development during the course of laboratory instruction.

Section one restated the purpose of the study, elaborates on the rationale behind the research questions, and presents an overview of the analysis, design, and methodology. Section two described the context and participants of the setting. Section three discusses the research instruments, measures, and techniques which include the: (1) Chemical Concepts Inventory, (2) Epistemological Beliefs Assessment for the Physical Sciences, (3) Nature of Scientific Knowledge Scale, (4) Students' Reflective Assessment of Laboratory Methods, and (5) In-depth semi-structured interviews. Section Four identifies the forms of treatment (pedagogy) involved in the laboratory instruction. This section offers an overview of the laboratory environment followed by a discussion of the three general areas under consideration, pre-laboratory, laboratory work, and post-laboratory for this study. Section six of this chapter summarizes how data will be collected during the study with a general overview of the phases of data collection and the researcher's role during the study. Section seven briefly summarizes how the data will be analyzed. In addition, this chapter described the potential quantitative and qualitative analysis methods implemented. The final section discusses the aspects to be used in monitoring the reliability and validity of the data collection and analysis.

Chapter four presents a description of the participant sample followed by the presentation of the quantitative analyses of the study's first research question and sub-questions. The questions are presented with the quantitative results of the analyses for all the participants (N=56) and of the twenty whom participated in the interviews. The results are discussed and related back to the key NOS and personal epistemological beliefs literature.

Chapter Four: Quantitative Findings

Introduction

Given the mixed-methods nature of this study's findings, the presentation of the data is necessarily embedded in a description of the findings in chapters four, five, six and seven. This chapter presents a description of the participant sample followed by the presentation of the quantitative analyses of the study's first research question and sub-questions. The questions are presented with the quantitative results of the analyses for all the participants (N=56) and of the twenty whom participated in the interviews. The results are discussed and related back to the key laboratory education literature as well as the NOS and personal epistemological beliefs literature.

Chapter five presents a description of the development of the participant's personal epistemological beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-b. The characterization of personal epistemological beliefs with the results of the analyses of the participants' responses to interview probes will be presented. The combination of interviews and quantitative measures will provide a glimpse into students' personal epistemological beliefs changes during the course of a semester and what the participants' believed influenced their beliefs.

Chapter six presents a description of the development of the participants' NOS beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-a. The characterization of NOS beliefs with the results of the analyses of the participants' responses to interview probes will be presented. The combination of interviews and quantitative measures will provide a glimpse into participants' NOS belief changes during the course of a semester and what the participants' believed influenced their beliefs.

Chapter seven characterizes the findings of the instructional features of the second research question and sub-questions 2-a and 2-b. The characterization of laboratory instruction with the quantitative and qualitative results from the Student Evaluation of Laboratory Instruction Questionnaire as well as the results of the analyses of the participants' responses to interview probes will be presented. This will provide a glimpse of the participants' overall beliefs concerning the laboratory aspects of the semester course.

The final chapter of this dissertation (Chapter 8) concludes by presenting some implications on theory and pedagogy, limitations to the study, a summary of the key findings, and areas for future research.

Characterization of Participants' Epistemological and NOS Beliefs

Research Question 1 and Sub-Questions

The first research question and sub-questions lent themselves to quantitative data analysis. They are:

RQ1. What range of personal epistemological and NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

RQ1a. Do students' images of the nature of chemistry (NOS) change by the completion of a semester general chemistry laboratory course?

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

Quantitative results regarding pre-post semester NOS and personal epistemological beliefs toward science are presented and discussed briefly in this chapter. Further discussion will be presented in chapters five and six.

Description of Participants

A sample of 56 undergraduate students at a major University in Florida volunteered and participated in the study. All participants were enrolled in the first semester of a two semester general chemistry laboratory course during the fall semester of 2006. Students who agreed to participate signed the participant consent form (Appendix L). Overall, the mean age of the participants was 21 years, with a range of 18 to 45 years of age. Approximately 64% of the participants were female and 36% were male. Overall 46% of the participants were freshman, 21% sophomores, 18% juniors, 9% seniors, and 7% with no college rank. All but five of the 56 participants had taken a high school chemistry and biology course. Seventy-seven percent of the participants were majoring in science with 13% undecided.

A sample of 20 participants from the total sample of 56 volunteered and participated in the initial and final interviews. Overall, the mean age of the interviewed participants was 22 years, with a range of 18 to 45 years of age. Approximately 85% of the participants were female and 15% were male. Overall 40% of the participants were freshman, 25% sophomores, 25% juniors, and 10% with no college rank. All of the 20 participants had taken a high school chemistry and biology course. Ninety percent of the participants were majoring in science with 10% undecided.

Chemical Concepts Inventory Results

The Chemical Concepts Inventory (CCI) discussed in chapter three is the prior knowledge assessment that was administered to explore the participants' prior mental models and their qualitative images of how chemistry works (see Appendix A).

Descriptive statistics of the CCI pre-assessment chemistry knowledge scores of the fifty-six participants are outlined in Table 17 to include means, standard deviations, and ranges of scores.

Table 17 Descriptive Statistics – Chemical Concept Inventory Scores

N	Minimum	Maximum	Mean	Std. Deviation
56	31.00	100.00	68.96	15.264
20	45.00	86.00	67.55	10.247

As shown in Table 17 the mean CCI pre-knowledge assessment scores for the participants (N=56) ranged from 31.00-100.00. The participants had a mean score of 68.96 with a standard deviation of 15.264. Using the laboratory instructional grading scale for the course the number of participants scoring within a specific range is indicated in Table 18. The scores appear to be normally distributed with a majority scoring (16) in the 65-74 range.

As shown in Table 18 the mean CCI pre-knowledge assessment scores for the interviewed participants (N=20) ranged from 45.00-86.00. The participants had a mean score of 67.55 with a standard deviation of 10.247. Using the laboratory instructional grading scale for the course the number of participants scoring within a specific range is indicated in Table 18. The scores appear to be normally distributed with a majority scoring (7) in the 65-74 range.

Table18 Distribution of Participants' CCI Scores

Score Range	Number Participants (N=56)	Number Participants (N=20)
85-100	8	1
75-84	11	5
65-74	16	7
55-64	12	5
0-54	9	2

Epistemological Beliefs Assessment - Physical Science Results

Descriptive Statistics All Participants

Participants' initial and final personal epistemological beliefs over the course of a semester were assessed using the Epistemological Beliefs Assessment for Physical Science (EBAPS). The EBAPS discussed in chapters two and three (see Appendix B & N) is designed to assess personal epistemological beliefs in five dimensions: the structure of knowledge, the nature of learning, real-life applicability, evolving knowledge, and the source of ability to learn (Elby, 2001). Prior to data analysis, a check on accuracy of data entry and missing data for the data set was done through SPSS frequencies. Each item is scored on a scale of 0 (least sophisticated) to 4 (more sophisticated). Descriptive statistics of the EBAPS pre- and post-assessment scores (N=56) of all the participants are outlined in Table 19 to include means, standard deviations, and ranges of scores from each dimension as well as the overall score. Pre- and post- assessment scores for all participants are located in Appendix P.

Table 19 Descriptive Statistics - EBAPS Scores – All Participants

Dimension	Pre-Mean	SD	Range	Post-Mean	SD	Range
Structure of Knowledge (A-1)	2.172	0.460	1.15-3.20	2.488	0.502	1.15-3.65
Nature of Knowing & Learning (A-2)	2.511	0.469	1.15-3.44	2.760	0.551	1.63-3.94
Real-life Applicability (A-3)	2.665	0.694	0.75-4.00	2.978	0.643	1.75-4.00
Evolving Knowledge (A-4)	2.357	0.687	1.00-4.00	2.804	0.788	0-4.00
Source of Ability to Learn (A-5)	2.896	0.730	0.80-4.00	3.107	0.721	1.20-4.00
Overall Score	2.514	0.352	1.58-3.23	2.771	0.388	1.28-3.55

As shown in Table 19 the mean pre-assessment overall EBAPS scores for the participants (N=56) ranged from 1.58 to 3.23. The participants had a mean pre-assessment score of 2.514 with a standard deviation of 0.352. The results also indicate that participants' EBAPS post-assessment scores ranged from 1.28 to 3.55. The participants had a mean post-assessment score of 2.771 with a standard deviation of 0.388. These results seem to suggest that the laboratory instructional experience had a small but positive effect on some of the participants' personal epistemological beliefs. However, each instructional method (pre-laboratory, Labwork, post-laboratory) included multiple pedagogical components (i.e., quiz, MBL, laboratory notebook, and analysis paper) that may or may not of influenced the participants' epistemological beliefs. Taking into consideration that the range of possible scores 0 to 4, the results suggest that some of the participants were neither prior to nor after the laboratory instruction homogeneous in terms of their overall epistemological stage as 22 participants' improved their epistemological beliefs by the end of the semester course (see Tables20-21 & Appendix P).

As indicated in Tables 20 and 21 one participant shifted from moderately sophisticated (2.85) to extremely sophisticated (3.55). Approximately 10 participants moved into the highly sophisticated belief level (3.0-3.4) by the end of the semester course while two participants' scores dropped from highly sophisticated beliefs (3.02 & 3.23) to moderately sophisticated beliefs (2.80 & 2.95). Twenty-four of the participants remained in the moderately sophisticated belief range (2.9-2.4) with small changes in their individual dimension scores. Four participants remained in the poorly sophisticated beliefs range (1.6-2.3), while two participants scores dropped from moderately sophisticated (2.47 & 2.50) to poorly sophisticated beliefs (1.83 & 2.38).

Table 20 Participant Shifts between Epistemological Belief Levels

H→E	H→H	H→M	M→H	M→M	M→P	M→U	P→H	P→M	P→P
1	1	2	7	24	2	1	5	9	4

Table 21 EBAPS Score Range – Pre-Post Count

Sophistication Level	Score Range	Scaled Score Range	Pre-Count N=56	Post-Count N=56
Extremely Sophisticated (E)	3.5 – 4.0	87 - 100	0	1
Highly Sophisticated (H)	3.4 – 3.0	86 – 75	3	13
Moderately Sophisticated (M)	2.9 – 2.4	74 - 60	35	35
Poorly Sophisticated (P)	2.3 – 1.6	59 - 40	17	6
Unsophisticated (U)	1.5 - 0	39 - 0	1	1

The overall average score for the EBAPS at the beginning of the semester course for all participants was 2.514 indicating a moderately sophisticated level of epistemological beliefs. Among them, the highest score was 3.23 indicating highly sophisticated epistemological beliefs and the lowest score was 1.58 indicating a poor level of sophistication in epistemological beliefs. It is worth noting, however, that for the pre-assessment overall score, only 3 of 56 students scored above 3.00 indicating high sophisticated epistemological beliefs while 18 of 56 participants scored below 2.40 indicating initially poor to unsophisticated epistemological beliefs. The majority of participants scored between 2.42-2.61 indicating moderately sophisticated epistemological beliefs.

By the end of the semester, the overall average EBAPS post-score for all the participants was 2.771. The highest post-score was 3.55 indicating superior sophisticated epistemological beliefs and the lowest score was 1.28 indicating a decrease from the initial lowest score of 1.58 falling into the range of poor epistemological beliefs. Again it is worth noting that for the post-assessment overall score, 14 of 56 students scored above 3.00 with 1 of the 14 scoring 3.55 while only 7 of

56 students scored below 2.40. The majority of the participants scored between 2.66-2.87 indicating moderately sophisticated epistemological beliefs.

EBAPS T-Test Results All Participants

Paired samples t-test were conducted for each axis mean score and overall mean score to compare the pre- and post-mean scores of the participants. Statistically significant ($p \leq 0.05$) differences were found in four of the five dimensions, structure of knowledge, nature of learning, real life applicability, evolving knowledge and in the overall score. In this dissertation, effect sizes were calculated from the mean difference score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. The results were analyzed by comparing pre and post test scores, the Hake gain (also called the Hake factor), and the maximum possible gain. The Hake gain is a normalized gain defined as

$$g = \frac{\text{actual gain}}{\text{max. possible gain}} = \frac{\text{posttest} - \text{pretest}}{\text{max score} - \text{pretest}}$$

The results are presented in Table 22.

There was a statistically significant increase in the structure of knowledge dimension scores from pre-assessment (M=2.172, SD=0.460) to post-assessment (M=2.488, SD=0.502), t (55) =-4.248, p≤0.000, d=0.57 (medium statistically significant effect). There was a statistically significant increase in the nature of learning dimension scores from pre-assessment (M=2.511, SD=0.469) to post-assessment (M=2.760, SD=0.551), t (55) =-2.988, p≤0.004, d=0.40 (small but statistically significant effect). There was a statistically significant increase in the real-life applicability dimension scores from pre-assessment (M=2.665, SD=0.694) to post-assessment (M=2.978, SD=0.643), t (55) =-2.809, p≤0.007, d=0.38 (small but statistically significant effect). There was a statistically significant increase in the evolving knowledge dimension scores from pre-assessment (M=2.357, SD=0.687) to post-assessment (M=2.804, SD=0.788), t (55) = -4.064, p≤0.000, d=0.54 (medium statistically significant effect). There was not a statistically significant increase in the source and ability to learn dimension scores from pre-assessment (M=2.896, SD=0.730) to post-assessment (M=3.107, SD=0.721), t (55) =-1.790, p≤0.079, d=0.24 (small not statistically significant effect). There was a statistically significant increase in the overall scores from pre-assessment (M=2.514, SD=0.352) to post-assessment (M=2.771, SD=0.388), t (55) =-4.568, p≤0.000, d=0.61 (medium statistically significant effect).

Table 22 EBAPS T-Test Analysis - All Participants

Dimension	Pre-Mean	Post-Mean	Gain	t-Value	p-Value	Effect Size	Eta^2
Structure of Knowledge (A-1)	2.172	2.488	0.27	-4.248	0.000*	0.57	0.25
Nature of Learning (A-2)	2.511	2.760	0.16	-2.988	0.004*	0.40	0.14
Real Life Applicability (A-3)	2.665	2.978	0.19	-2.809	0.007*	0.38	0.13
Evolving Knowledge (A-4)	2.357	2.804	0.33	-4.064	0.000*	0.54	0.23
Source/Ability to Learn (A-5)	2.896	3.107	0.11	-1.790	0.079	0.24	0.055
Overall Score (Tot)	2.514	2.771	0.17	-4.568	0.000*	0.61	0.28

*significant at p≤ 0.05

The average gain score of all participants was between 0.17-0.27 on a scale of 0 to 4.00 or 4-6 points on a scale of 0-100. The paired t-test shows that this gain score represents a statistically significant mean difference between the pretest and posttest with *t*=-4.568, *p*<0.000. This indicates a moderately significant increase in the sophistication level of several participants' epistemological beliefs over the course of the semester with an effect size of d=0.61. The results suggest that some of the participants in general improved their personal epistemological beliefs during the course of the semester.

Eta squared is the proportion of the total variance that is attributed to an effect. In other terms it is considered a variance proportion estimate that can be positively biased and over estimate true effect. However, it is usually calculated when performing a paired-sample t-test as an additional indicator of effect size (Pallant, 2003). The eta square index (hand calculated in this case) indicates that 28% of the variability in the pre- and post-overall scores may be explained in part by the semester of laboratory instruction. So while there is a statistical difference, the practical difference is moderate and warrants further investigation.

EBAPS results (table 22) show a significant increase in structure, nature, real life applicability of science, and evolving knowledge. The participants seem to struggle with ability to learn science. In summary based on the EBAPS results: (1) the mean gain scores for the overall test and all dimensions, except for the source of ability to learn were found to be significant at $p \leq .05$ and (2) the data suggest that laboratory instruction possibly had effected a change in the students' epistemological beliefs.

EBAPS Correlations – All Participants

The differences between participants' responses on the pre-assessment and the post-assessment were tested as follows. To check the pattern of internal relationships between dimensions, dimensions with overall scores, and pre- and post-overall scores, Pearson's correlations between the pre- and post-assessment dimensions were calculated. Table 23 shows the correlation coefficients and the p-level of these correlations.

The EBAPS (N=56) has good internal consistency, with a Cronbach's alpha coefficient of 0.703. The correlations shown in Table 22 indicate that the pre- and post-assessments for 14 out of the 16 were significantly correlated, either at .05 or .01 level, providing additional support for the instrumentation reliability.

The relationship between the EBAPS dimensional (Axis) mean scores and the overall pre- and post assessment mean scores was investigated using Pearson product-moment correlation coefficient. All of the initial means of the five EBAPS dimensions (Axis) significantly correlated with the initial total overall mean score at the 0.01 level (r (55) = 0.579, 0.709, 0.556, 0.421, and 0.647, respectively). All of the post means of the five EBAPS dimensions (Axis) significantly correlated with the post total overall mean score at the 0.01 level (r(55) = 0.682, 0.721, 0.507, 0.383, and 0.683, respectively).

Table 23 EBAPS Paired Samples Correlations (N=56)

Pair	Correlation	Significance
Sum A1in-Totin	0.579**	0.000
Sum A2in-Totin	0.709**	0.000
Sum A3in-Totin	0.556**	0.000
Sum A4in-Totin	0.421**	0.001
Sum A5in-Totin	0.647**	0.007
Sum A1F-TotF	0.682**	0.000
Sum A2F-TotF	0.721**	0.000
Sum A3F-TotF	0.507**	0.000
Sum A4F-TotF	0.383**	0.004
Sum A5F-TotF	0.683**	0.000
Sum A1in-A1F	0.332*	0.012
Sum A2in-A2F	0.266*	0.046
Sum A3in-A3F	0.226	0.093
Sum A4in-A4F	0.386**	0.003
Sum A5in-A5F	0.262	0.051
Sum Totin-TotF	0.356**	0.007

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

The structure of knowledge (A1) and nature of learning dimension (A2) pre- and post-means were significantly correlated at the 0.05 level, while the pre- and post means of the dimension, evolving knowledge (A-4) are significantly correlated at the 0.01 level (r(55) = 0.332, 0.266, and 0.386, respectively). The pre- and post total mean scores are significantly correlated at the 0.01 level (r (55) = 0.356). However, the results indicated the lack of significant correlations between the pre- and post mean scores of the dimensions, real-life applicability and source of ability to learn (r(55) = 0.226 and 0.262, respectively).

EBAPS Results Interview Participants

Descriptive Statistics Interview Participants

Interviewed participants' initial and final personal epistemological beliefs over the course of a semester were assessed using the EBAPS. Prior to data analysis, a check on accuracy of data entry and missing data for the data set was done through SPSS frequencies. Each item is scored on a scale of 0 (least sophisticated) to 4 (more sophisticated). Descriptive statistics of the EBAPS pre- and post-assessment scores (N=20) of all the interviewed participants are outlined in Table 24 to include means, standard deviations, and ranges of scores from each dimension as well as the overall score. Pre- and post- assessment scores for all interviewed participants are located in Appendix P.

Table 24 Descriptive Statistics – EBAPS Scores – Interview Participants

Dimension	Pre-Mean	SD	Range	Post-Mean	SD	Range
Structure of Knowledge (A-1)	2.090	0.407	1.20-2.90	2.512	0.558	1.65-3.50
Nature of Knowing & Learning (A-2)	2.569	0.351	1.56-3.06	2.935	0.549	1.75-3.94
Real-life Applicability (A-3)	2.788	0.480	1.50-3.50	3.138	0.594	2.00-4.00
Evolving Knowledge (A-4)	2.150	0.587	1.33-3.33	2.783	0.669	1.67-4.00
Source of Ability to Learn (A-5)	3.000	0.554	1.60-3.80	3.210	0.617	2.00-4.00
Overall Score	2.537	0.266	1.88-2.98	2.867	0.125	2.08-3.55

As shown in Table 24 the mean pre-assessment overall EBAPS scores for the interviewed participants (N=20) ranged from 1.88 to 2.98. The participants had a mean pre-assessment score of 2.537 with a standard deviation of 0.266. The results also indicate that the interviewed participants' EBAPS post-assessment scores ranged from 2.08 to 3.55. The participants had a mean post-assessment score of 2.867 with a standard deviation of 0.125. These results seem to suggest that the laboratory instructional experience had a small but positive effect on some of the participants' personal epistemological beliefs. However, each instructional method (pre-laboratory, Labwork, post-laboratory) included multiple pedagogical components (i.e., quiz, MBL, laboratory notebook, and analysis paper) that may or may not of influenced the participants' epistemological beliefs. Taking into consideration that the range of possible scores 0 to 4, the results indicated that some of the participants were prior to and after the laboratory instruction homogeneous in terms of their overall epistemological stage while 9 of the participants improved their epistemological beliefs (see Tables 25-26 & Appendix P).

As indicated in Tables 25 and 26 one participant shifted from moderately sophisticated (2.85) to extremely sophisticated (3.55). Approximately 6 participants moved into the highly sophisticated belief level (3.0-3.4), 3 from moderately sophisticated and 3 from poorly sophisticated beliefs by the end of the semester course. Nine of the participants remained in the moderately sophisticated belief range (2.9-2.4) with small changes in their individual dimension scores, while 3 participants moved from poorly sophisticated to moderately sophisticated beliefs. One participant remained in the poorly sophisticated beliefs range (1.6-2.3).

Table 25 Participant Shifts between Epistemological Belief Levels

H→E	M→H	M→M	P→H	P→M	P→P
1	4	9	2	3	1

The overall average score for the EBAPS at the beginning of the semester course for the interviewed participants was 2.537 indicating a moderately sophisticated level of epistemological beliefs. Among them, the highest score was 2.98 indicating highly moderate sophisticated epistemological beliefs and the lowest score was 1.88 indicating a poor level of sophistication in epistemological beliefs. It is worth noting, however, that for the pre-assessment overall score, none of the 20 interviewed participants scored above 3.00 indicating most of them began the semester with moderate or poor beliefs, while 6 of 20 participants scored below 2.40 indicating initially poor to unsophisticated epistemological beliefs. The majority of participants scored between 2.41-2.66 indicating moderately sophisticated epistemological beliefs.

Table 26 EBAPS Score Ranges –Pre-Post Count

Sophistication Level	Score Range	Scaled Score Range	Pre-Count N=20	Post-Count N=20
Extremely Sophisticated (E)	3.5 – 4.0	87 - 100	0	1
Highly Sophisticated (H)	3.4 – 3.0	86 – 75	0	6
Moderately Sophisticated (M)	2.9 – 2.4	74 - 60	14	12
Poorly Sophisticated (P)	2.3 – 1.6	59 - 40	6	1
Unsophisticated (U)	1.5 - 0	39 - 0	0	0

By the end of the semester, the overall average score for all the interviewed participants was 2.867. The highest score was 3.55 indicating superior sophisticated epistemological beliefs and the lowest score was 2.08 in the range of poor epistemological beliefs. Again it is worth noting that for the post-assessment overall score, 7 of 20 students scored above 3.00 with 1 of the 7 scoring 3.55 while only 1 of 20 students scored below 2.40. The majority of the participants scored in the range 2.70-3.03 indicating moderate to highly sophisticated epistemological beliefs.

EBAPS T-Test Results – Interview Participants

Paired samples t-test were conducted for each axis mean score and overall mean score to compare the pre- and post-mean scores of the interviewed participants. Statistically significant ($p \leq 0.05$) differences were found in four of the five dimensions, structure of knowledge, nature of learning, real life applicability, evolving knowledge and in the overall score. In this dissertation, effect sizes are calculated from the mean difference score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. The results were analyzed by comparing pre and post test scores, the Hake gain (also called the Hake factor), and the maximum possible gain. The Hake gain is a normalized gain defined as

$$g = \frac{\text{actual gain}}{\text{max. possible gain}} = \frac{\text{posttest} - \text{pretest}}{\text{max score} - \text{pretest}}$$

The results are presented in Table 27.

There was a statistically significant increase in the structure of knowledge dimension scores from pre-assessment (M=2.090, SD=0.407) to post-assessment (M=2.512, SD=0.558), t (19) =-4.064, p≤0.001, d=0.91 (large statistically significant effect). There was a statistically significant increase in the nature of learning dimension scores from pre-assessment (M=2.569, SD=0.351) to post-assessment (M=2.935, SD=0.549), t (19) =-2.905, p≤0.009, d=0.65 (medium but statistically significant effect).

Table 27 EBAPS T-Test Analysis - Interview Participants

Dimension	Pre-Mean	Post-Mean	Gain	t	p	Effect Size	Eta^2
Structure of Knowledge (A-1)	2.090	2.512	0.39	-4.064	0.001*	0.91	0.47
Nature of Learning (A-2)	2.569	2.935	0.23	-2.905	0.009*	0.65	0.24
Real Life Applicability (A-3)	2.788	3.138	0.20	-2.580	0.018*	0.58	0.26
Evolving Knowledge (A-4)	2.150	2.783	0.55	-4.371	0.000*	0.98	0.50
Source/Ability to Learn (A-5)	3.000	3.210	0.11	-1.213	0.240	0.27	0.072
Overall Score	2.537	2.867	0.21	-4.169	0.001*	0.93	0.48

*significant at $p \leq 0.05$

There was a statistically significant increase in the real-life applicability dimension scores from pre-assessment (M=2.788, SD=0.480) to post-assessment (M=3.138, SD=0.594), t (19) =-2.580, p≤0.018, d=0.58 (medium statistically significant effect). There was a statistically significant increase in the evolving knowledge dimension scores from pre-assessment (M=2.150, SD=0.587) to post-assessment (M=2.783, SD=0.669), t (19) = -4.371, p≤0.000, d=0.98 (large statistically significant effect). There was not a statistically significant increase in the source and ability to learn dimension scores from pre-assessment (M=3.000, SD=0.554) to post-assessment (M=3.210, SD=0.617), t (19) =-1.213, p≤0.240, d=0.27 (small not statistically significant effect). There was a statistically significant increase in the overall scores from pre-assessment (M=2.537, SD=0.266) to post-assessment (M=2.867, SD=0.353), t (19) =-4.169, p≤0.001, d=0.93 (large statistically significant effect).

The average gain score of all participants ranged from 0.21-0.33 on a scale of 0 to 4.00 or 5-8 points on a scale of 0-100. The paired t-test shows that this gain score represents a statistically significant mean difference between the pretest and posttest with t=-4.169, p<0.001. This indicates a largely significant increase in the sophistication level of several participants' epistemological beliefs over the course of the semester with an effect size of d=0.93. The results suggest that some of the interviewed participants in general improved their personal epistemological beliefs during the course of the semester.

Eta squared is the proportion of the total variance that is attributed to an effect. In other terms it is considered a variance proportion estimate that can be positively biased and over estimate true effect. However, it is usually calculated when performing a paired-sample t-test as an additional indicator of effect size (Pallant, 2003). The eta square index (hand calculated in this case) indicates that 48% of the variability in the pre- and post-overall scores may be explained in part by the semester of laboratory instruction. So while there is a statistical difference, the practical difference is moderate and warrants further investigation.

EBAPS results (table 27) show a significant increase in structure, nature, real life applicability of science, and evolving knowledge for the interviewed participants. The interviewed participants seem to struggle with ability to learn science as did the other 36 participants. In summary based on the EBAPS results: (1) the mean gain scores for the overall test and all dimensions, except for the source of ability to learn were found to be significant at $p \leq .05$ and (2) the data suggest that possibly laboratory instruction had effected a change in the students' epistemological beliefs.

EBAPS Correlations – Interview Participants

The differences between interviewed participants' responses on the pre-assessment and the post-assessment were tested as follows. To check the pattern of internal relationships between dimensions, dimensions and overall scores, and pre- and post-overall scores, Pearson's correlations between the pre- and post-assessment dimensions were calculated. Table 28 shows the correlation coefficients and the p-level of these correlations.

The EBAPS (N=20) has good internal consistency, with a Cronbach's alpha coefficient of 0.716. The correlations shown in Table 28 indicate that the pre- and post-assessments for 10 of the 16 correlations significantly correlated, either at .05 or .01 level, providing additional support for the instrumentation reliability. The smaller sample size (N=20) may of contributed to the lack of correlation between the pre- and post-dimension scores.

The relationship between the EBAPS dimensional (Axis) mean scores and the overall pre- and post assessment mean scores was investigated using Pearson product-moment correlation coefficient. Three of the initial means, (structure of knowledge, nature of knowing and learning, and real-life applicability) of the five EBAPS dimensions (Axis) significantly correlated with the initial total overall mean score at the 0.01 level (r(19) = 0.590, 0.740, and 0.674, respectively). Source of ability to learn significantly correlated with the initial overall mean score at the 0.05 level (r (19) = 0.489). Only evolving knowledge did not correlate with the initial overall mean score (r (19) = 0.105).

Table 28 EBAPS Paired Samples Correlations

Pair	Correlation	Significance
Sum A1in-Totin	0.590**	0.006
Sum A2in-Totin	0.740**	0.000
Sum A3in-Totin	0.674**	0.001
Sum A4in-Totin	0.105	0.658
Sum A5in-Totin	0.489*	0.029
Sum A1F-TotF	0.807**	0.000
Sum A2F-TotF	0.798**	0.000
Sum A3F-TotF	0.514*	0.020
Sum A4F-TotF	0.163	0.492
Sum A5F-TotF	0.475*	0.034
Sum A1in-A1F	0.575**	0.008
Sum A2in-A2F	0.279	0.234
Sum A3in-A3F	0.379	0.099
Sum A4in-A4F	0.474*	0.035
Sum A5in-A5F	0.129	0.587
Sum Totin-TotF	0.373	0.105

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

Two of the post means (structure of knowledge (A1) and nature of knowing and learning A2) of the five EBAPS dimensions (Axis) significantly correlated with the post total overall mean score at the 0.01 level (r(19) = 0.807 and 0.798, respectively). Real-life applicability and source of ability to learn significantly correlated with the final overall mean score at the 0.05 level (r (19) = 0.514 and 475, respectively). Evolving knowledge (A4) did not correlate with the final overall mean score (r (19) = 0.163).

The structure of knowledge (A1) dimension pre- and post-means were significantly correlated at the 0.01 level (r (19) = 0.575), while the dimension evolving knowledge (A4) pre- and post-means were significantly correlated at the 0.05 level (r (19) = 0.474). However, the results indicated the lack of significant correlations between the pre- and post mean scores of the dimensions, nature of knowing and learning, real-life applicability and source of ability to learn (r(19) = 0.279, 0.379, and 0.587, respectively). Once again the lack of correlation may be attributed to the small sample size.

Nature of Scientific Knowledge Results

The Nature of Scientific Knowledge Scale, NSKS, (Rubba & Anderson, 1978) discussed in chapters 2 and 3 was used as a supplementary source for research question one and two regarding changes in participant's understandings of scientific literacy, in particular nature of science issues (see Appendix O for scoring instructions). The NSKS contains 24 positively and 24 negatively written item statements with eight statements in each of six subscales. The response alternatives for each item are in a Likert-style format including strongly agree, agree, neutral, disagree, and strongly disagree.

The six dimensions of the instrument reflect different aspects of the nature of science. These dimensions measure participant's understandings of the amoral, creative, developmental, parsimonious, testable, and unified nature of science. The amoral dimension reflects that “scientific knowledge provides humans with many capabilities but not how to use them”, the creative dimension reflects that "scientific knowledge is partially a product of human creativity", the developmental dimension reflects that "scientific knowledge is tentative", the parsimonious dimension reflects that “ scientific knowledge moves toward being comprehensive and simplistic”, the testable dimension reflects that "scientific knowledge is capable of empirical test", and the unified dimension reflects that "the specialized sciences contribute to an interrelated network of laws, theories, and concepts" (Meichtry,1992; Rubba & Anderson, 1978).

The range of scores for each dimension is 8 to 40 points. For each dimension, a score of 24 points indicates a neutral (N) position or combination of realist and instrumentalist views on NOS while a score between 25 and 40 is within the accepted view of the nature of science (Instrumentalist-I), and a score between 8 and 23 is within the unaccepted NOS view (Realist-R). The overall score for all six dimensions ranges from 48 to 240 points (Figure 6). A score of 144 (141-147) on the overall scale score is considered neutral (N) while scores ranging from 145 and 240 (148-240) are within the accepted view of the nature of science (instrumentalist), and scores ranging from 48 and 143 (48-140) are within the unaccepted view (realist).

Realist-------------------------------------neutral----------------------------------Instrumentalist
(48) (unaccepted NOS view) (144) (accepted NOS view) (240)

Figure 6 NSKS Representative Placement Scale

Descriptive NSKS Statistics - All Participants

Participants' pre- and post scores concerning their nature of science (NOS) beliefs over the course of a semester were assessed using the NSKS. The NSKS discussed in chapters two and three (see Appendix C) is designed to assess NOS beliefs in six dimensions: amoral, creative, developmental, parsimonious, testable, and unified. Each dimension is scored on a scale of 8 (realist-R) unaccepted of NOS views to 40 (instrumentalist-I) accepts NOS views. The overall NSKS score is the sum of all six dimensions ranging from 48-240. Prior to data analysis, a check on accuracy of data entry and missing data for the data set was done through SPSS frequencies. Before calculating the dimension (subscale) scores for both the pre- and post-assessments, scores for the negatively worded items were reversed using SPSS 15.0.

Descriptive statistics of the NSKS pre- and post-assessment scores (N=56) of all the participants are outlined in Table 29 to include means, standard deviations, and ranges of scores from each dimension as well as the overall score. Pre- and post-assessment scores for all participants are located in Appendix P.

Table 29 Descriptive Statistics - NSKS Scores – All Participants

Dimension	Pre-Mean	SD	Range	Post-Mean	SD	Range
Amoral (D-1)	23.643	3.205	18-38	24.196	2.713	18-31
Creative (D-2)	22.893	2.095	18-27	23.670	2.288	18-32
Developmental (D-3)	23.625	1.950	19-27	24.768	2.123	19-31
Parsimonious (D-4)	24.625	2.378	20-31	26.321	2.552	20-33
Testable (D-5)	24.196	1.986	19-28	24.982	2.004	21-34
Unified (D-6)	23.643	1.494	20-28	24.411	1.735	20-28
Overall Score	142.482	7.027	122-158	148.375	7.845	118-169

As shown in Table 29 the mean pre-assessment overall NSKS scores for the participants (N=56) ranged from 122-158. The participants had a mean pre-assessment score of 142.482 with a standard deviation of 7.027. The results also indicate that participants' NSKS post-assessment scores ranged from 118-169. The participants had a mean post-assessment score of 148.375 with a standard deviation of 7.845. These results seem to suggest that the laboratory instructional experience had a small but positive effect on some of the participants' NOS beliefs. However, each instructional method (pre-laboratory, Labwork, post-laboratory) included multiple pedagogical components (i.e., quiz, MBL, laboratory notebook, and analysis paper) that may or may not of influenced the participants' NOS beliefs. In addition, explicit NOS instruction discussed in chapter 2 was not included or monitored during this particular study. Taking into consideration that the range of possible overall scores 48- 240, the results indicated that some of the participants were not homogeneous prior to and after the semester of laboratory instruction in terms of their overall NOS beliefs as 32 of the 56 participants moved towards the acceptance of NOS views score range (see Tables 30-31 & Appendix P).

As indicated in Tables 30 and 31 eleven participant's overall scores shifted from non acceptance of NOS views (R) to neutral views (N). Approximately 4 participants moved from non acceptance (R) of NOS views to the acceptance of NOS views (I) by the end of the semester course while no participants' scores dropped from acceptance of NOS views (I) to non acceptance (R). Seventeen of the participants moved from having neutral (N) views of NOS to accepting views of NOS (I). Six participant scores remained in the neutral range (N), while 5 participants remained in the non accepted views (R) of NOS range with minor changes in their individual dimension scores.

Table 30 NSKS Assessment Ranges

Belief Dimension	R-Pre	R-Post	N-Pre	N-Post	I-Pre	I-Post
Amoral (D-1)	30	21	9	11	17	24
Creative (D-2)	30	25	11	13	15	18
Developmental (D-3)	26	12	9	12	21	32
Parsimonious (D-4)	18	4	13	8	25	45
Testable (D-5)	16	8	13	17	27	31
Unified (D-6)	22	16	21	16	13	24
Overall Score	20	5	23	16	13	35

The overall average score for the NSKS at the beginning of the semester course for all participants was 142.482 indicating most participants NOS beliefs lie in the unaccepted NOS views. Among them, the highest score was 158 indicating acceptance of NOS views and the lowest score was 122 suggesting non acceptance of NOS views. For the pre-assessment overall scores, 13 of 56 students scored above 147 indicating an acceptance of NOS views while 20 of 56 participants scored below 141 indicating initial non acceptance of NOS views. The majority of participants scored from 141-147 considered the neutral range indicating they held some of the accepted and non accepted NOS views but not all the views.

Table 31 NSKS Beliefs Shift Pre-Post Assessment – All Participants

Dimension	R→R	N→N	I→I	R→N	R→I	N→I	N→R	I→R	I→N
Amoral (D-1)	14	2	13	8	8	4	3	3	1
Creative (D-2)	15	4	8	7	7	3	5	5	2
Developmental (D-3)	9	2	16	7	10	5	2	1	4
Parsimonious (D-4)	3	2	21	3	12	11	0	1	3
Testable (D-5)	7	7	22	5	4	5	1	0	5
Unified (D-6)	7	5	4	7	8	12	4	5	4
Overall Score	5	6	13	11	4	17	0	0	0

By the end of the semester, the overall average score for all the participants was 148.375 indicating a slight shift from non accepted views to neutral views of NOS . The highest score was 169 indicating an acceptance of NOS views and the lowest score was 118 in the range of non acceptance of NOS views. Again it is worth noting that for the post-assessment overall score, 16 of 56 students scored in the neutral range of NOS views while 5 participant's scores remained in the unaccepted NOS views range. The majority of the participants (35) scored in the accepted range of NOS views.

NSKS T-Test Results – All Participants

Paired samples t-test were conducted for each axis mean score and overall mean score to compare the pre- and post-mean scores of the participants. Statistically significant ($p \leq 0.05$) differences were found in five of the six dimensions, creative, developmental, parsimonious, testable, unified, and in the overall score. In this dissertation, effect sizes are calculated from the mean difference score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. The results were analyzed by comparing pre and post test scores, the Hake gain (also called the Hake factor), and the maximum possible gain. The Hake gain is a normalized gain defined as

$$g = \frac{\text{actual gain}}{\text{max. possible gain}} = \frac{\text{posttest} - \text{pretest}}{\text{max score} - \text{pretest}}$$

The results are presented in Table 32.

There was not a statistically significant increase in the amoral dimension scores from pre-assessment (M=23.643, SD=3.205) to post-assessment (M=24.196, SD=2.713), t (55) =-1.414, p≤0.163, d=0.19 (small not statistically significant effect). There was a statistically significant increase in the creative dimension scores from pre-assessment (M=22.893, SD=0.0470) to post-assessment (M=23.670, SD=2.288), t (55) =-2.262, p≤0.028, d=0.30 (small but statistically significant effect).

Table 32 NSKS T-Test Analysis - All Participants

Dimension	Pre Mean	Post Mean	Gain	t-test	p-value	Effect size	Eta^2
Amoral	23.643	24.196	0.0338	-1.414	0.163	0.19	0.035
Creative	22.893	23.670	0.0470	-2.262	0.028*	0.30	0.085
Developmental	23.625	24.768	0.0700	-4.021	0.000*	0.54	0.227
Parsimonious	24.625	26.321	0.1103	-5.401	0.000*	0.72	0.346
Testable	24.196	24.982	0.0500	-2.537	0.014*	0.34	0.104
Unified	23.643	24.411	0.0470	-2.695	0.009*	0.36	0.117
Overall Score	142.482	148.375	0.0604	-8.152	0.000*	1.00	0.547

N = 56 *significant at p≤ 0.05

There was a statistically significant increase in the developmental dimension scores from pre-assessment (M=23.625, SD=1.950) to post-assessment (M=24.768, SD=2.123), t (55) =-4.021, p≤0.000, d=0.54 (medium statistically significant effect). There was a statistically significant increase in the parsimonious dimension scores from pre-assessment (M=24.625, SD=2.378) to post-assessment (M=26.321, SD=2.552), t (55) = -5.401, p≤0.000, d=0.72 (medium statistically significant effect). There was a statistically significant increase in the testable dimension scores from pre-assessment (M=24.196, SD=1.986) to post-assessment (M=24.982, SD=2.004), t (55) =-2.537, p≤0.014, d=0.34 (small but statistically significant effect). There was a statistically significant increase in the unified dimension scores from pre-assessment (M=23.643, SD=1.494) to post-assessment (M=24.411, SD=1.735), t (55) =-2.695, p≤0.009, d=0.36 (small but statistically significant effect). There was a statistically significant increase in the overall scores from pre-assessment (M=142.482, SD=7.027) to post-assessment (M=148.375, SD=7.845), t (55) =-8.152, p≤0.000, d=1.00 (large statistically significant effect).

The average gain score of all participants ranged from 0.0604-5.750 on a scale of 8-40 or approximately 4.471-7.351 points on a scale of 48-240. The paired t-test shows that this gain score represents a statistically significant mean difference between the pretest and posttest with *t*=-8.152, *p*<0.000. This indicates a moderately significant increase toward the acceptance of NOS views of several participants' over the course of the semester with an effect size of d=1.00. The results suggest that some of the participants in general changed their NOS beliefs during the course of the semester.

Eta squared is the proportion of the total variance that is attributed to an effect. In other terms it is considered a variance proportion estimate that can be positively biased and over estimate true effect. However, it is usually calculated when performing a paired-sample t-test as an additional indicator of effect size (Pallant, 2003). The eta square index (hand calculated in this case) indicates that 55% of the variability in the pre- and post-overall scores may be explained in part by the semester of laboratory instruction. So while there is a statistical difference, the practical difference is moderate and warrants further investigation.

NSKS results (table 32) show a significant increase in the creative, developmental, parsimonious, testable, and unified dimensions for some of the participants. However, the participants seemed to struggle with the amoral dimension. In summary based on the NSKS results: (1) the mean gain scores for the overall test and all dimensions, except for amoral were found to be significant at p ≤ .05 and (2) the data suggest that possibly laboratory instruction had effected a change in the students' NOS beliefs.

NSKS Correlations – All Participants

The differences between participants' responses on the pre-assessment and the post-assessment were tested as follows. To check the pattern of internal relationships between dimensions, dimensions and overall scores, and pre- and post-overall scores, Pearson's correlations between the pre- and post-assessment dimensions were calculated. Table 33 shows the correlation coefficients and the p-level of these correlations.

The NSKS (N=56) has good internal consistency, with a Cronbach's alpha coefficient of 0.729. The correlations shown in Table 32 indicate that the pre- and post-assessments for 18 of the 19 were significantly correlated, either at .05 or .01 level, providing additional support for the instrumentation reliability.

The relationship between the NSKS dimensional mean scores and the overall pre- and post assessment mean scores was investigated using Pearson product-moment correlation coefficient. All of the initial means of the six NSKS dimensions (D) significantly correlated with the initial total overall mean score at the 0.01 level (r (55) = 0.646, 0.556, 0.471, 0.522, 0.361, and 0.557, respectively). All of the final means of the six NSKS dimensions (D) significantly correlated with the final total overall mean score at the 0.01 level (r (55) = 0.547, 0.677, 0.647, 0.633, 0.594, and 0.365, respectively).

The amoral, developmental, and parsimonious dimensions as well as the overall NSKS pre- and post-mean scores were significantly correlated at the 0.01 level (r(55) = 0.521, 0.457, 0.547, and 0.741, respectively), while the creative and testable dimensions pre- and post-means were significantly correlated at the 0.05 level (r(55) = 0.266 and 0.325, respectively). However, the results indicated a lack of significant correlation between the pre- and post mean scores of the unified dimension (r (55) = 0.135).

Table 33 NSKS Paired Samples Correlations (N=56)

Pair	Correlation	Significance
Sum D1in-Totin	0.646**	0.000
Sum D2in-Totin	0.552**	0.000
Sum D3in-Totin	0.471**	0.000
Sum D4in-Totin	0.522**	0.000
Sum D5in-Totin	0.361**	0.006
Sum D6in-Totin	0.557**	0.000
Sum D1F-TotF	0.547**	0.000
Sum D2F-TotF	0.677**	0.000
Sum D3F-TotF	0.647**	0.000
Sum D4F-TotF	0.633**	0.000
Sum D5F-TotF	0.594**	0.000
SumD6F-TotF	0.365**	0.006
Sum D1in-D1F	0.521**	0.000
Sum D2in-D2F	0.266*	0.047
Sum D3in-D3F	0.457**	0.000
Sum D4in-D4F	0.547**	0.000
Sum D5in-D5F	0.325*	0.014
Sum D6in-D6F	0.135	0.322
Sum Totin-TotF	0.741**	0.000

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

Descriptive NSKS Statistics - Interview Participants

Interviewed participants' (N=20) pre- and post scores concerning their nature of science (NOS) beliefs over the course of a semester were assessed using the NSKS. The NSKS discussed in chapters two and three (see Appendix C) is designed to assess NOS beliefs in six dimensions: amoral, creative, developmental, parsimonious, testable, and unified. Each dimension is scored on a scale of 8 (realist-R) unaccepted of NOS views to 40 (instrumentalist-I) accepts NOS views. The overall NSKS score is the sum of all six dimensions ranging from 48-240. Prior to data analysis, a check on accuracy of data entry and missing data for the data set was done through SPSS frequencies. Before calculating the dimension (subscale) scores for both the pre- and post-assessments, scores for the negatively worded items were reversed using SPSS 15.0.

Descriptive statistics of the NSKS pre- and post-assessment scores (N=20) of interviewed participants is outlined in Table 34 to include means, standard deviations, and ranges of scores from each dimension as well as the overall score. Pre- and post-assessment scores for participants are located in Appendix P.

Table 34 Descriptive Statistics - NSKS Scores - Interview Participants

Dimension	Pre-Mean Score	SD	Range	Post-Mean Score	SD	Range
Amoral (D-1)	23.150	2.368	20-28	24.350	1.954	20-28
Creative (D-2)	22.550	2.089	18-25	24.100	1.971	20-28
Developmental (D-3)	24.000	1.654	20-26	24.700	1.418	22-27
Parsimonious (D-4)	24.550	2.114	21-29	26.700	2.105	23-31
Testable (D-5)	24.050	2.089	19-27	24.300	1.418	21-26
Unified (D-6)	23.750	1.333	21-26	24.750	1.333	23-28
Overall Score	141.650	4.196	132-149	148.900	3.960	142-155

As shown in Table 34 the mean pre-assessment overall NSKS scores for the participants (N=20) ranged from 132-149. The participants had a mean pre-assessment score of 141.650 with a standard deviation of 4.196. The results also indicate that participants' NSKS post-assessment scores ranged from 142-155. The participants had a mean post-assessment score of 148.900 with a standard deviation of 3.900. These results seem to suggest that the laboratory instructional experience had a small but positive effect on some of the participants' NOS beliefs. However, each instructional method (pre-laboratory, Labwork, post-laboratory) included multiple pedagogical components (i.e., quiz, MBL, laboratory notebook, and analysis paper) that may or may not of influenced the participants' NOS beliefs. In addition, explicit NOS instruction discussed in chapter 2 was not included or monitored during this particular study. Taking into consideration that the range of possible overall scores 48- 240, the results indicated that some of the participants were homogeneous prior to and after the semester of laboratory instruction in terms of their overall NOS beliefs (see Tables 34-35 & Appendix P).

As indicated in Tables 35 and 36 five participant's overall scores shifted from non acceptance of NOS views (R) to neutral views (N). Approximately 3 participants moved from non acceptance (R) of NOS views to the acceptance of NOS views (I) by the end of the semester course while no participants' scores dropped from acceptance of NOS views (I) to non acceptance (R). Nine of the participants moved from having neutral (N) views of NOS to accepting views of NOS (I) while two participants' scores remained in the neutral range (N).with minor changes in their individual dimension scores.

The interviewed participants' overall average scores for the NSKS at the beginning of the semester course was 141.650 indicating most participants held neutral NOS belief. Among them, the highest score was 149 indicating acceptance of NOS views and the lowest score was 132 suggesting non acceptance of NOS views. For the pre-assessment overall scores, only 1 of the 20 interviewed participants scored above 147 indicating an acceptance of NOS views while 8 of 20 participants scored below 141 indicating an initial non acceptance of NOS views. The majority of participants (11) scored from 141-147 considered the neutral range indicating they held some of the accepted and non accepted NOS views but not all the views.

By the end of the semester, the overall average score for all the interviewed participants was 148.900. The highest score was 155 earned by 2 participants indicating acceptance of NOS views and the lowest score was 142 also scored by 2 participants in the range of non acceptance of NOS views. Again it is worth noting that for the post-assessment overall score, 13 of 20 students scored in the range of acceptance of NOS views with the remaining 7 scoring in the neutral range. Therefore the majority of the participants scored in the acceptance of NOS views range by the end of the semester.

Table 35 NSKS Score Range – Pre-Post Count (N=20)

Belief Dimension	R-Pre	R-Post	N-Pre	N-Post	I-Pre	I-Post
Amoral (D-1)	11	6	4	5	5	9
Creative (D-2)	12	5	3	6	5	9
Developmental (D-3)	6	3	5	8	9	9
Parsimonious (D-4)	5	1	8	3	7	16
Testable (D-5)	8	4	3	5	9	11
Unified (D-6)	7	3	10	7	3	10
Overall Score	8	0	11	7	1	13

Table 36 NSKS Belief Shifts Pre-Post Assessment

Dimension	R→R	N→N	I→I	R→N	R→I	N→I	N→R	I→R	I→N
Amoral (D-1)	5	2	5	3	3	1	1	0	0
Creative (D-2)	3	1	4	5	4	1	1	1	0
Developmental (D-3)	2	2	6	3	2	2	1	0	2
Parsimonious (D-4)	1	2	7	1	3	6	0	0	0
Testable (D-5)	3	1	8	3	1	1	1	0	2
Unified (D-6)	1	2	1	3	2	7	1	1	2
Overall Score	0	2	1	5	3	9	0	0	0

NSKS T-Test Results - Interview Participants

Paired samples t-test were conducted for each axis mean score and overall mean score to compare the pre- and post-mean scores of the participants. Statistically significant ($p \leq 0.05$) differences were found in three of the six dimensions, creative, parsimonious, unified*,* and in the overall score. In this dissertation, effect sizes are calculated from the mean difference score (mean Time 2 – mean Time 1) divided by the pooled standard deviation of the Time 1 and Time 2. The results were analyzed by comparing pre and post test scores, the Hake gain (also called the Hake factor), and the maximum possible gain. The Hake gain is a normalized gain defined as

$$g = \frac{\text{actual gain}}{\text{max. possible gain}} = \frac{\text{posttest} - \text{pretest}}{\text{max score} - \text{pretest}}$$

The results are presented in Table 36.

There was not a statistically significant increase in the amoral dimension scores from pre-assessment (M=23.150, SD=2.368) to post-assessment (M=24.350, SD=1.954), t (19) =-2.074, p≤0.052, d=0.46 (small not statistically significant effect). There was a statistically significant increase in the creative dimension scores from pre-assessment (M=22.550, SD=2.089) to post-assessment (M=24.100, SD=1.971), t (19) = -2.747, p≤0.013, d=0.61 (medium statistically significant effect).

Table 37. NSKS T-Test Analysis - Interview Participants

Dimension	Pre Mean	Post Mean	Gain	t-test	p-value	Effect size	Eta^2
Amoral	23.150	24.350	0.0712	-2.074	0.052	0.46	0.185
Creative	22.550	24.100	0.8882	-2.747	0.013*	0.61	0.284
Developmental	24.000	24.700	0.0438	-1.853	0.079	0.41	0.153
Parsimonious	24.550	26.700	0.1391	-4.060	0.010*	0.91	0.464
Testable	24.050	24.300	0.0157	-0.677	0.506	0.15	0.024
Unified	23.750	24.750	0.0615	-2.297	0.033*	0.51	0.217
Overall Score	141.650	148.900	0.0737	-7.623	0.000*	1.00	0.753

*significant at p≤ 0.05

There was not a statistically significant increase in the developmental dimension scores from pre-assessment (M=24.000, SD=1.654) to post-assessment (M=24.700, SD=1.418), t (19) =-1.853, p≤0.079, d=0.41 (small not statistically significant effect). There was a statistically significant increase in the parsimonious dimension scores from pre-assessment (M=24.550, SD=2.114) to post-assessment (M=26.700, SD=2.105), t (19) = -4.060, p≤0.010, d=0.91 (large statistically significant effect). There was not a statistically significant increase in the testable dimension scores from pre-assessment (M=24.050, SD=2.089) to post-assessment (M=24.300, SD=1.418), t (19) =-0.677, p≤0.506, d=0.15 (small not statistically significant effect). There was a statistically significant increase in the unified dimension scores from pre-assessment (M=23.750, SD=1.333) to post-assessment (M=24.750, SD=1.333), t (19) =-2.297, p≤0.033, d=0.51 (medium statistically significant effect). There was a statistically significant increase in the overall scores from pre-assessment (M=141.650, SD=4.196) to post-assessment

(M=148.900, SD=3.960), t (19) =-7.623, p≤0.000, d=1.00 (large statistically significant effect).

The average gain score of the interviewed participants ranged from 0.0737-6.85 on a scale of 8 to 40 or 5.259-9.241 points on a scale of 48-240. The paired t-test shows that this gain score represents a statistically significant mean difference between the pretest and posttest with *t*=-7.623, *p*<0.000. This indicates a largely significant increase in the sophistication level of several participants' epistemological beliefs over the course of the semester with an effect size of d=1.00. The results suggest that some of the interviewed participants in general improved their NOS beliefs during the course of the semester.

Eta squared is the proportion of the total variance that is attributed to an effect. In other terms it is considered a variance proportion estimate that can be positively biased and over estimate true effect. However, it is usually calculated when performing a paired-sample t-test as an additional indicator of effect size (Pallant, 2003). The eta square index (hand calculated in this case) indicates that 75% of the variability in the pre- and post-overall scores may be explained in part by the semester of laboratory instruction. So while there is a statistical difference, the practical difference is moderate and warrants further investigation.

NSKS results (table 37) show a significant increase in the creative, parsimonious, and unified dimension scores for the interviewed participants. The interviewed participants seem to struggle with the amoral, developmental, and testable dimensions. In summary based on the NSKS results: (1) the mean gain scores for the overall test and three dimensions (amoral, developmental, and testable) were found to be significant at p ≤ .05 and (2) the data suggest that possibly laboratory instruction had effected a change in the participants' scores in the three NSKS dimensions.

NSKS Correlations – Interview Participants

The differences between interview participants' responses on the pre-assessment and the post-assessment were tested as follows. To check the pattern of internal relationships between dimensions, dimensions and overall scores, and pre- and post-overall scores, Pearson's correlations between the pre- and post-assessment dimensions were calculated. Table 38 shows the correlation coefficients and the p-level of these correlations. The correlations in Table 38 indicate that only 2 of the 19 the pre- and post-assessments were significantly correlated, either at .05 or .01 level. The smaller sample size (N=20) may of contributed to the lack of correlation between the pre- and post-dimension scores and the pre- and post dimension scores with the overall scores.

The relationship between the NSKS dimensional mean scores and the overall pre- and post assessment mean scores was investigated using Pearson product-moment correlation coefficient. None of the initial or post means of the six NSKS dimensions significantly correlated with the initial or final total overall mean score. As suggested previously this lack of correlation may be due to the small sample (N=20).

The testable dimension pre- and post-means were significantly correlated at the 0.01 level (r (19) = 0.616), while the overall pre- and post-means were significantly correlated at the 0.05 level (r (19) = 0.457). However, the results indicated the lack of significant correlations between the pre- and post mean scores of the remaining 5 dimensions, amoral, creative, developmental, parsimonious, and unified (r(19) = 0.295, -0.229, 0.404, 0.370, and 0.067, respectively). Once again the lack of correlation may be due to the small sample size.

Table 38 NSKS Paired Samples Correlations (N=20)

Pair	Correlation	Significance
Sum D1in-Totin	0.440	0.052
Sum D2in-Totin	0.239	0.310
Sum D3in-Totin	0.409	0.073
Sum D4in-Totin	0.408	0.074
Sum D5in-Totin	0.188	0.427
Sum D6in-Totin	0.266	0.257
Sum D1F-TotF	0.404	0.077
Sum D2F-TotF	-0.025	0.916
Sum D3F-TotF	-0.070	0.769
Sum D4F-TotF	0.292	0.211
Sum D5F-TotF	0.028	0.906
SumD6F-TotF	0.014	0.954
Sum D1in-D1F	0.295	0.206
Sum D2in-D2F	0.229	0.332
Sum D3in-D3F	0.404	0.077
Sum D4in-D4F	0.370	0.108
Sum D5in-D5F	0.616**	0.004
Sum D6in-D6F	0.067	0.780
Sum Totin-TotF	0.457*	0.043

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

Discussion

Range of Initial Beliefs

RQ1. What range of personal epistemological and NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

Participants' initial scores on the Epistemological Beliefs Assessment for Physical Science (EBAPS) represent a range of beliefs from unsophisticated to highly sophisticated with the majority falling into the moderately sophisticated range (2.4-2.9). No participants scored in the top sophistication level, extremely sophisticated, meaning that there were no participants at the beginning of the semester course that held a high level of epistemological beliefs theorized in the models (Baxter-Magolda, 1986; Schommer, 1990; Hofer & Pintrich, 1997; Perry, 1970). Most of the participants initial scores fell in the range of late dualism to late multiplicity (levels 2-4) in Perry's model and in the absolute knowing to transitional knowing range of Baxter Magolda's model. The average EBAPS overall score of 2.514 would place the participants in the early multiplicity stage or transitional knowing stage of epistemological development. This gives some support to Perry and Baxter Magolda's findings that students depending on their year in college and other factors such as age and gender begin as a dualist or multiplist.

Participants at level 2 or absolute knowing usually perceive the world especially scientific knowledge from a dualistic viewpoint. They divide scientific knowledge into either right or wrong answers based on what is known to authority. These participants' beliefs are guided by obedience to authority and hard work. Participants at level 3 or transitional knowing acknowledge the existence of diversity of opinion and uncertainty of scientific knowledge and are considered relativistic students. This shift represents an increase in tolerance of uncertainty with notions of right and wrong having meaning only in context and uncertainty becomes legitimate (Moore, 2002).

The results of the study support an initial personal epistemological belief range (1.58-3.23) of unsophisticated to highly sophisticated at the beginning of the semester course with the majority of the participants falling at the low end of moderately sophisticated beliefs (2.514) or multiplicity. However, according to the multi dimensional epistemological beliefs models of Schommer (1994) and Hofer and Pintrich (1997) beliefs are a system of independent distributions. In other words, students may be sophisticated in some beliefs but not necessarily sophisticated in other beliefs. According to Schommer (1994), there are multiple dimensions to be considered and thought of independently as well as in various combinations (Hofer & Pintrich, 1997).

The EBAPS measured the participants' beliefs in five dimensions: structure of scientific knowledge, nature of knowing and learning science, real-life applicability of science, evolving scientific knowledge, and the source of ability to learn science. The participants initially held naïve beliefs about the structure of scientific knowledge (2.172) and evolving knowledge in science (2.357). This average score suggests a dualistic perspective about the structure of scientific knowledge. Participants holding this view see scientific knowledge as right or wrong and authority is always correct. At the beginning of the semester course participants held low moderately sophisticated beliefs about the nature of knowing and learning science (2.511). This average score suggests an early multiplist view of the nature of knowing and learning science. Here the participants are beginning to recognize diversity and uncertainty is possible and truth is knowable. However, the participants scored slightly higher in real-life applicability of science (2.665) moving toward the mid-range of moderately sophisticated beliefs or multiplicity. The highest initial average score was in the source of ability to learn science

(2.896) which lies at the high end of the moderately sophisticated beliefs range or multiplicity. Here participants are inclined to believe that there are no absolute answers and all views are equally valid and that each individual has a right to his or her own opinion. The distribution of average scores within each epistemological dimension corresponds with Schommer (1994) and Hofer and Pintrich (1997) views that beliefs are better described in terms of distributions rather than a single point along a continuum as described in the uni-dimensional models (Baxter Magolda, 1986, Belenky, et al., 1986; King & Kitchener, 1994; Kuhn, 1991; Perry, 1970).

Participants' initial scores on the Nature of Scientific Knowledge Scale, NSKS, (Rubba & Anderson, 1978) represent a range of beliefs from realist to instrumentalist with the majority falling into the neutral range (141-147). No participants scored at the high end of the scale (240) of accepted views of the nature of science (NOS) meaning that there were no participants at the beginning of the semester course that held a high level of NOS beliefs theorized in the NOS model (Abd-El-Khalick & Lederman, 1998; Lederman, Wade & Bell, 1998; Ryder, Leach & Driver, 1999). A majority of the participants' initial scores fell in the neutral and high range of relativist. According to Hogan (2000), students have mixed views about the NOS suggesting that some indicate a view of science as dynamic while others indicate a view of science as static.

Learners at many age levels seem to understand that scientific knowledge changes but tend to see change as a “right” idea replacing a “wrong” one. However, they do not believe that theories as a whole change (Driver et al., 1996; Khishfe & Abd-El-Khalick, 2002; Lederman & O'Malley, 1990; Linn & Songer, 1993). Learners do not recognize these theoretical changes and view scientific knowledge as trouble-free and providing right answers (Carey et al., 1989; Driver et al., 1996). Students believe that getting the “right” answer relies on proper implementation of the scientific method

(Hogan, 1999; Linn & Songer, 1993; Millwood & Sandavol, 2004).

Changes in NOS Beliefs

RQ1a. Do students' images of the nature of chemistry (NOS) change by the completion of a semester general chemistry laboratory course?

Participants' final scores on the Nature of Scientific Knowledge Scale, NSKS, (Rubba & Anderson, 1978) represent a range of beliefs from a "high-end" realist to a "low-end" instrumentalist with the majority of the participants falling into the "low-end" of the instrumentalist (148.375) range. This suggests that some of the participants moved toward the acceptance of NOS views during the course of the semester. Within each dimension shifts from realist views (non acceptance of NOS views) to neutral views (acceptance of some NOS views) and instrumentalist views (acceptance of NOS views) occurred. For this study the desired shift for the participants was towards the instrumentalist views. As shown in Table 39 there was an overall improvement towards the acceptance of NOS views by the end of the semester course.

Table 39 NSKS Percent Change

Dimension	R Pre	R Post	R Δ	N Pre	N Post	N Δ	I Pre	I Post	I Δ
Amoral	54%	37%	-17	16%	20%	+4	30%	43%	+13
Creative	53%	47%	-6	20%	23%	+3	27%	30%	+3
Developmental	46%	21%	-25	16%	22%	+6	38%	57%	+19
Parsimonious	34%	7%	-27	23%	14%	-9	43%	79%	+36
Testable	27%	13%	-14	23%	30%	+7	50%	57%	+7
Unified	39%	28%	-11	38%	29%	-9	23%	43%	+20

*R Pre = Realist Pre; R Post = Realist Post; R Change =Realist Change
*N Pre = Neutral Pre; N Post = Neutral Post; N Change = Neutral Change
*I Pre = Instrumentalist Pre; I Post = Instrumentalist Post; I Change = Instrumentalist Change

The study shows that some participants became more accepting of NOS views for the dimensions related to the importance of experimental tests and observations, the tentativeness of scientific knowledge, the simplicity of scientific knowledge, and the unity of nature on the NSKS. As shown in Table 39 most participants in this study had limited problems with the acceptance of NOS views for the parsimonious dimension of the NSKS that scientific knowledge tends toward simplicity (79%). Some of the participants realized the importance of experimental tests and\or observations, that scientific knowledge is tentative, and the unity of nature on the NSKS. For example, 78% of the students understood that scientific laws, theories, and concepts should be stated as simply as possible. Additionally, the NSKS dimension of developmental states that scientific knowledge is never “proven” and changes over time. Fifty-seven percent of the participants agreed that today’s scientific laws, theories, and concepts may have to be changed in the face of new evidence. Seventy-nine percent of the participants thought that scientific knowledge needs be capable of experimental testing.

Many participants in this study agreed with the model on the testable and unified nature of scientific knowledge. They believe that scientific knowledge must be subject to testing and the interaction of the various disciplines of science contributes to the overall understanding of the nature of science.

However, many participants were confused on the amoral, creative, and unified levels of the NOS on the NSKS. Within the dimension of amoral, participants final scores reflected a minimal change from the “high-end” of realist to the neutral range. By the end of the semester course 43% of the participants reported that even if the applications of a scientific theory are judged to be bad, we should not judge the theory itself. This result shows that some of the participants seem to realize the difference between scientific theory itself and the applications of the theory. However, the participants thought that moral judgment needs to be placed on both the applications of scientific knowledge and the knowledge itself. This suggests that many of the participants did not understand that the cause of some mistakes is not because of scientific knowledge, but how humans make use of scientific knowledge. That may be why 37% of the participants indicated that certain pieces of scientific knowledge are good and others are bad. This result suggests that the participants could not clearly distinguish between scientific knowledge and the applications of scientific knowledge in moral judgment.

The creative dimension involves the aspect that scientific knowledge is a product of the human intellect and is a tenet scientists want students to believe. Only 30% of the participants in this study believed that scientific knowledge expresses the creativity of scientists and represents imaginative thoughts, whereas almost one half of the participants (47%) thought that “scientific theories are discovered, not created by man”. Two possible answers probably can shed some light on this controversial problem. First, these participants believed that scientific theories are not created by man; and the theories are just discovered by man. In this view, participants thought that scientific theories are already there and are just waiting for man to discover. Second, these participants may not realize the difference between creativity and discovery. In this view, the problem will be related to meanings of words, not related to knowledge of the NOS. Lederman (1992) stresses that even though scientific knowledge is at least partially based on and/or derived from observations of natural world; it involves human imagination and creativity. He stated that science involves the invention of explanation, which requires a great deal of creativity.

The unified dimension of the NSKS is the belief that scientific knowledge is born out of an effort to understand the unity of nature. That the knowledge produced by biology, chemistry, and physics contributes to a network of laws, theories and concepts. Forty-three percent of the participants indicated that there are similarities among biology, chemistry, and physics.

According to Lederman (1992) references to the NOS as part of a science curriculum topic have appeared throughout the 20" century. However, increased emphasis in this area began in the 1960s culminating in the inclusion of the nature of science as a key topic in the scientific literacy curriculum focus that has predominated over the last 20 years.

The inclusion of the measure of participants' understanding of the NOS was included primarily because of the view that students often do not have an adequate understanding of the NOS, which is a critical component for scientific literacy (Lederman et al., 2002; Schwartz & Crawford, 2003) and success in the science fields. It is also a small component of the major research focus of epistemological beliefs. The EBAPS variables structure of knowledge and evolving knowledge presented some questions related to NOS (see Appendix N). The influence of NOS on student's epistemological beliefs as related to science and learning science needs to be investigated further.

Changes in Personal Epistemological Beliefs

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change, if any, by the completion of a semester general chemistry laboratory course?

Participants' final scores on the Epistemological Beliefs Assessment for Physical Science (EBAPS) represent a range of beliefs from unsophisticated to extremely sophisticated with the majority still falling into the moderately sophisticated range (2.4-2.9) at the end of the semester course. One participant scored in the top sophistication level, extremely sophisticated, while several moved from moderately sophisticated to highly sophisticated by the end of the course. This adds support to the research on epistemological beliefs theorized in the models (Perry, 1970; Baxter-Magolda, 1986; Schommer, 1990; Hofer & Pintrich, 1997) that some change in beliefs occurs as learners interact with the educational environment and respond to new learning experiences by either integrating to their existing cognitive frameworks or accommodating the framework itself. This suggests that change is brought about through cognitive disequilibrium. However, in this study cognitive disequilibrium was not directly monitored. Therefore, as learners with naïve personal epistemological beliefs encounter complex and uncertain information as presented in higher education courses in science these complexities and uncertainties bring about a change that results in a maturing of their epistemological beliefs. Therefore the learner will move from a dualistic level (1-2) to hopefully at a minimum the beginnings of a relativistic level (5-6) by their senior year of college.

Most of the participant's final EBAPS scores fell in the range of early to late multiplicity (levels 3-4) in Perry's model and in the transitional knowing range of Baxter Magolda's model. The average EBAPS overall score of 2.771 would place the participants in the middle of the multiplicity stage or transitional knowing stage of epistemological development. This gives some support to findings that students depending on their year in college and other factors such as age and gender will progress in a positive manner toward higher epistemological beliefs at different rates (Perry, 1970; Baxter Magolda, 1986; Moore, 2002). As in Perry's study not all the participants in this study began in the dualistic stage nor did all the participants improve in their beliefs. This is due in part to the shortness of the study over the course of a semester where many of the studies discussed were over longer periods of time.

The results of the study support a final personal epistemological belief range (1.28-3.55) of unsophisticated to extremely sophisticated by the end of the semester course with the majority of the participants falling in the mid to upper range of moderately sophisticated beliefs (2.771) or multiplicity. Participants at the higher end of level 3, multiplicity or transitional knowing make the departure from looking for certainty from an authority figure to accepting that some things in science will never be known and that one's own opinion is important. According to Moore (2002), the beginning of participant ownership of ideas and knowledge emerge.

The EBAPS measured the participants' end of course beliefs in five dimensions: structure of scientific knowledge, nature of knowing and learning science, real-life applicability of science, evolving scientific knowledge, and the source of ability to learn science. The participants moved from naïve beliefs about the structure of scientific knowledge (2.172) to more moderately sophisticated beliefs (2.488) during the course of the semester. This move from a dualistic view to one of multiplicity suggests that some growth occurred in participants' views that the structure of scientific knowledge is an accumulation of concrete, discrete facts to viewing it as an interrelated network of strongly connected and highly structured concepts.

At the beginning of the semester course participants held low moderately sophisticated beliefs about the nature of knowing and learning science (2.511) whereas by the end of the semester their beliefs had moved slightly (2.760) into holding mid-range moderately sophisticated beliefs. This final average score suggests a move towards holding a mid-range multiplist view of the nature of knowing and learning science meaning that the participants are beginning to recognize diversity and uncertainty is possible and truth is knowable.

The participants' scored slightly higher in real-life applicability of science (2.978) moving toward the high range of moderately sophisticated beliefs or multiplicity. Students moved from accepting diversity and uncertainty as legitimate but temporary to believing that all views are equally valid and shifts to self as an active maker of meaning.

The greatest increase from initial to post scores was seen in the dimension of evolving knowledge in science (2.804). For some of the participants the degree to which they viewed scientific knowledge as fixed (set in stone) or fluid (tentative) changed during the course of the semester. This change suggests that some participants began to view scientific knowledge as approximate, tentative, refutable rather than absolute, exact, and final.

Once again the highest final average score was in the source of ability to learn science (3.107) which places some of the participants at the low end of the highly sophisticated beliefs range. This average score models Perry's (1970) position involving relativism and Baxter Magolda's (1986) position of independent knowing. Here participants are inclined to take more responsibility for their own learning rather than relying heavily on authority and acknowledge that some viewpoints are more valid than others. This move from multiplism or transitional knowing to relativism or independent knowing is considered a significant development in an individual's epistemological beliefs (Moore, 2002).

As stated earlier the distribution of average final scores within each epistemological dimension corresponds with Schommer (1994) and Hofer and Pintrich (1997) views that beliefs are better described in terms of distributions rather than a single point along a continuum as described in the uni-dimensional models (Baxter Magolda, 1986, Belenky, et al., 1986; King & Kitchener, 1994; Kuhn, 1991; Perry, 1970).

Summary

This chapter presented and discussed the quantitative findings related to research question-1 and sub-questions 1a and 1-b concerning the range of personal epistemological and NOS beliefs at the beginning of the semester chemistry laboratory course and the change, if any, in the range of both beliefs at the end of the semester course.

There was a 5.8% average increase in the overall NSKS participant scores by the end of the semester course. The average NSKS score was 142 at the beginning of the semester placing more of the participants on the relativist end of the NSKS scale holding non NOS views. However, by the end of the semester the average NSKS score was 148 placing more of the participants on the instrumentalist end of the NSKS scale holding NOS views. Three categories of NOS beliefs as indicated on the NSKS showed the highest improvement within the group of participants. The greatest improvement in scores was seen in the variables parsimonious, unified, and developmental. The participants presented higher levels of mature beliefs within the variables of parsimonious, developmental, and testable. The participants presented higher levels of mature beliefs within the variables of parsimonious, developmental, and testable.

There was a 6.4% average increase in the overall EBAPS participant scores by the end of the semester course. The average EBAPS score was 2.514 at the beginning of the semester placing more of the participants in the moderately-poor sophistication level of epistemological beliefs. However, by the end of the semester the average EBAPS score was 2.771 placing more of the participants in the moderately-highly sophistication level of epistemological beliefs. Three categories of the EBAPS evaluating epistemological beliefs showed the highest improvement within the group of participants. The greatest improvement in scores was seen in the variables evolving knowledge, structure of knowledge, and real-life applicability. The participants presented higher levels of mature beliefs within the variables of source of ability to learn, evolving knowledge, and real-life applicability.

The next chapter presents a description of the development of the participants' personal epistemological beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-b. The characterization of personal epistemological beliefs and any changes in those beliefs that may have resulted with analyses of the participants' responses to interview probes will be presented. The combination of interviews and quantitative measures will provide a glimpse into participants' epistemological beliefs changes during the course of a semester and what the participants' believed influenced their beliefs.

Chapter Five: Development of Epistemological Beliefs

Introduction

Chapter five presents a description of the development of the participant's personal epistemological beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-b. The characterization of the participants' personal epistemological beliefs as related to science is discussed with the use of the participant's responses to interview probes. The combination of the interviews and the quantitative measures previously discussed in chapter four will provide a glimpse into the participants' personal epistemological belief changes during the course of the semester.

Because the major objective of this research was to determine if students' personal epistemological beliefs change over the course of a semester in a laboratory instructional setting, the next step looks closely at the epistemological data. These descriptions will be generated from the pre and post EBAPS test data and more importantly the participants' responses during the initial and final interviews. The results are discussed and related back to the key personal epistemological beliefs literature.

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological belief changes in light of specific science laboratory instructional features for future research.

Method of Analysis

This analysis was conducted in a multi-layered, multi-stage process, through reading, and sorting participants' responses to epistemological questions, both general in nature and specific to the course. The analyses below are organized by the EBAPS dimensions (axes): structure of knowledge, nature of knowing and learning, real-life applicability, evolving knowledge, and source of ability to learn. The aforementioned dimensions (axes) served as the major theme codes giving a framework from which first-order themes originally derived from the participants' verbatim quotations or raw data themes could be analyzed. Within each dimension (axis), the responses to interview and reflective questions regarding personal epistemological beliefs at the beginning and end of the semester are presented. The intent of this analysis is to expand the theoretical understanding of the dimensions (axes) of personal epistemology in science and the continuum of beliefs, as expressed in context. Illustrative quotes have been selected from the interviewed participants as representative of the range of beliefs along the continuum. Table 40 presents a demographic overview of the interview participants with their participation identification number. Quotes are identified with the letters ST followed by the participants' identification number (Table 40). The final interview quotes follow the initial interview quotes (In) and are identified in bold text and coded with the letter F.

Table 40 Demographic Statistics of Interview Participants

ID	Sex	Age	Major	College Year
1	F	19	Pre-Pharmacy	Fr
2	F	21	Psychology	So
3	F	21	Biomedical Science	Jr
4	M	24	Electrical Engineering	So
5	M	22	Environmental Science	Jr
6	F	27	Marine Science	None
7	F	20	Biomedical Sciences	Jr
8	M	18	Undeclared	Fr
9	F	18	Environmental Science	Fr
10	F	20	Environmental Science	So
11	F	19	Nursing	Fr
12	F	18	Undecided	Fr
13	F	18	Pre-Pharmacy	Fr
14	F	19	Pre-Pharmacy	Fr
15	F	20	Biology	So
16	F	18	Environmental Science	Fr
17	F	24	Physical Ed	Jr
18	F	20	Athletic Training	Jr
19	F	19	Biomedical Sciences	So
20	F	45	Masters Nursing	None

The main research questions that guided this portion of the study were:

RQ1. What range of personal epistemological beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

Summary of EBAPS Overall Scores

Using the overall scores on the EBAPS (Table 41) discussed in chapter four to measure relative increases or decreases in epistemological understandings, the results show forty-five participants increased their total scores while ten participants' scores decreased by the end of the semester course. One participant's score remained unchanged from the pre-test to the post-test. The total overall mean score between the pre-test and the post-test resulted in an average increase of 0.26 (6.5 points).

What is clear is that several of the participants' overall scores did show some improvement in epistemological beliefs by the end of the semester course. Nineteen of the fifty-six participants improved their EBAPS scores by 6.5 points or less (0.26), while twenty-five improved their score by more than 6.5 points (8-35 points; 0.32-1.40). Therefore, 79% of the participants improved their EBAPS scores. The remaining twelve either had no change in their score or lost points. Whether this lack of improvement was in any way influenced by laboratory instruction or outside factors will be presented later in chapter seven.

Table 41 Descriptive Statistics - EBAPS Scores – All Participants

Dimension	Pre-Mean Score N=56	Pre-Mean Score N=20	Post-Mean Score N=56	Post-Mean Score N=20
Structure of Knowledge (A-1)	2.172	2.090	2.488	2.512
Nature of Knowing & Learning (A-2)	2.511	2.569	2.760	2.935
Real-life (A-3) Applicability	2.665	2.788	2.978	3.138
Evolving (A-4) Knowledge	2.357	2.150	2.804	2.783
Source of Ability to Learn (A-5)	2.896	3.000	3.107	3.210
Overall Score	2.514	2.537	2.771	2.867

Summary of EBAPS Interview Scores

As for the interview participants (N=20), 85% improved their EBAPS score by the end of the semester (Table 42). Eight participants improved their scores by 6.5 points (0.26) or less, while another nine improved their scores by more than 6.5 points (0.35-1.40; 9-35 points). Three of the interview participants showed no overall gain in their scores. As stated earlier whether the improvements or lack of improvements were in any way influenced by laboratory instruction or other possible factors will be presented later in chapter seven.

Student five had the lowest overall EBAPS pretest score of 1.88 (47), followed by student 10 (2.05; 51). Although 85% of the interview participants showed an increase in total EBAPS scores, student ten had the largest total score increase (1.40; 35) for the entire population sample (see Table 42). Student ten improved her sophistication in all five dimensions of the EBAPS. Student five put forth great effort to gain understanding during instruction but showed only a small quantitative increase in overall epistemological sophistication, as measured in the EBAPS pre-test to the post-test.

Student 16s pre- and post-test scores were the highest of the interview participants (2.85 (71); 3.55 (89), respectively). This was an above average increase of 17.5 points (0.70) suggesting a marked improvement in the sophistication of her epistemological beliefs. In addition students 1, 6, 8, 14, 15 all improved their epistemological beliefs scoring in the highly sophisticated level by the end of the semester course. This marked improvement supports the basic theory of the epistemological belief models discussed in chapter two that some students undergo a developmental progression in their epistemological beliefs (Perry, 1970; Belenky et al., 1986; King & Kitchener, 2002; Baxter Magolda, 2002; Kuhn, 1991; Schommer-Aikins, 1990; & Hofer & Pintrich, 1997).

Table 42 Descriptive EBAPS Statistics - Interview Participants

ID	Gender	CCI	EBAPS Pre	EBAPS Post	Difference
1	F	72	2.70	3.13	0.43***
2	F	76	2.35	2.55	0.20**
3	F	81	2.38	2.97	0.59***
4	M	67	2.70	2.62	-0.08*
5	M	86	1.88	2.08	0.20**
6	F	63	2.37	3.12	0.75***
7	F	63	2.32	2.77	0.45***
8	M	72	2.83	3.22	0.39***
9	F	45	2.53	2.60	0.07**
10	F	72	2.05	3.45	1.40***
11	F	58	2.80	2.98	0.18**
12	F	63	2.63	2.78	0.15**
13	F	49	2.63	2.48	-0.15*
14	F	65	2.48	3.02	0.54***
15	F	76	2.98	3.12	0.14**
16	F	77	2.85	3.55	0.70***
17	F	65	2.50	2.45	-0.05*
18	F	76	2.63	2.77	0.14**
19	F	67	2.52	2.87	0.35***
20	F	58	2.65	2.80	0.15**

* decrease in score
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

Characterization of Epistemological Beliefs

Although the EBAPS assessment serves the purpose of finding out if, and in what categories, students beliefs are changing, we needed a way to explore how these beliefs changed during the semester. Using a set of probe questions initial and final interviews were conducted to ascertain if at all, whether participant epistemological beliefs changed during the semester of laboratory instruction.

Key areas that appeared to provide opportunities for participants to make inferences about their beliefs included the initial and final interviews. The initial interviews lasted approximately 15 – 20 minutes and focused on the five dimensions (axes) of the EBAPS and four of the NSKS dimensions to be discussed in chapter 6.

The final interviews lasted 30-45 minutes and focused on EBAPS beliefs discussed in chapters 4 and 5, NOS beliefs discussed in chapters 4 and 6, the EBAPS dimensions in relation to the instructional features/practices discussed in chapter 7, and general NOS beliefs in relation to the instructional features/practices discussed in chapter 7. The following discussion will present an overview of the responses by the interview participants to the personal epistemological beliefs probes during the initial and final interviews. The discussion is organized with the use of the five EBAPS dimensions.

Initial and Final Epistemological Beliefs Interviews

During the initial and final interviews, five questions related to the multi-dimensional axes of the EBAPS: structure of scientific knowledge, nature of knowing and learning science, real-life applicability of science, evolving scientific knowledge, and source of ability to learn science were used to probe the participants (Appendices B & N). These were designed to investigate the participant's epistemological beliefs.

The interview participants were asked to elaborate on the questions in order to invoke the participant's thoughts about the EBAPS variables. The questions themselves were meant to look at different areas of epistemological beliefs within the EBAPS. According to Wood and Kardash (2000) one must be aware of the interconnectedness of epistemological beliefs and the placement of questions into specific categories based on the assessment tool implemented. The interconnectedness of the variables of epistemological beliefs is established by the answers of the interview participants. These answers can often display different epistemological categories within one question. This suggests that one cannot fully isolate these variables and only search for evidence in the participants' reflections and interviews.

This study investigated the change from the beginning to the end of the semester within each of the five categories of epistemological beliefs identified in the EBAPS. First the overall participant scores were compared to those of the interview subjects. After a comparison between interview subjects and the overall class based on quantitative scores, an attempt was made to briefly look at what might have changed using the qualitative data from the interviews based on the epistemological beliefs within each variable.

Responses to the Personal Epistemological Beliefs Probes

On the subsequent pages portions of the initial and final interview responses are presented and discussed concerning the participants epistemological beliefs. The interview probes were designed using the EBAPS variables discussed in previous chapters. Each variable interview probe will be presented and discussed separately.

Structure of Scientific Knowledge

In the current literature on personal epistemology the dimension, structure of scientific knowledge is viewed as operating on a continuum that ranges from viewing scientific knowledge as an accumulation of concrete, discrete, knowable facts without much structure to viewing it as an interrelated network of strongly connected and highly structured concepts that are contextual, contingent, and relative.

Within this dimension the overall participant (N=56) pre-test mean was 2.172 (54.3) while the post-test mean was 2.488 (62.2) (see Table 41) with 36 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 2.090 (52.2) and 2.512 (62.8), respectively with 16 participants improving their score. This was also a category that quantitatively shows an above average (> 0.32 or 7.9 points) increase in 30 of the 56 participants, and 10 of the 20 interviewed participants' scores. The gain on the "structure of knowledge" dimension is an indicator that some participants are moving away from a view of science as disconnected facts to one of science as a coherent body of knowledge.

Although increases were observed quantitatively (Table 43) with a majority of the interview participants, the difference in their understandings is best reflected in their initial and final interview responses in Table 44. In order to query participants, understanding of the structure of scientific knowledge, the interview question asked whether science (chemistry) was a weakly connected subject without much structure or a strongly connected and highly structured subject. Although initially the majority of the interviewed participants believed that science was a strongly connected and highly structured subject (ST 2, 3, 6, 8, 10, 12, 15-17, and 20) several also felt science consisted mainly of learning facts and formulas (ST 7 and 14). Several participants initially indicated they believed that the structure of scientific knowledge was a combination with structure and involved many facts and formulas (ST 1, 4-5, 9, 11, 13, 18, and 19).

When comparing participants' initial interview comments with their initial EBAPS scores for the structure of scientific knowledge several mirror each other. For instance participants 1, 4, 7, 11, and 14 had initial scores in the poorly sophisticated range and reflected that range in their interview statements that science (chemistry) is a lot of facts and formulas. While participants 3, 15, 16, and 18 all had initial scores in the moderately sophisticated range and reflected that range in their interview statements that science (chemistry) was strongly connected and highly structured. Therefore, the majority of the participants' EBAPS scores were supported by their initial interview statements.

Table 43 EBAPS - Structure of Knowledge Pre-Post Statistics

ID	Pre	Post	Difference
1	2.30	2.80	0.50***
2	1.80	2.05	0.25**
3	2.90	2.95	0.05**
4	2.20	1.85	-0.35*
5	1.20	1.90	0.70***
6	1.95	2.95	1.00***
7	1.65	1.80	0.15**
8	2.25	3.10	0.85***
9	2.00	1.95	-0.05*
10	2.00	3.50	1.50***
11	2.10	2.95	0.85***
12	1.95	2.60	0.65***
13	1.65	1.65	0.00*
14	1.75	2.05	0.30***
15	2.50	2.90	0.40***
16	2.65	3.40	0.75***
17	2.00	2.60	0.60***
18	2.50	2.15	-0.35*
19	1.85	2.40	0.55***
20	2.60	2.70	0.10**

* decrease in score
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

The final interviews reflect a shift in a few of the participants' beliefs. At the beginning of the semester course 10 of the 20 interviewed participants believed that science was a strongly connected and highly structured subject (ST 2, 3, 6, 8, 10, 12, 15-17, and 20). By the end of the course approximately 17 of the participants held the belief that science is strongly connected and highly structured (ST 1-4, 6-13, and 16-20) while none of the participants felt science consisted mainly of learning facts and formulas. Several participants still indicated they believed that the structure of scientific knowledge was a combination with structure and involved many facts and formulas (ST 5 and 15).

When comparing participants' final interview comments with their final EBAPS scores (Table 43) for the structure of scientific knowledge the majority of the participants' scores and interview comments mirror each other while others present opposite views. For instance participants 2, 4-5, 7, 9, 13-14, and 18 had final EBAPS scores at the high end of poorly sophisticated range closer to the moderated sophisticated range. However, the majority of the aforementioned participants reflected moderate beliefs in their final interview statements as shown in Table 44. The majority of the aforementioned participants stated that they believed science to be strongly connected and highly structured. This difference could be attributed to several factors such as: distracted during the administration of the EBAPS resulting in incorrect bubbling of answer choice or interpretation of the EBAPS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester. While participants 12, 17, and 19 all had final scores in the moderately sophisticated range and reflected that range or higher in their final interview statements that science (chemistry) was strongly connected and highly structured. Participants 1, 3, 6, 8, 10-11, 15-16, and 20 final EBAPS score reflected a moderately high to high epistemological belief that science is highly structured and strongly connected. All of the aforementioned participants except participant 15 reflected that belief in their final interview. Participant 15 felt that scientific knowledge has gray areas where it can be weakly connected and strongly connected in others.

Table 44 Participants' Reflections – Structure Scientific Knowledge (N=20)

Initial and Final Epistemological Beliefs Interview Question-1
Structure of Scientific Knowledge – Science (chemistry) is a weakly connected subject consisting mainly of facts and formulas without much structure versus being a strongly connected and highly structured subject.
Quotation Comments
ST-1: "Mainly facts and formulas because everything has a reason for why it happens. i.e., chemical reactions. I would also say that it's coherent and highly structured. Almost everything in chemistry can be explained and applied." (In) **"I would say it's strongly connected and highly structured. It all works together." (F)**
ST-2: **"**I disagree. As I learn more chemistry I find the facts are connected. For instance the different types of characteristics in atoms and how they interact with each other to form new compounds. I believe chemistry can be understood. It Is highly structured." (In) **"Scientific knowledge is always changing but it is always connected. I think it is a combination. It is highly connected and structured but it allows for flexibility." (F)**
ST-3: "I don't think science is a bunch of weakly connected pieces. My view of chemistry is that it is a very specific science. That it has strong foundations, rules and practices. I think it has a lot of structure. The difficulty is becoming familiar and comfortable with it." (In) "**I definitely think it is strongly connected and highly structured." (F)**
ST-4: "Absorbing information yes, but also practicing mathematical skills to better understand given information. For instance stoichiometry and balancing, finding properties, etc all goes beyond just absorbing info. You definitely build upon your own individual knowledge base when studying sciences. Relating new experiences to old ones, and reflecting upon your own personal understanding is going on all the time." (In) **"I would say the latter, strongly connected and highly structured." (F)**
ST-5: **"**Yes, I do agree with all of this statement. All the facts and formulas in chemistry make more sense when they are connected. Chemistry is structured so that every thing fits like a puzzle." (In) **"I kind of fall in the middle because using formulas can involve absorbing while other concepts are actually truly structured." (F)**
ST-6: "I think everything in science connects. For instance the periodic table. I'd say it's highly structured." (In) **It's more toward that all sciences are connected and structured." (F)**
ST-7: "I agree, chemistry is a lot of work and memorization. There is a lot of formulas. Chemistry is a broad topic and refers to an abundance of information therefore it can not be placed in one category." (In) **"I think scientific knowledge is all connected. One just needs to understand the knowledge to see how it is connected." (F)**
ST- 8: "I disagree the knowledge of chemistry can be applied to many real life situations and is more than just facts and formulas. I would say chemistry knowledge is coherent and conceptual in the sense that it is all logically connected with basic concepts and ideas." **(In) "Strongly connected and highly structured." (F)**
ST- 9: "No. Although chemistry is mainly composed of facts and formulas, there is structure behind it based on proven facts and experiments. I believe that it is highly structured." (In) **"I think it's strongly connected and highly structured." (F)**

Continued on next page

Table 44 (Continued)

ST-10: "I disagree because I think it has as much structure as math. I think it is a pretty organized body of knowledge. I think it's just as important and just as unified as any other kind of science and I think it's probably the most important science being that it is the basis for anything else, including biology." (In) **"I say weakly connected without much structure is not something you normally think about as having to do with scientific knowledge, but in the beginning of any kind of scientific theory you don't really have all the pieces yet, so it would be weakly connected without much structure because it's something that hasn't been completely explored." (F)**
ST-11: "Chemistry is much more than weakly connected pieces, although it has facts and formulas. There are many experiments that have taken place to support theories that are now helping us to improve things in the world i.e. technology. Chemistry is a combination, it is based on certain concepts but it is a unified whole knowledge." (In) **"Strongly connected and highly structured." (F)**
ST-12: "I think that when you go through the textbook it seems that science is mainly facts and formulas. However, when you perform the labs you see a lot more about how everything in science is tied together. I think it is a whole knowledge and unified knowledge because the concepts interrelate." (In) **"All science is connected so it's strongly connected and highly structured." (F)**
ST-13: "I think that chemistry knowledge is more about understanding how chemistry works. It is a lot about facts and formulas but its more in depth than that. Chemistry is highly structured and conceptual in some aspects." (In) **"I think it's strongly connected and highly structured." (F)**
ST-14: "I don't think that it is weakly connected but I do believe that chemistry, to me, looks like facts and formulas. I am far from seeing the big picture. Highly structured knowledge, it seems like there is a detailed explanation for every formula or equation." (In) **"I fall in the middle. However I think it's more toward being strongly connected and highly structured." (F)**
ST-15: "No, I believe it is a very structured science with a lot to learn and understand besides memorizing facts and formulas. Highly structured, because you have to learn everything in steps to understand chemistry as a whole. I think science is easier to understand when it is highly structured." (In) **"I think there were some gray areas where it was weakly connected and other areas where it was strongly connected and highly structured especially during laboratory activities." (F)**
ST-16: "I would say no because chemistry is actually very based on theories. It's not weakly connected. It's all interrelated. And, it has a lot of structure. It's theoretical and it is a unified whole knowledge as it is all interrelated." (In) **"Strongly connected and highly structured." (F)**
ST-17: "No, I have used chemistry in a lot of my other classes, mostly biochemistry. But you need to have the basic understanding of chemistry to understand that, and the roles that chemistry plays in our lives. I see how it relates to other concepts and sciences. I guess that is the "whole knowledge, unified" part to me." (In) **"More structured and connected." (F)**
ST-18: "Well, from what I've learned so far in chemistry everything is connected. Yes, it is facts and formulas, but it is more conceptual. It's understanding how it works, analyzing things as well. Well, I agree to this comment because it is highly structured, but yet there is room for interpretation." (In) **"I would say strongly connected and highly structured." (F)**

Continued on next page

Table 44 (Continued)

ST-17: "No, I have used chemistry in a lot of my other classes, mostly biochemistry. But you need to have the basic understanding of chemistry to understand that, and the roles that chemistry plays in our lives. I see how it relates to other concepts and sciences. I guess that is the "whole knowledge, unified" part to me." (In) **"More structured and connected." (F)**
ST-18: "Well, from what I've learned so far in chemistry everything is connected. Yes, it is facts and formulas, but it is more conceptual. It's understanding how it works, analyzing things as well. Well, I agree to this comment because it is highly structured, but yet there is room for interpretation." (In) **"I would say strongly connected and highly structured." (F)**
ST-19: "I believe that there is much more to chemistry and that everything does connect in some way. The facts and formulas help to explain why things happen the way they do. I do believe that chemistry knowledge is a unified whole science." (In) **"I think it's definitely strongly connected and highly structured." (F)**
ST- 20: "I strongly disagree with that. I think it is based on a bunch of very painstakingly researched much interconnected data. I think it is painstakingly structured with many facts and formulas that are difficult to keep track of. I agree with most of the statement. I think there is still a lot of theory out there that needs further unification. There is a lot of long standing knowledge that has been verified for years." (In) **"I lean toward it being strongly connected and highly structured." (F)**

Nature of Knowing and Learning Science

In the current literature on personal epistemology the dimension, nature of knowing and learning science is viewed as operating on a continuum that ranges from viewing that learning science as consisting mainly of absorbing information such as facts to relying on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, knowledge, and intuitions, and by reflecting upon and monitoring one's understanding.

Within this dimension the overall participant (N=56) pre-test mean was 2.511 (62.8) while the post-test mean was 2.760 (69.0) (see Table 41) with 30 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 2.569 (64.2) and 2.935 (73.4), respectively with 14 participants improving their score. This category that quantitatively shows an average (> 0.25 or 6.2 points) increase in 28 of the 56 participants, and 12 of the 20 interviewed participants' scores. The gain on the "nature of knowing and learning science" dimension is an indicator that some participants are moving away from a view that learning science is just about absorbing information and learning facts to one of constructing one's own knowledge by using prior knowledge, experiences, and intuition in order to reflect upon and monitor one's own understanding.

Although increases were observed quantitatively (Table 45) with a majority of the interview participants, the difference in their understandings is best reflected in the interview responses in Table 46. In order to query participants, understanding of the nature of knowing and learning science, the initial interview question asked whether learning science (chemistry) consisted mainly of absorbing information or that learning science relies on constructing one's own understanding, working actively through the material, relating new material to prior experiences and/or intuitions and/or knowledge, and reflecting upon and monitoring one's understanding. The majority of the interviewed participants believed that the nature of scientific knowledge was a combination of absorbing information as well as constructing one's own knowledge (ST 1, 3-6, 8-12, 14, 17, and 19-20). Several felt the nature of scientific knowledge consisted mainly of absorbing information (ST 7 and18) while the remaining participants (ST 2, 13, and 15-16) indicated they believed that the nature of scientific knowledge was a result of constructing one's own knowledge through connecting prior experiences with new learning experiences.

When comparing participants' initial interview comments with their initial EBAPS scores (Table 45) for the nature of scientific knowledge some of the initial scores for this axis are mirrored in the participants' initial interview comments while others were not. For instance participants 1, 3, 6, 8-12, 17, and 19-20, all had initial scores in the moderately sophisticated range and reflected that range in their interview statements that the nature of scientific knowledge was a combination of absorbing information as well as constructing one's own knowledge. While participants 15 and 16 both had initial scores at the high end of the moderately sophisticated range they reflected highly sophisticated views in their initial interview stating that the nature of scientific knowledge was a result of constructing one's own knowledge through connecting prior experiences with new learning experiences. Even though participants 7 and 18 scored in the moderately sophisticated belief range their comments in the initial interview reflected the belief that the nature of scientific knowledge involved mainly absorbing material.

Table 45 EBAPS - Nature of Knowledge – Pre-Post Statistics

ID	Pre	Post	Difference
1	2.813	3.375	0.562***
2	2.375	2.813	0.438***
3	2.438	3.313	0.875***
4	3.063	2.938	-0.125*
5	1.563	1.813	0.250**
6	2.438	2.938	0.500***
7	2.375	2.813	0.438***
8	2.813	2.813	0.000*
9	2.813	2.750	-0.063*
10	2.438	3.938	1.50***
11	2.813	2.938	0.125**
12	2.688	2.500	-0.188*
13	3.000	2.438	-0.562*
14	2.063	3.188	1.125***
15	2.813	3.438	0.625***
16	2.813	3.563	0.750***
17	2.500	1.750	-0.750*
18	2.438	3.563	1.125***
19	2.813	3.130	0.317***
20	2.313	2.688	0.375**

* decrease in score or no change
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

By the end of the semester course the majority of the interviewed participants continued to hold the belief that the nature of scientific knowledge was a combination of absorbing information as well as constructing one's own knowledge (ST 5, 8-9, 12-14, 17, and 19-20). Two participants expressed the belief that the nature of scientific knowledge consisted mainly of absorbing information (ST 18 and 20) while the remaining participants (ST 1-4, 6-7, 10-11 and 15-16) indicated they believed that the nature of scientific knowledge was a result of constructing one's own knowledge through connecting prior experiences with new learning experiences.

When comparing participants' final interview comments with their final EBAPS (Table 45) scores for the nature of scientific knowledge once again some of the final scores for this axis are mirrored in the participants' final interview comments while others were not. For instance participants 8-9 and 12-13, had final EBAPS scores in the moderately sophisticated range and reflected that range in their interview statements that the nature of scientific knowledge was a combination of absorbing information as well as constructing one's own knowledge. While participants 2 and 7 both had final EBAPS scores at the high end of the moderately sophisticated range they reflected highly sophisticated views in their final interview stating that the nature of scientific knowledge was a result of constructing one's own knowledge through connecting prior experiences with new learning experiences. Even though participant 20 scored in the moderately sophisticated belief range her comments in the final interview reflected the belief that the nature of scientific knowledge involved mainly absorbing material. Participants 1, 3-4, 6, 10-11, and 15-16 final scores were in the highly sophisticated range reflecting their final interview belief that the nature of scientific knowledge involved constructing one's own knowledge. The final EBAPS scores of participants 5 and 17 suggested that the nature of scientific knowledge mainly involved absorbing facts and formulas. However their final interview comments suggested they believed the nature of scientific knowledge was a combination of absorbing information as well as constructing one's own knowledge.

This difference could be attributed to several factors such as: distracted during the administration of the EBAPS resulting in incorrect bubbling of answer choice or interpretation of the EBAPS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester. A major difference in the EBAPS score and final interview comments were reflected in participants 18 and 20. Even though their final EBAPS scores reflected moderately to highly sophisticated beliefs respectively about the nature of scientific knowledge their final interview comments suggested otherwise. Both participants believed that the nature of scientific knowledge leaned more towards consisting of absorbing and memorizing information and facts.

Table 46 Participants' Reflections – Nature of Knowing-Learning (N=20)

Initial and Final Epistemological Beliefs Interview Question-2
Nature of Knowing and Learning Science- Learning science (chemistry) consist mainly of absorbing information or learning science relies on constructing one's own understanding, working actively through the material, relating new material to prior experiences/intuitions/knowledge, and reflecting upon and monitoring one's understanding.
Quotation Comments
ST-1: "No, I think it's a combination of absorbing information and applying it to real life. I think that's why labs help when learning chemistry. You need to see how chemistry works in the world by relating it to yourself. Also, you can only learn the material by thinking of it in your own terms." (In) **"It would be developing your own understanding. Everything in science is connected." (F)**
ST-2: "Not alone, you have to be able to apply what you learn. One can learn more with hands on than trying to beat it in your head by memorizing. Yes, you to find a way to translate chemistry into your own language so that you can learn and apply." (In) **"You can memorize all of you want but if you can't apply it you are going to struggle with chemistry." (F)**
ST-3: "Of course one has to absorb the information, but a key to learning science is being able to analyze the data and form conclusions. In addition, critical thinking is necessary. One has to absorb the information, analyze, reflect and draw conclusions so that it can be applied later on. I think that learning chemistry relies on understanding material and being able to relate it to other experiences. I would also say that it involves reflecting and monitoring understanding." (In) **"The least effective way for me to learn science is by absorbing or memorizing information in order to just remember facts. But by applying prior knowledge helped me to really understand." (F)**

Continued on next page

Table 46 (Continued)

ST- 4: "Absorbing information yes, but also practicing mathematical skills to better understand given information. It all goes beyond just absorbing information. You definitely build upon your own individual knowledge base when studying sciences. Relating new experiences to old ones, and reflecting upon your own personal understanding is going on all the time." (In) **"I would say constructing one's own knowledge." (F)**
ST-5: "No, I do not agree because it is not just absorbing the information. The information must be experienced in lab. It is more of a doing experience. " (In) **"I am probably in the middle again. Some things like the learning the chemical formulas would be constructing knowledge while learning to use the temperature probe involved absorbing information." (F)**
ST-6: "Yes and no. I mean, you have to absorb and memorize a large quantity of facts and formulas. However, you need to be able to apply it. So, it's not all just absorbing the material. But you're not going to know how to apply it unless you practice the concepts. You definitely have to work through the material." (In) **"I lean more toward relating new material to prior knowledge. You can learn memorize all of the material that you want but you may not be able to apply it. One needs to know how to think and solve problems versus just trying to memorize." (F)**
ST-7: "Yes, chemistry involves a lot of facts and formulas. A person must get past one problem in order to proceed to the next. In order to obtain the maximum of information one must do all of the following: one must know what they are studying, how to work through the problems and relate the information to other areas." (In) **"I think one has to construct one's own views to understand science. I think using real life experiences help to understand science." (F)**
ST-8: "Yes, but I also believe experiencing that information through laboratory work also plays a big role in learning chemistry. The relation of new material to past experiences and one's own knowledge and understanding of the subject is essential in the analysis and understanding of new found data." (In) **"A combination of absorbing information and constructing knowledge. One still needs to relate the new concepts to prior knowledge so you can combine the knowledge to construct understanding." (F)**
ST-9: "Yes. Because you will have to use that information later on as it never goes away. It always comes back to the basics in science. You have to build up your understanding and shape it. You also have to be able to analyze and understand each method." (In) **"I fall in the middle as I believe some people learn better by memorizing while another group understand better by like rewriting or rephrasing it in their mind." (F)**
ST-10: "I think in the beginning your probably absorbing information, but once you learn basic rules and how to apply them to chemistry then you can absorb less and apply more. Once you learn something and you understand it then you check yourself every time you apply it. You build knowledge as you learn different steps, it's like it's a building block." (In) **"You can only absorb and memorize so much. For instance in math and science you have building blocks. You have to understand an earlier concept to understand or move onto the next concept or formula. I think that you have to construct your own understanding by relating new material to prior knowledge, experiences and actively work with the new material." (F)**
ST-11: "True, but the information absorbed can be used to develop new concepts in the long run. You have to understand how to do conversions and learn the basics of chemistry in order to go any farther in the subject. Yes one works actively through the material so that it can be learned and used to gain further knowledge and if you relate new material to past experiences and knowledge you may then understand why something did not go right." (In) **"Constructing one's own knowledge helped with my learning." (F)**

Continued on next page

Table 46 (Continued)

ST-12: "I agree with that because you do have to memorize a lot of formulas and understand a lot of concepts and how to calculate. I think you have to create your own understanding but you can do that by working through the material. For instance you can read the book and create your own understanding of the text. In addition, when you perform the experiment you learn more through working with the material." (In) **"Well, learning science is connected to one's prior knowledge." (F)**
ST-13: "It is about learning and understanding the information. You have to develop your own understanding. You need to be able to reflect on everything you did and know as well as relate things you know to things you are learning." (In) "**A combination of absorbing information and constructing knowledge in order to understand." (F)**
ST-14: "Yes, comprehending detail is very important. Working through the material as well as relating prior knowledge is how I rely on learning chemistry. it can be very difficult trying to relate prior knowledge when it has been years without lab experience. Slowly small things come back to me both in the lecture as well as the lab." (In) **"I would say absorbing and memorizing information because that's how I learn. However, prior knowledge and prior experiences play a role. But, I'm starting to recognize chemistry in every day life and I never did that before." (F)**
ST-15: "It is not enough to just absorb information. If you cannot apply the information then there is no point in absorbing the information. All of those are essential to learning science." (In) **"You have to relate your prior knowledge to completely understand." (F)**
ST-16: "No. You can't just memorize chemistry. You have to actually understand the concepts behind it in order to learn. Chemistry takes practice to understand it. Everything you have learned prior is connected to your new learning." (In) **"I believe in using one's prior knowledge in order to construct one's own understanding." (F)**
ST-17: "I think a student could easily make it through a basic chemistry course by absorbing the information, but to actually learn it you need to conceptualize it and understand it, especially if they plan on taking any other science classes." (In) **"In lecture it involves absorbing information or knowledge while in laboratory one applies prior and new knowledge for understanding." (F)**
ST-18: "It is a lot of memorization but, it's also something I like about science. Sometimes there isn't a yes or a no answer. You can analyze it but if one experiences something they'll probably remember it. "(In) **"I would say it consists mainly of absorbing, memorizing information and facts." (F)**
ST-19: "Yes, I agree because you must learn the basic material to move onto the harder material. This is why labs are good because they make you think and reflect on why certain things happened." (In) **"Learning science requires you absorb the information. However, the repetition helps one understand." (F)**
ST-20: "I think it is learning in action. This makes it a more realistic experience. I have been able to relate it to a lot of things I do at work. Especially the reactions, pH blood gasses and IV fluids that I am administering. I think it is an action science. I think you have to construct your own conceptual framework so that you can understand the material that is there. Hopefully the material can be interrelated with our life, experiences and prior knowledge." (In) **"As it pertains to this course I'd say I lean more toward it consisting mainly of absorbing and memorizing the information." (F)**

Real-Life Applicability of Science

In the current literature on personal epistemology the dimension, real-life applicability of science is viewed as operating on a continuum that ranges from the view that is science is applicable to everyone's life inside and outside the classroom or laboratory versus that it is an exclusive concern of the scientific world.

Within this dimension the overall participant (N=56) pre-test mean was 2.665 (66.6) while the post-test mean was 2.978 (74.4) (see Table 40) with 35 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 2.788 (69.7) and 3.138 (78.4), respectively with 16 participants improving their score. This was also a category that quantitatively showed an above average (> 0.31 or 7.8 points) increase in 32 of the 56 participants, and 13 of the 20 interviewed participants' scores. The gain on the "real-life applicability of science" dimension is an indicator that some participants are moving away from the view that science only belongs in the realm of scientists to one that science is applicable to everyone's daily lives.

Although increases were observed quantitatively with a majority of the interview participants (Table 47), the difference in their understandings is best reflected in the initial and final interview responses in Table 48. In order to query participants, understanding of the real-life applicability of science, the initial and final interview question asked whether scientific knowledge and scientific ways of thinking applied only to the classroom and laboratory settings, not to real life.

In the initial interview the majority of the participants stated that they believed that science is always applicable to their everyday life (ST 1, 3-9, 11-13, and 15-20) while 3 participants (ST 2, 10, and 14) indicated that in certain cases it applied more to a classroom or laboratory setting. None of the participants felt that science was only applicable to a classroom or laboratory environment.

When comparing participants' initial interview comments with their initial EBAPS scores (Table 47) for the real life applicability of science most of the initial scores for this axis are reflected in the participants' initial interview comments. For instance participants 1, 4, 8-9, 11-13, and 15-20, all had initial scores in the moderately to highly sophisticated range and reflected that range in their interview statements that scientific knowledge applied to real life not just the classroom or laboratory setting. Participants 3, 5, and 7 had initial EBAPS scores in the poorly sophisticated range however in their initial interview they each stated that scientific knowledge was applicable to real life situations. As suggested earlier this discrepancy could have been due to several factors including misinterpretation of the question and/or possible answers or incorrect bubbling of answer choice as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 47 EBAPS - Real Life Applicability – Pre-Post Statistics

ID	Pre	Post	Difference
1	3.88	3.50	0.12**
2	3.13	2.13	-1.00*
3	2.25	2.50	0.25**
4	2.63	2.63	0.00*
5	1.50	2.00	0.25**
6	2.25	3.63	1.38***
7	2.25	2.63	0.38***
8	3.00	3.25	0.25**
9	2.88	3.38	0.50***
10	2.50	3.25	0.75***
11	2.63	3.38	0.75***
12	3.50	2.50	-1.00*
13	3.38	3.38	0.00*
14	2.88	3.38	0.50***
15	3.25	4.00	0.75***
16	2.88	3.75	0.87***
17	3.00	3.63	0.63***
18	2.88	2.50	-0.38*
19	2.63	3.50	0.87***
20	3.00	3.88	0.88***

* decrease in score or no change
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

The final interviews reflected a shift for two of the participants (ST 10 and 14) from a view that scientific knowledge is applicable more often in the classroom or laboratory to that it is often applicable to real life. The majority of the interviewed participants in the final interview still supported the belief that science is always applicable to their everyday life (ST 1, 3-9, 11-13, and 16-20) while 1 participant (ST 15) indicated that in certain cases it applied more to a classroom or laboratory setting and real life in other. None of the participants felt that science was only applicable to a classroom or laboratory environment.

When comparing participants' final interview comments with their final EBAPS scores (Table 47) for the real life applicability of science most of the initial scores for this axis are mirrored in the participants' initial interview comments. For instance participants

1, 3-4, 6-14, and 16-20, all had final EBAPS scores in the moderately to highly sophisticated range and reflected that range in their interview statements that scientific knowledge applied to real life not just the classroom or laboratory setting. Participants 2 and 12 final scores decreased from highly sophisticated to poorly and moderately sophisticated beliefs respectively. However, this sophistication level was not reflected in their final interview comments as they each stated that scientific knowledge was applicable to real life situations. As suggested earlier these discrepancies may have been due to several factors including misinterpretation of the questions and/or possible answers or incorrect bubbling of choice as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 48 Participants' Reflections – Real Life Applicability Science (N=20)

Initial and Final Epistemological Beliefs Interview Question-3
Real-life Applicability of Science – Scientific knowledge and scientific ways of thinking apply only to the classroom and laboratory settings, not to real life
Quotation Comments
ST-1: "It applies to the real world more than anything else. Everything in the world is linked to science such as all matter is made up of elements." (In) **"It definitely applies to everyday life." (F)**
ST-2: "**:** No, people are able to apply it outside. However, the scientific way of thinking is more investigative, therefore more accurate. You acquire more thinking and problem solving skills. Not enough people are able to apply the knowledge." (In) **"It depends. The reason is I believe one could get a way with not applying chemistry to anything in life. However, my neighbor is gifted in chemistry. We'll be sitting there talking about diet. He discusses how the foods chemically work with my body to lose the weight. You can apply it but whether you do apply it depends on whether you want to or not." (F)**
ST-3: "I would imagine that it would apply to real life. Chemistry involves a lot of analytical thinking, which can be applied in every aspect of life. It also involves a lot of detail and specific and accurate data/ results which can also apply to life outside the lab. Well there is the more broad approach that could be used in problem solving. Just the other night I was talking to my boyfriend and he spilled olive oil. We started discussing how soap breaks up the compound of the oil. My mom and I were discussing how penicillin was made and how it cured so many people." (In) **"I think it would be easy for one to think chemistry is just in the classroom and doesn't have anything to do with real life. Both professors state that when they view a traffic light they picture the LEDs firing or when the weather changes they check their tires to see if air (gas) needs to be added as gases expand and contract as the temperature changes. Now I see that science is part of our daily life." (F)**

Continued on next page

Table 48 (Continued)

ST-4: “I disagree there are real life situations where scientific ways of thinking are used. Diagnosing a problem with your car is one off the top of my head that I just used this weekend. I would say scientific knowledge is used a lot in the lab/classroom as well as real life, but would lean a little more towards being used more in a lab or classroom.” (In) **“I would say to real life.” (F)**
ST-5: **“**No, I believe that classroom and lab have an effect on real life. Like how to take care of the environment for getting rid of PCB's.” (In) **“First one has to understand the concepts which require learning experiences in the classroom. Then one can go out and apply it to the real world.” (F)**
ST-6: “No, there are scientific ways in every way of thinking. It’s about evaluating things. We use science in everything. It’s about gathering data or ideas and combining it all. No matter what you do you always kind of look at all your options to make a decision and even in everyday life. Maybe there are several possible methods that might work and you try them all if necessary.” (In) **“I use science every day. It is not restricted to the classroom as we use it in all kinds of daily situations. For instance the heat transfer concept involved in a hot water heater.” (F)**
ST-7: “Not true, science is everywhere. People can apply scientific ways of thinking to everyday activities. When cleaning it is important to know what you can and cannot mix and how much solution is needed. Being able to understand that is basic science.” (In) **“I think scientists and non-scientists use science everyday.” (F)**
ST-8: “No, scientific thinking is used in every day life. For instance, most of the household products we find in our homes could be made in the chemistry lab very easily. We just tend to overlook things the way they can be seen scientifically.” (In) **“Applies to real life situations.” (F)**
ST-9: “No, it applies to everyday life. Having an understanding of science that we learn inside the classroom or laboratory, allows us to understand the science in everyday life.” (In) **“It applies to real life situations.” (F)**
ST-10: “Well, that depends on your career choice. I think it does apply to real life. Other than that, I think that it would apply mostly to your career choice. Scientific knowledge and ways of thinking would be most helpful in your career if it has to do with a scientific field, but I think in real life it does apply but not as much as it would in a career.” (In) **“I don’t agree. Scientific knowledge isn’t restricted to just the classroom or laboratory. Once you have learned scientific knowledge in a classroom one can apply it to everyday life.” (F)**
ST-11: “No, we use chemistry in our everyday lives, the air we breathe and the things we eat and drink, they all have to do with chemistry.” (In) **“I believe it applies to the real world. Everything in life deals with science. For instance from starting the car, producing electricity, and eating everything relates to chemical processes.” (F)**
ST-12: “No because you can use scientific thinking in your everyday life like reading the back of a shampoo bottle to see the ingredients. That involves scientific thinking. However, they are more specifically used in the classroom or like at a pharmacy.” (In) **“It applies to everyday situations. For instance the demonstration of how fireworks are produced relates to real life.” (F)**
ST-13: “I do not agree with that because scientific knowledge is used all over the world in everyday life, not just in the classrooms and laboratories. Scientific knowledge is used in everyday life. For instance when people are cooking, the use of temperature and how things react with each other. I think that we all use knowledge and scientific ways of thinking.” (In) **“Scientific knowledge is applicable to both.” (F)**

Continued on next page

Table 48 (Continued)

ST-14: “I know science does apply to real life. I am just not aware of it at all times. Something as simple as a physical change.” (In) **“It includes real life situations as chemistry is everywhere. It’s not only restricted to the classroom or lab. For instance it is involved in such things as one’s diet and health.” (F)**
ST-15: “No, science applies to everyday life. Life involves strategically taking apart all the pieces and figuring them out and being able to analyze situations as one does in the classroom or lab. In lab you need to analyze your data and, if something went wrong, sort through and figure out what went wrong. For instance if you took apart the brakes on your bike to fix them then put them back on and they do not work, one has to figure out what went wrong to fix the brakes and avoid that same problem the next time.” (In) **“Some aspects are restricted to the classroom but more are applicable to everyday life.” (F)**
ST-16: “No. Everything is chemistry. Some real life examples are the desk, traffic lights with LEDs, blinkers, and gas to run our cars.” (In) **“Think about the chemicals you clean with in your home. That’s science being used in an everyday real life situation. I don’t know if you’ve seen that commercial on TV, the chemistry one.” (F)**
ST-17: “It definitely applies to real life, science is all around us. It’s in the plants outside, the weather, the food we eat, its everywhere so there is no way we can say its limited to a lab.” (In) **“Applies to everyday real life situations as demonstrated in laboratory.” (F)**
ST-18: “That’s not true. You deal with science everyday in just starting your car. Even though some people don’t realize its science, everything involves science.” (In) **“Applies to everyday real life situations. For instance you become more familiar with chemicals and one can apply that knowledge to household cleaning supplies learning that some of them are more hazardous than others.” (F)**
ST-19: “No. I disagree because science is all around us everyday. For instance the air we breathe and the water in which we swim or drink. Making plastic and we use plastic everyday. We just do not often think of it in that way, that it’s science.” (In) **We learned to understand why science related to real life. For instance the activity with fireworks can be applied outside the classroom or laboratory.” (F)**
ST-20: “Those are the very things that are my real life. We are science - biology, physics, chemistry, mathematics. For instance, analyzing my patient's blood work post-operatively. Deciding which IV fluids should be hung, determining if their urine output is sufficient, whether they need a fluid challenge, monitoring their vital signs and their physiological changes to determine if they are stable or going into shock postoperatively, determining a blood loss, adjusting my ventilator setting based on blood gasses.” (In) **“I lean strongly to it applying to everyday real life.” (F)**

Evolving Scientific Knowledge

In the current literature on personal epistemology the dimension, evolving scientific knowledge is viewed as operating on a continuum that ranges from viewing scientific knowledge as absolute, “set in stone” to viewing it as changing and dynamic. This dimension also considers the justification and source of knowledge in terms of the evaluation of evidence and the opinion of experts.

Within this dimension the overall participant (N=56) pre-test mean was 2.357 (58.9) while the post-test mean was 2.804 (70.1) (see Table 41) with 29 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 2.150 (53.8) and 2.783 (69.6), respectively with 14 participants improving their score. This was also a category that quantitatively shows an above average (> 0.45 or 11 points) increase in 27 of the 56 participants, and 12 of the 20 interviewed participants' scores. The gain on the "evolving scientific knowledge" dimension is an indicator that some participants are moving away from a realist view of science being "set in stone" to a more instrumentalist point that science changes over time.

Although increases were observed quantitatively (Table 49) with a majority of the interview participants, the difference in their understandings is best reflected in the interview responses in Table 50. In order to query participants, understanding of evolving knowledge in science, the initial interview question asked to react to the following: whether (A) All scientific knowledge is set in stone. (B) There is no difference between scientific evidence-based reasoning and mere opinion. (C) Sometimes different science instructors give different explanations for scientific events/concepts/phenomena. When 2 instructors explain the same thing differently, can one be more correct than the other? Explain. (D) When 2 explanations are given for the same situation, how would you go about deciding which explanation to believe? Please give details and examples. (E) Can one ever be sure of which explanation to believe? If so, how can you? If not, why not?

Initially nineteen of the interviewed participants (ST 1-8 and10-20) agreed that scientific knowledge is not set in stone, that there is a difference between opinion and evidence based reasoning, that one explanation can be more justified than another but not necessarily incorrect, and that one needs some type of supporting documents other than a textbook in order to determine which explanation to believe. However one participant (9) felt that scientific knowledge is set in stone and would use the textbook as the first source for deciding which explanation to believe.

When comparing participants' initial interview comments with their initial EBAPS scores (Table 49) for their understanding of evolving knowledge in science a few of the initial scores for this axis are mirrored in the participants' initial interview comments. For instance ten participants (ST 2, 4-6, 9, 14-15, and 18-20) all had initial scores in the moderately to highly sophisticated range that aligned with their initial interview reflections that scientific knowledge is not set in stone, that there is a difference between opinion and evidence based reasoning, that one explanation can be more justified than another but not necessarily incorrect, and that one needs some type of supporting documents other than a textbook in order to determine which explanation to believe. However some of the scores did not reflect the participants' interview comments and vice versa. The initial EBAPS scores for the remaining participants (ST 1, 3, 7-8, 10-13, and 16-17) fell in the poorly sophisticated and unsophisticated range while their initial interview comments suggest moderately to highly sophisticated beliefs. For instance all of the aforementioned participants stated that scientific knowledge was not set in stone and was constantly changing as technology improved. However, participant 9 scored in the moderately sophisticated range (2.67) which conflicted with her interview statement that scientific knowledge is set in stone. As suggested earlier discrepancies between EBAPS scores and interview statements may have been due to several factors including misinterpretation of the questions and/or possible answers or incorrect bubbling of choice as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

The final interviews reflected a shift in only one of the participant's beliefs (ST 5) from totally supporting scientific knowledge is not set in stone to a more moderate position that in some cases it knowledge may be set and unchanging. The remaining participants' final interview reflections remained unchanged from their initial interview.

Table 49 EBAPS - Evolving Knowledge – Pre-Post Statistics

ID	Pre	Post	Difference
1	2.00	1.67	-0.33*
2	2.33	1.67	-0.66*
3	1.67	2.67	1.00***
4	3.00	3.00	0.00*
5	2.67	2.67	0.00*
6	2.67	3.00	0.33**
7	2.00	3.00	1.00***
8	2.00	3.00	1.00***
9	2.67	2.67	0.00*
10	1.33	2.67	1.34***
11	2.00	3.33	1.33***
12	1.33	1.67	0.34***
13	1.67	2.33	0.66***
14	2.67	3.67	1.00***
15	3.33	4.00	0.67***
16	1.33	2.67	1.34***
17	1.33	2.67	1.34***
18	2.33	4.00	1.67***
19	2.33	2.33	0.00*
20	2.33	3.00	0.67***

* decrease in score or no change
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

However, when comparing participants' final interview comments with their final EBAPS scores (Table 49) there were decreases, increases, or no change in participant scores. that scientific knowledge is not set in stone, that there is a difference between opinion and evidence based reasoning, that one explanation can be more justified than another but not necessarily incorrect, and that one needs some type of supporting documents other than a textbook in order to determine which explanation to believe. For instance two participants' (ST 1-2) EBAPS scores decreased however they still both supported the view that scientific knowledge is not set in stone, that there is a difference between opinion and evidence based reasoning, that one explanation can be more justified than another but not necessarily incorrect, and that one needs some type of supporting documents other than a textbook in order to determine which explanation to believe in their final interviews. The final EBAPS scores of participants 4-5, 9, and 19 remained unchanged as well as their views from the beginning of the semester. The final scores of participants 3, 6-8, 10-18, and 20 all increased by the end of the semester supporting their interview views that scientific knowledge is not set in stone, that there is a difference between opinion and evidence based reasoning, that one explanation can be more justified than another but not necessarily incorrect, and that one needs some type of supporting documents other than a textbook in order to determine which explanation to believe. As suggested earlier discrepancies between EBAPS scores and interview statements may have been due to several factors including misinterpretation of the questions and/or possible answers or incorrect bubbling of choice as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

The tentativeness of scientific knowledge, the differences between opinion and evidence-based reasoning and the need for evidence are the concepts that some participants struggled with throughout the course as indicated in the pre-post interviews. The need to perform the laboratory activities prior to the lecture discussion of the concepts and theories surrounding the material may improve the participants' views on evolving knowledge. The participants knowing the basis of the theories surrounding the laboratory concepts may have tried to fit the data to the theory instead of considering the probable reasons for the data making a "perfect" fit.

Table 50 Participants' Reflections - Evolving Knowledge (N=20)

Initial and Final Epistemological Beliefs Interview Question-4
Evolving Knowledge – **A)** All scientific knowledge is set in stone. **B)** There is no difference between scientific evidence-based reasoning and mere opinion. **C)** Sometimes different science instructors give different explanations for scientific events/concepts/phenomena. When 2 instructors explain the same thing differently, can one be more correct than the other? Explain. **D)** When 2 explanations are given for the same situation, how would you go about deciding which explanation to believe? Please give details and examples. **E)** Can one ever be sure of which explanation to believe? If so, how can you? If not, why not?
Quotation Comments
ST-1: A) "I disagree. Theories change all the time. It was once thought that God created everything but science has brought up the theory of evolution." **B)** "False, because opinions could be founded on ignorance whereas if it's scientific evidence based, it's concrete truth." **C)** "Not really. I think that everyone learns differently and how one teacher explains it to a student could be much clearer than if another teacher explained it. Both teachers would be equally correct." **D)** "When you're converting one unit to another. One teacher could tell you to move the decimal place and another could tell you to multiply by factors of 10 depending on the conversion. I think it depends on the student, but I just move the decimal place. I think it's easier that way. Another student might think the other way would be easier." **E)** "I don't think there is going to be a "right" way. If you can get the same answer both ways, one should just use the method that is easiest for them." (In) **"I don't believe scientific knowledge is set in stone. I think that science is experimental. There might be a theory that is disproved by something or somebody. So, everything is sort of coming and going. In 100 years we could believe completely different things than what we believe today." (F)**
ST-2: A) "No, one of the main cornerstones of science, is that one can disprove something. Therefore science is always changing." **B)** "No, there is a lot of difference. Opinion is based on a belief system designed by family life, religion, society and science if you think that way. Scientific evidence is based on experiments performed many times with many counter experiments to disprove, which is always changing." **C)** "One could be more right than the other, however, it nature there a many ways something can happen. For example, the dinosaurs." **D)** "Some say the dinosaurs became extinct because of meteors crashing to earth and because of the dust suffocated the dinosaurs, others believe the meteor it, killed plant life etc. You can decide on what you conceive as more believable based on your life experiences, research the topic to find many other points of few, and draw your own conclusions." **E)** "I think one can only be sure within themselves, what you believe is up to you, if you are in position though to, you need to prove it." (In) "**I don't believe science is set in stone as it is constantly changing. I don't believe that we are supposed to know everything. What happened 100 years ago may not apply to now." (F)**

Continued on next page

Table 50 (Continued)

ST-3: **A)** “Well, the first thing that I think of is how much has changed scientifically over the course of history. More than thousands of new discoveries have been made throughout time, if it was set in stone there would be no room for more knowledge. I think there are certain core principles but there is always room for growth and more development.” **B)** “Well that makes me question their results. Opinions can be given perhaps in the form of a hypothesis, but evidence based reasoning should always be separated from opinion to gain true scientific results.” **C)** “I think that it would depend on the concept being explained. If it was the result of an experiment and one professor analyzed it differently, I wouldn't know if he/she would be less correct than the other.” **D)** “Yes, that could be tricky. Well at that point, I would have to use different resources available to come to a decision. I could look it up at the library, online, or ask other students or professors, for examples.” **E)** “I think so, once you have come to your own conclusion, you would have to choose to reject one explanation and accept the other. If they were in fact so different to begin with.” (In) **“Whenever I hear this I always think back years ago to when they thought the earth was flat. Then over time that view changed. I think there are definitely some things that are set in stone so I’m kind of in the middle. There are ground rules.” (F)**
ST-4: **A)** “Not true. New discoveries are being made all the time. Physicists/astronomers and other scientists work on problems without solutions all the time.” **B)** I disagree. Evidence-based reasoning includes experimental data to prove a point where as opinions are not necessarily as factually supported.” **C)** “I don’t know about being "more correct", but i think instructors vary in their clarity and explanation of a topic. So I wouldn’t say it’s a matter of correctness most of the time, but rather a degree of clarity and success at teaching or conveying ideas.” **D)** “I suppose some trial and error with data collection should be used. Also trying to get some third party explanations would be good as well. Just going to other sources for information or explanations. Other professors or info sources like the library or Internet.” **E)** I think yes, if you physically try to justify an answer or explanation through experimental trial and error yourself, and come up with identical data and conclusions. Also getting verification through interrelated concepts that support the initial topic.” (In) **“I don’t think science is set in stone. I think there’s a difference between mere opinion and evidence-based reasoning. Evidence based reasoning involves testing a theory or making observations based on experimental procedures. Then coming up with data and results that explain what’s happening.” (F)**
ST-5: A) “No, I do not believe scientific knowledge is set in stone because the matter on the earth and in the universe still have mysteries to solve no matter how big or small they are to science.” **B)** “No, there is a difference. Reasoning is based on what is truly understood and opinion is based on one’s own perceptions.” **C)** “No, the instructors may have learned different things throughout their lives through their own instructors in the past. I must just accept the right one that is easiest for me to understand.” **D)** “The explanation that I go for is the one in the simplest form.” **E)** “Yes, because one person might go the long hard way and end up with an answer, and another person might use the short easy way and still end up with the same answer as the first person.” (In) **“I’m in the middle again as everything in life changes. For instance the information on black holes in space. On the other hand science is merely human thought. Some knowledge may change while other knowledge may not change.” (F)**

Continued on next page

Table 50 (Continued)

ST-6: **A)** “No. Science is always changing. New things are always being discovered. So, I wouldn’t say that it’s set in stone. Well, a formula might be set in stone, but there are always new discoveries Things change such as the number of planets. Life’s always changing.” **B)** Yes. Mere opinion could be based on anything but scientific evidence is where you just have supporting evidence that backs up your opinion by experiments. You can have an opinion about anything and not really have anything to back it.” **C)** “No. If they’re explaining the same thing, I don’t think one is more correct than the other. Maybe one has a way of explaining something that you can understand better. Everybody understands concepts differently.” **D)** “Well, I would just go with the one that made sense to me and use that.” **E)** “Well, I think it’s important to always question things. I never just believe something without questioning. Then one can decide which one has the most evidence to back it and that makes sense to you. Scientific evidence that offers support for that explanation. So if you have two explanations, you come up with points that can support each and decide which one has more evidence.” (In) **“It is not set in stone things are always changing and things are evolving. Things that may have been true before may not be true now. Opinions are based on personal beliefs while evidence-based reasoning involves discovery.” (F)**
ST-7: **A)** “No science is changing every day. What was considered fact years ago is not necessarily fact today. Like the earth being flat that was once the case however with the increase of knowledge and information we found that, that was not the case.” **B)** “There is a clear difference between scientific evidence and a mere opinion. An opinion is something someone personally believes and does not necessarily need to be proven. While scientific evidence has been researched and can be proven.” **C)** “One might be easier to understand than the other but not necessarily more correct.” **D)** “Which ever one I understood better. I would go with the explanation that best described the situation in a more scientific manner that justifies its reasons with facts and hypothesis.” **E)** “Not really you just have to go with your best judgment.” (In) **“I don’t think it is set in stone as science changes all the time. If it is based on opinion there may or may not be some facts to support the opinion. (F)**
ST-8: **A)** “No, scientific knowledge should be tested to the point of exhaustion in order to determine its truth.” **B)** “No there is a big difference. With scientific evidence-based reasoning, you have specific data and supporting evidence to reason your conclusions. A person's opinion has no evidence, it's just a hypothetical conclusion based on what one thinks.” **C)** “I don't think it's an issue of correctness. I think that each professor knows what they are trying to get across and merely achieves this by their own explanation and method.” **D)** “I would believe the one that was closest to my own understanding and knowledge. If the two explanations are very similar and differ just slightly, I would look to a third source say another instructor or through research on the subject. Testing the data presented to me by searching for what others have concluded about it.” **E)** “Yes if the right explanation has been found to be absolute truth through observation or experimentation.” (In) **“I wouldn’t say all scientific knowledge is set in stone. I don’t think it is all set in stone as technology progresses things are modified.” (F)**

Continued on next page

Table 50 (Continued)

ST-9: A) “Yes it is set in stone. It has been researched and studied by professionals who have been able to scientifically prove it.” **B)** “Yes there is a difference. Evidence is something that has been proven, to back up a theory. Opinion is one's own personal belief on whether or not something is true.” **C)** “They can be equally correct. Everyone understands science differently and has a different way of explaining it. Therefore although different explanations may be given, they can still mean the same in the end.” **D)** “Whichever one I could relate to better or I would create my own so that I could understand it more clearly.” **E)** “By referring to the text book. Well if 2 explanations are given, if you are unsure about them just look up the concept in the text book and read that. Or you could ask the professor to explain it to you as an individual.” (In) “**I believe that scientific knowledge is set in stone.” (F)**
ST-10: A) “I disagree with that because I think all scientific knowledge is based on theories which although are accepted as basic truth are always apt to change.” **B)** “There is a difference because one is educationally based reasoning and then the other is just an opinion probably based on ones own beliefs or religion or whatever, they happen to think. Whereas one is actually applying knowledge which is different than just throwing out an opinion that may or may not be accurate.” **C)** “Possibly. I couldn’t really say unless I knew what they were talking about. I think there are different explanations for all sorts of things and it doesn’t mean that necessarily one’s more correct than another.” **D)** “Probably look at critics of both points of view and decide then which would be either the less critiqued one or the most reasonable seeming explanation. Well, I think then in order to decide whether you believe something or not, you have to look at both sides. You have to look at their critiques and you have to look at the support or look at the research. I find a lot of information that comes from either schools or classrooms or other online classes.” **E)** “I feel whichever one presented the information in the most factual manner and with limited opinion.” (In) **“Even though most scientific knowledge is well backed up it is still based on theory. So, nothing is set in stone. There’s a distinction between evidence based reasoning and mere opinion. Evidence based reasoning is a result of experiments and theories.” (F)**
ST-11: **A)** “New knowledge is showing up every day.” **B)** “Wrong, scientific based evidence is generally proven through numerous experiments while opinions are only what someone thinks and hasn’t necessarily been experimented with.” **C)** “No, both are equally correct, since science is changing all the time, there are no real right answers. One may base his explanation on one theory while the other bases his on another theory.” **D)** “I would experiment with both ways that were explained to me and see which one I better understand.” **E)** “No, science is always changing. Both instructors could be right they just explain the concept differently.” (In) **“I don’t believe all of science is set in stone as science is changing all the time. There is room for change.” (F)**

Continued on next page

Table 50 (Continued)

ST-12: A) “No because most of the knowledge we have about science is represented by theories. So everything is subject to change.” **B)** “Yes and no because you can formulate an excepted theory based on clear scientific evidence but if someone else were to look and that same data they might interpret something different and that’s where the mere opinion comes in.” **C)** “No because as long as both the instructors know what they are talking about and give valid explanations of a concept then they both can be right they just explain it in different ways.” **D)** “I would believe the one that I can relate to the most. For instance if one instructor gives an explanation that I understand then I am going to believe that one. It’s like whatever explanation is easier for me to wrap my head around.” **E)** “No not really because everyone is going to interpret data in different ways. Many different explanations might be believable it just depends on who wrote the interpretation.” (In) **“No, science is not set in stone. Everyone has their own opinion. Scientists interpret the data in different ways. ” (F)**
ST-13: A) “I don’t think that is true, because many new scientific things are being discovered explored and changed. Scientific knowledge is not set in stone. Scientists are discovering new things everyday about science.” **B)** “An opinion is the way someone feels while, scientific evidence-based reasoning is more about fact, what is already known, and has been researched.” **C)** “I think that each person is different and views things differently. That’s why it could be explained different. I think one can be better than the other depending on the reasoning.” **D)** “I would go with whichever one made more sense to me or matched my reasoning. For instance if teacher A and B were explaining different ways to do a problem I would try both methods and whichever one worked for me I would use. Which ever method makes more sense to me.” **E)** “I don’t think that you can ever be sure on which explanation to believe unless you see how it works for yourself, and honestly believe that there is no other way that would work.” (In) **“Again I am in the middle however I do not believe all scientific knowledge is set in stone. There is a difference between opinion and evidence based reasoning.” (F)**
ST-14: A) “Change occurs.” **B)** “One should take evidence-based reasoning over mere opinion.” **C)** “If they are explaining the same thing and their bottom line is the same then I don’t think that one would be more correct than the other.” **D)** “I would review both explanation and believe the one that makes the most sense to me. It may not be the right one, but if it’s the one I understand the most then I will believe that one.” **E)** “No, one can not ever be sure because an explanation is based on someone else’s studies not your own, evidence based over opinion.” (In) **“No, not all scientific knowledge is set in stone. Evidence based reasoning is like the experiment itself and supposition so I would say there’s a difference between that and mere opinion. You need evidence to back up reasoning.” (F)**
ST-15: A) “No, scientific knowledge is constantly changing as new discoveries are made.” **B)** “There is a big difference, opinion is not supported by any evidence but scientific reasoning has evidence. Evidence to support the facts.” **C)** “If one has the evidence to support their reasoning then yes one can be more correct than the other. If it is merely opinion based then no one can be more correct than the other.” **D)** “Researching, gathering information on the two different explanations and finally drawing a conclusion based on the information gathered and your own thoughts/opinions.” **E)** “It depends. If one finds enough evidence to support one of the explanations then yes, but if it turns out to be just opinion-based then no.” (In) **“I have always believed that science knowledge changes. For example since the discovery of the atom knowledge has changed.” (F)**

Continued on next page

Table 50 (Continued)

ST-16: A) “No. It’s not because with the new technologies we have today we can disprove something from before. For instance the controversy with Pluto about not being a planet. So, it’s not set in stone.” **B)** “I would say there is a difference. If it’s scientific evidence it’s been peer reviewed by others and a mere opinion would just be an individual opinion. ” **C)** “No. If it’s like a concept or an event, they could both be wrong or they could both be right because they could interpret it differently. For instance when someone gets in a car accident and one person describes it occurring in one way while another person says it happened differently. They could both be right or wrong. It’s just in the way they interpret it or the way they experienced it.” **D)** “If possible I would try to experience the same situation. I would research it so that I could try and figure it out. For instance read other lab reports.” **E)** “I would say it depends as you can’t ever be sure of which explanation to believe. For me it’s hard to believe everything about the atom because it’s so small.” (In) “**I believe there is a distinction between evidence based reasoning and mere opinion. I definitely don’t believe that scientific knowledge is set in stone. I believe that science is always evolving.” (F)**
ST-17: A) “No, new information is always being discovered resulting in change. Such as when they discover or create new elements that change the periodic table.” **B)** “One would definitely need to make that distinction. When it has to do with science most of the concepts should be based on evidence not on opinion.” **C)** “Not necessarily more correct but some students will respond better to one or the other instructor based on their learning style.” **D)** “If I was having a difficult time deciding which to believe I would research the topic and see which one was either correct or made more sense to me. I would use either the text or look online. I believe the text would be more reliable.” **E)** “I suppose unless they have witnessed it or if there is a lot of believable evidence supporting it.” (In) **“I have a strong belief that science is not set in stone.” (F)**
ST-18: A) “Nothing is set in stone even theories.” **B)** “No. Because an opinion is what someone thinks. If you have evidence then it is viewed as true.” **C)** “One may make more sense to you than the other. Again one can base it on their different life experiences.” **D)** “I would try to relate it to an experience that I’ve had so I would understand it better.” **E)** “I would say it’s hard to really be sure which explanation you’re supposed to believe. Because again, you may not know exactly what is right and wrong. Nothing is set in stone. You can always do your own research using other books. However, even books are not always correct. It would be actually something that they feel is correct.” (In**) “I don’t think scientific knowledge is set in stone because it changes everyday. Someone can develop a new theory or add to an old one. There is a distinction between evidence based reasoning and mere opinion.” (F)**

Continued on next page

Table 50 (Continued)

ST-19: A) “No not all scientific knowledge is set in stone because there are theories and new material found daily in the world.” **B)** “No there is a difference because evidence based reasoning is based upon knowledge where as an opinion is your views.” **C)** “Yes there can be more than one way because one instructor may explain the concept using a different method than the other instructor and still both are correct.” **D)** “I would believe the one that matches the textbook. I would use whatever way is easiest and makes the most sense for me personally.” **E)** “Yes all you need to do is look it up on the internet or in your textbook. Usually these sources will tell you what explanation is right.” (In) **“Well, I don’t think all scientific knowledge is set in stone. I think there’s a distinction between evidence based reasoning and opinion.” (F)**
ST-20: A) “There is always room for enlightenment. Some things are as they should be and just seem to fall in to place.” **B)** “There is a vast difference between someone who has verifiable proof to validate outcomes and someone telling you that they know something.” **C)** “Possibly. I have heard different theologians do the same. It certainly makes you think though and it would make you research it a little harder to find the "true" meaning, to find the more correct answer.” **D)** “I would have to research it. Get out the books, get on the net. Perhaps both of them are not incorrect perhaps both of them are looking at different aspects of the same situation.” **E)** “Whichever one proves itself over the test of time. For instance drug trials. Certain drugs are given over a period of time work better under certain conditions. If someone tells me they know something, I may listen to what they have to say but I am not going to risk anything of importance on something that someone cannot prove to me by research studies, statistics, and repetitive results.” (In**) “I don’t believe that it’s all set in stone. I think that science involves evidence based reasoning.” (F)**

Source of Ability to Learn Science

In the current literature on personal epistemology the dimension, source of ability to learn science is viewed as operating on a continuum that ranges from viewing that learning science takes natural ability to viewing that anyone with effort and self – confidence can learn science.

Within this dimension the overall participant (N=56) pre-test mean was 2.896 (72.4) while the post-test mean was 3.107 (77.7) (see Table 40) with 29 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 3.000 (75.0) and 3.210 (80.2), respectively with 12 participants improving their score. This was also a category that quantitatively shows an above average (> 0.21 or 5.3 points) increase in 27 of the 56 participants, and 10 of the 20 interviewed participants’ scores. The gain on the “source of ability to learn science” dimension is an indicator that some participants are moving away from a view that you must have a natural ability to learn science to that if one puts forth the effort and has self-confidence anyone can successfully learn science.

Although increases were observed quantitatively (Table 51) with a majority of the interview participants, the difference in their understandings is best reflected in the interview responses in Table 52. In order to query participants, understanding of the source of ability to learn science, the initial and final interview question inquired whether being good at learning and doing science is mostly a matter of fixed natural ability so most people cannot become better at learning and doing science. Initially the majority of the interviewed participants (ST 1-4, 6, 8-9, 14-15, and 19-20) expressed the belief that the ability to learn science was a combination of the desire to learn, some natural ability, and/or working hard. The remaining participants (ST 5, 7, 10-13, and 16-18) supported the belief that anyone can learn science. Their interview comments reflected the ideas that one only needs the desire and the willingness to work hard to be successful in learning science.

When comparing participants' initial interview comments with their initial EBAPS scores (Table 51) for their understanding of the source of ability to learn science a majority of the initial scores for this axis are reflected in the participants' initial interview comments. For example six participants (ST 5, 11-13, and 16-17) all had initial EBAPS scores in the high to the extremely sophistication range that aligned with their initial interview reflections that one only needs the desire and the willingness to work hard to be successful in learning science. Ten of the participants (ST 1, 2, 4, 6, 8-9, 14-15, and 19-20) scored in the moderately or highly sophisticated belief range which supported their interview belief that the ability to learn science is a combination of the desire to learn, some natural ability, and/or working hard.

The final interviews reflected a shift in three of the participants' beliefs (ST 5, 15, and 19). Participant five beliefs changed from that one only needs the desire and the willingness to work hard to be successful in learning science to the ability to learn science is a combination of the desire to learn, some natural ability, and/or working hard. By the end of the semester the other two participants' beliefs (ST 15 and 19) moved from that the ability to learn science is a combination of the desire to learn, some natural ability, and/or working hard to that one only needs the desire and the willingness to work hard to be successful in learning science. These belief changes may have been due to their own personal experiences with chemistry in the lecture and laboratory during the semester. The final interviews with the remaining participants did not reveal any belief changes concerning the ability to learn science.

However, when comparing participants' final interview comments with their final EBAPS scores (Table 51) a few decreases in participant scores were noted. For example five participants (ST 5, 15, 17-18, and 20) EBAPS final scores decreased. One score decrease is reflected in participant five's final interview where she shifts from believing that one only needs the desire and the willingness to work hard to be successful in learning science to the ability to learn science is a combination of the desire to learn, some natural ability, and/or working hard. The other score decrease was participant 15, however in her final interview she moved from the belief that the ability to learn science is a combination of the desire to learn, some natural ability, and/or working hard to that one only needs the desire and the willingness to work hard to be successful in learning science. The beliefs of the remaining participants with score decreases did not change from the initial to final interview. The majority of the participants with no change or increases in their final EBAPS scores maintained their initial beliefs in the final interviews. As suggested earlier discrepancies between EBAPS scores and interview statements may have been due to several factors including misinterpretation of the questions and/or possible answers or incorrect bubbling of choice as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 51 EBAPS - Source of Ability to Learn Science – Pre-Post Statistics

ID	Pre	Post	Difference
1	3.00	3.80	0.80***
2	2.60	3.40	0.80***
3	1.60	3.00	1.40***
4	2.60	2.80	0.20**
5	3.00	2.40	-0.60*
6	2.80	3.40	0.60***
7	2.60	3.80	1.20***
8	3.20	4.00	0.80***
9	2.40	3.00	0.60***
10	2.20	3.20	1.00***
11	3.60	3.40	-0.20*
12	3.60	4.00	0.40***
13	3.80	3.20	-0.60*
14	3.40	4.00	0.60***
15	3.60	2.60	-1.00*
16	3.20	4.00	0.80***
17	3.20	2.80	-0.40*
18	2.80	2.00	-0.80*
19	3.40	3.20	-0.20*
20	3.40	2.20	-1.20*

* decrease in score or no change
** ≤ 0.26 (6.5 points) gain in score
*** > 0.26 gain in score

Table 52 Participants' Reflections - Source of Ability to Learn Science

Initial and Final Epistemological Beliefs Interview Question-5
Source of Ability to Learn - Being good at learning and doing science is mostly a matter of fixed natural ability so most people cannot become better at learning and doing science
Quotation Comments
ST-1: "In part everyone can improve their skills in science or any other subject just by diligently studying the material and relating the material to their lives." (In) **"I think if you want to learn science you can. I do believe however that some are born with the natural ability to learn. If you want to learn something you may have to work hard at it while it may be easier for others." (F)**
ST-2: "Some people get it others don't. Chemistry and math are harder subjects for me to grasp. I have to really work at it, and sometimes it doesn't show. Some have to do it a lot more." (In) **"I believe it is a combination. For instance I really have to work hard at succeeding in math and science. History, English, psychology, and music are my passion. I don't have to constantly go over the content for those courses like I do for science and math. It is in part a natural draw." (F)**
ST-3: "I definitely think that in order to be a really good scientist you have to have a passion for what your doing, but I don't think natural ability is the only component. Discipline, attention to detail, diligence, all of those characteristics should be applied and taken into consideration as well." (In) **"I am kind of split on this statement. I put in a lot of time and hard work which is why I'm probably more successful than some other people One can probably really learn science if they really put your mind to it. I do feel I do have a little more natural ability." (F)**
ST-4: "I think to some degree one can be naturally gifted at learning sciences. However, you can improve your understanding concepts by repetition and practicing concepts. The amount of time needed to learn a new concept will vary from person to person." (In) **"I think that most anyone can learn science if they put a lot of time, effort and hard work into it." (F)**
ST-5: "No, if someone want to learn science and has an interest they can even if they do not have a natural ability. Some are better at just learning the material without doing anything else." (In) **"I believe that most individuals can learn science if they want to." (F)**
ST-6: "You definitely have to work through the material especially if you don't understand it. Everyone has their own way to understand and learn science." (In) **"I think some people are better at it than others. (F)**
ST-7: "No I do not believe in natural ability. I believe a person must obtain information through working hard. Some people may be able to grasp the concepts quicker than other. However, it is not because of natural ability but due to their intellect. People can learn whatever they want it just takes practice and take and time." (In) **"I think if you want to learn science you can. I don't believe in natural ability. If you are motivated and spend time on anything you can learn it. I don't think motivation is the same as natural ability. Natural ability means if your parents can learn something you should be able to learn it. However my parents know nothing about science so I'm not born with natural ability." (F)**

Continued on next page

Table 52 (Continued)

ST-8: "No, natural ability plays a small role. A person who is hard working is more likely to succeed in chemistry through practice and familiarization. Chemistry is coherent and logically connected material. Therefore if a person continues to practice the person will become better at learning/doing science." (In) **"Most individuals can learn science if they want to." (F)**
ST-9: "Yes and no. I believe that some individuals are born with a greater sense of knowledge in certain fields such as chemistry but I believe that everyone is capable of learning and understanding it. With practice one can understand science better." (In) **"I believe that all individuals can learn science if they want to. However, for some I think it's much easier. I think some people are born with the ability to think analytically. I have a harder time learning science." (F)**
ST-10: "I don't think that's right at all. They told my mom that she wouldn't be good at math or science when she graduated high school. She studied really hard and became a chemical engineer. She is like the shining light that makes me realize that you don't have to be naturally good at something to be able to do it." (In) **"If you want to learn science you can learn it. I know a number of people who aren't naturally able to think scientifically and they've managed to learn and understand science." (F)**
ST-11: "No, if you take the time to study science you can learn it and eventually become good at it. If someone really wants to learn science all they really have to do is sit down and read to understand the general concepts." (In) **"I don't think you have to have natural ability to learn science. I just believe one needs to work hard. I don't understand a lot of the chemical reactions however I 'm really good at math. So I reread everything and learn science with hard work." (F)**
ST-12: "No I think that if you just study and really try to learn the best way you can then you can be good at anything. Some people might catch on faster and have a natural ability but that doesn't mean others can't learn science." (In) **"I think that anyone can learn science if they want to. I don't think just because one is not naturally good at science that they can't learn it." (F)**
ST-13: "If someone works hard enough they can become better at learning and doing science. It depends on how much time and effort they are willing to put into improving their learning." (In) **"Anyone can learn science you just have to use your prior knowledge and work hard." (F)**
ST-14: "Yes natural ability is always a plus but dedicating oneself to understanding the material helps. People can become better at science over time and with repetition. For example in the lab using the same techniques when performing certain tasks. More repetition results in perfecting the task resulting in more reliable results." (In) **"I would say most individuals can learn science if they want to. Because I don't think of myself as an intelligent but if I dedicate myself I can learn anything." (F)**
ST-15: "Natural ability helps but being good at something involves the student's own will-power. One needs to be able to sort through the information and understand it. For instance, if you wanted to be better at rollerblading, you would have to practice, practice, and practice. The same goes for science. Sitting around and not doing anything about it won't get you anywhere." (In) "**You have to want to learn science. If you open your mind and believe you can then anyone can learn science." (F)**
ST-16: "No, that's not true. It takes practice and studying so you can understand it. Some people are better at learning science but it's because they work hard to understand it. Practicing problems in the book and going to lab class help in understanding the concepts." (In) **"I lean towards most individual's can learn science if they want to. I know if they tried hard enough they could learn and understand it. Laziness keeps some from trying hard enough." (F)**

Continued on next page

Table 52 (Continued)

ST-17: "I think anyone can learn science so I say it's not a natural ability. You would need the desire and motivation and work hard " (In) **"Since I have taken a number of other science courses I would say anyone can learn science if they really want to." (F)**
ST-18: "No, everything just takes practice. You might not be the smartest person, but if you know how to apply yourself and you constantly work at it, it's not impossible, it's just more difficult." (In) **"From my own experiences when I even mention that I am a science major other students react by saying they can't imagine taking chemistry. I think one has to have an interest. I just really like science so learning has never been that big of a deal for me." (F)**
ST-19: "Yes it's true that some people learn things easier but everyone can learn any kind of material if they set their minds to it. It's just that some people might need to study for hours where as others can read through the material once and already understand it." (In) **"I believe that an individual can learn science if they want to. You have to put more time and work into learning science as well as be able to think. If people aren't willing to try and learn then they're not going to be successful." (F)**
ST-20: "Then there would be no point in trying to learn or do better at anything. Perhaps everyone is not meant to be a scientist or a physicist or a doctor but we can all be better at anything." (In) **"I lean slightly toward it being more a natural ability. You can learn a lot the harder you work. But, I think if you don't have some natural ability to understand the concepts that you can work all you want and you're still not going to get it." (F)**

Discussion

Changing Epistemological Beliefs

RQ1. What range of personal epistemological of beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

Participants' initial scores on the Epistemological Beliefs Assessment for Physical Science (EBAPS) represent a range of beliefs from unsophisticated to highly sophisticated with the majority falling into the moderately sophisticated range (2.4-2.9). No participants scored in the top sophistication level, extremely sophisticated, meaning that there were no participants at the beginning of the semester course that held a high level of epistemological beliefs theorized in the models (Perry, 1970; Baxter-Magolda, 1986; Schommer, 1990; Hofer & Pintrich, 1997). Most of the participants initial scores fell in the range of late dualism to late multiplicity (levels 2-4) in Perry's model and in the absolute knowing to transitional knowing range of Baxter Magolda's model. The average EBAPS overall score of 2.514 would place the participants in the early multiplicity stage or transitional knowing stage of epistemological development. This gives some support to Perry and Baxter Magolda's findings that students depending on their year in college and other factors such as age and gender begin as a dualist or multiplist.

In the current literature on personal epistemology the dimension, structure of scientific knowledge is viewed as operating on a continuum that ranges from viewing scientific knowledge as an accumulation of concrete, discrete, knowable facts without much structure to viewing it as an interrelated network of strongly connected and highly structured concepts that are contextual, contingent, and relative. The initial EBAPS scores of the participants (N=56) resulted in 8.9 % of the participants beginning the semester with highly to extremely sophisticated beliefs about the structure of scientific knowledge. Only one of the interview participants (N=20) initially scored in the highly sophisticated level for this dimension. In the initial interviews 50% of the participants believed that structure of scientific knowledge involved interrelated concepts.

In the current literature on personal epistemology the dimension, nature of knowing and learning science is viewed as operating on a continuum that ranges from viewing that learning science as consisting mainly of absorbing information such as facts to relying on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, knowledge, and intuitions, and by reflecting upon and monitoring one's understanding. The initial EBAPS scores of the participants (N=56) resulted in 19.6 % of the participants beginning the semester with highly to extremely sophisticated beliefs about the nature of knowing and learning scientific knowledge. Two of the interview participants (N=20) initial EBAPS scores fell in the highly sophisticated level for this dimension. In the initial interviews 10% of the participants believed that the nature of knowing and learning scientific knowledge involved interrelating concepts and constructing one's own knowledge.

In the current literature on personal epistemology the dimension, real-life applicability of science is viewed as operating on a continuum that ranges from the view that is science is applicable to everyone's life inside and outside the classroom or laboratory versus that it is an exclusive concern of the scientific world. The initial EBAPS scores of the participants (N=56) resulted in 39.3 % of the participants beginning the semester with highly to extremely sophisticated beliefs about the real life applicability of scientific knowledge. Eight of the interview participants (N=20) initial EBAPS scores fell in the highly sophisticated level for this dimension. In the initial interviews 80% of the participants believed that the real life applicability of scientific knowledge included life outside the classroom or laboratory.

In the current literature on personal epistemology the dimension, evolving scientific knowledge is viewed as operating on a continuum that ranges from viewing scientific knowledge as absolute, "set in stone" to viewing it as changing and dynamic. This dimension also considers the justification and source of knowledge in terms of the evaluation of evidence and the opinion of experts. The initial EBAPS scores of the participants (N=56) resulted in 23.2 % of the participants beginning the semester with highly to extremely sophisticated beliefs about the evolving nature of scientific knowledge. Two of the interview participants (N=20) initial EBAPS scores fell in the highly sophisticated level for this dimension. In the initial interviews 70% of the participants believed that scientific knowledge changes and evolves over time.

In the current literature on personal epistemology the dimension, source of ability to learn science is viewed as operating on a continuum that ranges from viewing that learning science takes natural ability to viewing that anyone with effort and self – confidence can learn science. The initial EBAPS scores of the participants (N=56) resulted in 55.3 % of the participants beginning the semester with highly to extremely sophisticated beliefs about the source of ability to learn scientific knowledge. Twelve of the interview participants (N=20) initial EBAPS scores fell in the highly sophisticated level for this dimension. In the initial interviews 30% of the participants believed that anyone can learn science.

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

The epistemological beliefs of 39% of the participants (N=56) improved their EBAPS scores by the end of the semester resulting in a shift in their epistemological beliefs towards a more sophisticated level. The epistemological beliefs of 50% of the interview participants (N=20) improved their EBAPS scores by the end of the semester resulting in a shift in their epistemological beliefs towards a more sophisticated level. This shift suggests that personal epistemological beliefs can change over time. However the characterization of the participants' personal epistemological beliefs scores is better reflected in their interview responses.

Prior studies concerning learners' personal epistemological beliefs conducted with college students indicate that their personal epistemological beliefs can change during the college years (Baxter Magolda, 1992; Perry, 1981). Perry's (1968) investigation found that entering college freshmen believe knowledge is certain and provided by authority while college seniors believed that knowledge is complex and tentative and is derived through reason. Schommer (1997) conducted a longitudinal study to determine whether high school students' epistemological beliefs changed over time. Using the questionnaire Schommer (1990) developed she found that students' epistemological beliefs changed between students' freshman and senior years in high school in all four dimensions. These findings support the idea that epistemological beliefs develop over time. However, a student's beliefs about the structure of scientific knowledge may develop independently from his or her beliefs about the stability of scientific knowledge (i.e., evolving). Therefore, examining the dimensions of epistemological beliefs rather than epistemological beliefs as a coherent whole may allow a clearer picture of how beliefs change.

In this study the structure of scientific knowledge is described in terms of ranging from isolated bits of knowledge to interrelated concepts. Participants' views ranged from viewing the structure of scientific knowledge as discrete, concrete, knowable facts to seeing the structure of scientific knowledge as relative, contingent and contextual. From the data it is clear that although 54% of the participants (N=56) experienced an increase in sophistication of this dimension of epistemological beliefs, the changes were not complete as to become sophisticated in all participants. In the initial interviews 50% of the participants believed that structure of scientific knowledge involved interrelated concepts. By the end of the semester 80% of the interview participants (N=20) reflected improved epistemological beliefs concerning the structure of scientific knowledge in their interview statements. Participants' views may have been related to their beliefs about the processes of knowing and the nature of scientific knowledge. For example, if a student believes that scientific knowledge consists of factual information the student may believe that recalling the information constitutes knowing. As a result the student may believe that learning scientific knowledge consists of memorizing information and not understand how the knowledge interrelates. However if a student believes that scientific knowledge is complex resulting from interpretation of evidence then the student may believe that scientific knowledge involves interrelated concepts. Participating in a laboratory environment where interpretation of evidence was used as an instructional tool may have influenced the participants' epistemological beliefs.

Prior studies such as Songer and Linn (1991) suggest that students' classroom experiences may impact their beliefs about the structure of scientific knowledge. They suggest that students may not integrate material presented in science courses if they believe that scientific knowledge consists of isolated principles. Additionally, learners may not develop a consistent historical view of science if science is taught as a collection of fairly unrelated facts and ideas. Learners need to understand that scientific knowledge is best described as a set of strongly integrated and highly structured concepts rather than a series of weakly connected isolated ideas. Understanding that scientific knowledge is a set of strongly integrated and highly structured concepts are associated with a highly sophisticated belief of the coherence of scientific knowledge. For instance, learners should understand the principles that underlie scientific investigation such as causality, explanation, and using experiments to determine causality or construct scientific explanations.

According to Linn and Hsi (2000) research on students' views on the structure of scientific knowledge suggests that students develop a repertoire of ideas about scientific knowledge rather than a cohesive view. In another study some college students expressed beliefs that scientific knowledge was a collection of separate pieces of knowledge such as formulas and symbols that only experts could understand. However, other students believed that the structure of scientific knowledge was an integrated body of knowledge made up of concepts in which one could construct their own understanding (Hammer, 1994). Elder (2002) suggests that the relatively sophisticated ideas of that scientific knowledge is a coherent system of concepts develops later than other epistemological beliefs about science constructs such as that scientific knowledge evolves.

The nature of knowing and learning scientific knowledge can be described in terms of ranging from that learning science consists mainly of absorbing information such as facts to relying on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, knowledge, and intuitions, and by reflecting upon and monitoring one's understanding. In this study participants' ideas about the nature of knowing and learning scientific knowledge were viewed in terms of absorbing facts or by constructing one's own knowledge. From the data it is clear that although 50% of the participants experienced an increase in sophistication of this dimension of epistemological beliefs, the changes were not complete as to become sophisticated in all participants. In the initial interviews 10% of the participants believed that the nature of knowing and learning scientific knowledge involved interrelating concepts and constructing one's own knowledge. By the end of the semester 50% of the interview participants (N=20) reflected improved epistemological beliefs concerning the nature of knowing and learning scientific knowledge in their interview statements. Participants' views may have been related to their learning strategies and the belief that science mainly facts to be memorized. Participants tended to equate learning scientific knowledge with practicing problems or generating scientific knowledge in the laboratory.

In a prior study Songer and Linn (1991) investigated eighth grade students' strategies for learning science in combination with their study of students' views about the nature of knowing and learning science. They found that some of the students who held static beliefs about the nature of knowing and learning science preferred the use of memorization as their approach to learning science. However other students that held dynamic beliefs about the nature of knowing and learning science approached learning via efforts to create meaningful understanding. If a learner believes that the nature of learning and knowing scientific knowledge is complex as a result of interpretation of evidence then the learner may believe that learning science requires mental effort to understand the complexities and interrelationships of the scientific knowledge (Roth & Roychoudury, 1994; Schommer & Walker, 1995).

The real life applicability of scientific knowledge can be described in terms of ranging from only applicable in the classroom or laboratory to applicable to everyday life. From the data it is clear that although 57% of the participants experienced an increase in sophistication of this dimension of epistemological beliefs, the changes were not complete as to become sophisticated in all participants. In the initial interviews 80% of the participants believed that the real life applicability of scientific knowledge included life outside the classroom or laboratory. By the end of the semester 90% of the interview participants (N=20) reflected improved epistemological beliefs concerning the real life applicability of scientific knowledge in their interview statements. Participants' views may have been related to their scientific literacy. The more experiences participants had with applying scientific knowledge to their daily lives the more sophisticated their epistemological beliefs. Participants in this study tended to describe the real life applicability of science in terms of examples of how scientific knowledge applied to real life. Several described how specific science concepts related to everyday life such as checking the gas pressure in one's tires with temperature changes in the weather, personal diet, and health.

Studies involving the epistemological viewpoints of both "public science knowledge" and "personal understandings of science" are found throughout research literature. "Public science knowledge" may be defined as scientific knowledge that harbors consensus within a community of scientists. Epistemological viewpoints of ‘public science knowledge” addresses the processes involved in generating public science knowledge and justification of reliability. A citizen’s interest in science occurs within specific social decision-making purposes including personal matters such as health care, safety risks at work, fabric choices, and protesting the building of an industrial plant. The citizen who wishes to engage in decision-making about an issue has to learn some science.

Studies that address the epistemological viewpoints of scientific knowledge used by students from K-16 have been reported. Given the variety of methods used, the findings are quite similar (Lederman & O’Malley, 1990; Aikenhead & Ryan 1992; Meyling, 1997). Perhaps the most significant point to emerge from these studies is that students do indeed develop epistemological viewpoints of public science knowledge because of their interactions with science during their education and everyday life.

According to Cobern (2000) many citizens including students find science disconnected from everyday life and thinking. They view science as a “school” subject not an important part of everyday life. Even in a college science course only a fraction of the information generated by scientific knowledge is taught during a semester course. Therefore, it is important for science courses to prepare learners to be able to think critically about science related issues that may impact their everyday life (Carey & Smith, 1993).

Evolving scientific knowledge can be described in terms of ranging from viewing scientific knowledge as absolute to viewing it as changing and dynamic. In this study participants’ ideas about the nature of evolving scientific knowledge were viewed in terms of “set in stone” to constantly evolving. From the data it is clear that although 48% of the participants experienced an increase in sophistication of this dimension of epistemological beliefs, the changes were not complete as to become sophisticated in all participants. In the initial interviews 70% of the participants believed that scientific knowledge changes and evolves over time. By the end of the semester 90% of the interview participants (N=20) reflected improved epistemological beliefs concerning the evolving nature of scientific knowledge in their interview statements. Participant's ideas in this study about evolving scientific knowledge (e.g., certainty) and the justification of scientific knowledge tend to be described in terms of whether they understand knowledge to be verified by authority (e.g., first hand source) or via evidence (second hand source). Participants' views about evidence were related to their ideas about the certainty of knowledge. Some suggested that evidence is related to how or why ideas in science might change over time. Other participants suggested that scientific knowledge is associated with both sources of evidence. In terms of first hand sources, participants indicated that one can obtain information from investigations such as experiments, direct experiences with situations, or from tools. Participants suggested textbooks and the Internet as second hand sources.

The idea that scientific knowledge changes over time to be consistent with evidence from data and/or new reasoning and that scientific knowledge can change through growth or revision should have an effect on a learner's epistemological beliefs. In addition, the idea that because scientists are influenced by their prior knowledge, multiple explanations can be produced from the same set of data would seem to have a potential to effect learner's epistemological beliefs.

Studies have shown that learners' prior scientific knowledge does influence their ideas about the certainty and justification of knowledge. In addition, learners generally hold a wide range of ideas about science that are resistant to change (Fensham, 1994; Gabel, 1998; Taber, 2002a). Learners' views of scientific knowledge develop over time.

They are shaped and influenced by a variety of factors such as home, media, school, and technology.   Learners that have the ability to critically examine the results of scientific literature rather than simply accept the interpretations of “authority figures” have a better understanding of the formation of scientific knowledge. According to Carey and Smith (1993), science courses should prepare learners to value “the kind of knowledge that is acquired through a process of careful experimentation and argument.” Nevertheless, studies show that regardless of taking science courses, some learners do not understand that scientific knowledge is always evolving and constructed through theoretical interpretations of evidence (Ryan & Aikenhead, 1992).

The source of ability to learn scientific knowledge can be described in terms of ranging from viewing that learning science takes natural ability to viewing that anyone with effort and self –confidence can learn science. In this study participants’ ideas about the nature of one’s ability to learn scientific knowledge were viewed in terms of the role natural ability played in a participants’ success. From the data it is clear that although 48% of the participants experienced an increase in sophistication of this dimension of epistemological beliefs, the changes were not complete as to become sophisticated in all participants. In the initial interviews 30% of the participants believed that anyone can learn science. By the end of the semester 45% of the interview participants (N=20) reflected improved epistemological beliefs concerning the evolving nature of scientific knowledge in their interview statements. Participant’s ideas in this study about the source of ability to learn science ranged from the belief that some natural ability is required to all one needs to be able to learn science is motivation and the desire to work hard. One underlying theme is the attitude a student has about learning science and their ability to learn science. Expected achievement is another variable that appeared to heavily influenced learners’ beliefs about their source of ability to learn science.

As would be expected, positive attitudes toward science lead to better results on achievement measures of science capability (Weinburgh, 1998). A student's attitude toward science is more likely to influence achievement in science than achievement influencing attitude (Schibeci & Riley, 1986).   For instance, Steiner and Sullivan (1984) found that organic chemistry students who received a grade of a C or lower more frequently self-reported themselves as worried or anxious about the subject. Steiner and Sullivan (1984) found that the best predictor for success (C+ or better) is a positive attitude towards chemistry. This belief is characterized by claiming an interest and confidence in learning organic chemistry.

The organizing role of prior scientific knowledge and understandings in gaining new scientific knowledge and skills include not only epistemological beliefs but other aspects of knowledge structures and patterns of reasoning, such as attitudinal beliefs and reasoning abilities. For instance, there is evidence indicating that students' scientific epistemological beliefs play an important role in determining their learning orientations towards science and the ways of organizing cognitive structures of scientific knowledge. There is also evidence indicating the importance of scientific epistemological beliefs on conceptual change (Perry, 1970; Posner et al., 1982; King & Kitchener, 1994). The epistemological beliefs of middle and high school students were determined to relate to the ability to learn, speed of learning, and stability of knowledge. The study found that if a student believes in quick learning, it may affect problem-solving strategies over time (Schommer-Aikins et al., 2005).

Hofer and Pintrich (1997) suggested that, "beliefs about learning and teaching are related to how scientific knowledge is acquired, and in term of the psychological reality of the network of individuals' beliefs, beliefs about learning and teaching are probably intertwined." According to Hofer and Pintrich (1997), there is continuing speculation that college educational experiences may serve as the force for change in personal epistemological beliefs but limited research has been performed to refute or support the idea. Hofer (1994) compared the epistemological beliefs of college students that experienced two different forms of calculus instruction over a semester course. Some students experienced instruction that emphasized active learning, cooperative learning, and problem solving while other students experienced instruction as lectures and demonstrations of problem sets. Results indicated significant differences in the epistemological beliefs of the students with those students experiencing active learning, cooperative learning, and problem solving scoring higher. However, interpretations of these results are limited because student beliefs were not assessed prior to instruction.

An understanding of epistemological beliefs is important because they may reveal that college students are being influenced by unconscious and initial beliefs about the nature of knowledge and learning. Pintrich (2002) suggested that epistemology is developmental. Development is the goal of education. Therefore part of the goal of education should be to promote epistemological development.

Summary

In summary the overall findings of the study (N=56) in answering research question -1, sub-question-b was as follows: Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

1. Noticeable increase in posttest scores with a statistically significant medium effect size of 0.61.
2. The mean gain scores is lowest for source of ability to learn and highest for evolving knowledge.
3. The mean gain score for overall increased by 4-6 points on a scale of 0-100.

4. The mean gain scores for four of the EBAPS dimensions and the overall score are significant at $p \leq 0.05$.

5. The mean gain score for source of ability to learn is not significant at $p \leq 0.05$.

In summary the findings related to the interview participants of the study (N=20) in answering research question -1, sub-question-b was as follows: Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

1. Noticeable increase in posttest scores with a statistically significant medium effect size of 0.93.

2. The mean gain scores is lowest for source of ability to learn and highest for evolving knowledge.

3. The mean gain score for overall increased by 5-8 points on a scale of 0-100.

4. The mean gain scores for four of the EBAPS dimensions and the overall score are significant at $p \leq 0.05$.

5. The mean gain score for source of ability to learn is not significant at $p \leq 0.05$.

Not unexpectedly, given the literature on epistemological beliefs, the participants in the study showed a moderately significant change in their overall epistemological beliefs and in four of the five dimensions the exception being the source and ability to learn scientific knowledge. This lack of development may not be so surprising since the source and ability to learn scientific knowledge may be influenced by the participant's own self-efficacy and prior experiences learning science.

Overall, minimal to moderate gains were made for the participants (N=56) in general within the EBAPS dimensions. The participants overall had quantitative scores that were mixed with four dimensions showing increases. Slightly better results were obtained from the interview subjects quantitatively in terms of increased sophistication of epistemological beliefs. The interview participants had increases within the same four dimensions with the exceptions being participants 4, 13, and 17.

With the interview participants, it seemed they either held the belief or not, as minimal to moderate growth could be seen qualitatively within the interviews over time. Although increases were seen quantitatively, these may well be insignificant. It seems apparent that some participants have very naïve epistemological beliefs while most possess moderately sophisticated beliefs and a few surprisingly have highly sophisticated beliefs. The naïve views are to be expected since the development of sophisticated beliefs is normally seen only during the latter college years, as described in Perry's work (1970).

The next chapter presents a description of the development of the participants' NOS beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-a. The characterization of NOS beliefs and any changes in those beliefs that may have resulted with analyses of the participants' responses to interview probes will be presented. The combination of interviews and quantitative measures will provide a glimpse into participants' NOS beliefs changes during the course of a semester and what the participants' believed influenced their beliefs. The results are discussed and related back to the key laboratory NOS beliefs literature.

Chapter Six: Development of NOS Beliefs

Introduction

Chapter six presents a description of the development of the participants' NOS beliefs through the presentation of qualitative analyses of the study's sub-question 2-b. The characterization of the participants' NOS beliefs is discussed with the use of the participant's responses to interview probes. The combination of the interviews and quantitative measures previously discussed in chapter four will provide a glimpse into participants' NOS belief changes during the course of a semester.

Another objective of this research was to determine if participants' NOS beliefs change over the course of a semester in a laboratory instructional setting, the next step looks closely at the NOS data. These descriptions will be generated from the NSKS assessment and more importantly the participants' responses during the initial and final interviews. No specific explicit NOS pedagogical methods or instruction were included in the semester laboratory course.

The nature of this study was to explore and lay a foundation for focusing on more specific features of reasoning related to NOS belief changes in light of specific science laboratory instructional features for future research.

Method of Analysis

This analysis was conducted in a multi-layered, multi-stage process, through reading, and sorting participants' responses to NOS questions, both general in nature and specific to the course. The analysis below is organized by four of the six NSKS assessment dimensions (axes): creative, developmental, parsimonious, and testable.

The aforementioned dimensions (axes) served as the major theme codes giving a framework from which first-order themes originally derived from the participants' verbatim quotations or raw data themes could be analyzed. Within each dimension (axis), the responses to interview and reflective questions regarding NOS beliefs are presented. The intent of this analysis is to expand the theoretical understanding of the NSKS dimensions (axes) as related to the NOS and the continuum of beliefs, as expressed in context. Illustrative quotes have been selected from the interviewed participants as representative of the range of beliefs along the continuum. Table 53 presents a demographic overview of the interview participants with their participation identification number. Quotes are identified with the letters ST followed by the participant's identification number (Table 53). Figure 7 represents the scale used to identify the each participant's range of NOS beliefs.

The main research questions that guided this portion of the study were:

RQ1. What range of NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

RQ1a. Do students' NOS beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

Summary of NSKS Overall Scores

Using the overall scores on the NSKS (Table 54) discussed in chapter four to measure relative increases or decreases in NOS understandings, the results show forty-four participants (N=56) increased their total scores while seven participants' scores decreased and five scores remained unchanged from the pre-test to the post-test. The total overall mean score between the pre-test and the post-test resulted in an average increase of 5.9 points. The overall average increase within the dimensions was 0.96 points.

Table 53 Demographic Statistics - Interview Participants

ID	Sex	Age	Major	College Year
1	F	19	Pre-Pharmacy	Fr
2	F	21	Psychology	So
3	F	21	Biomedical Science	Jr
4	M	24	Electrical Engineering	So
5	M	22	Environmental Science	Jr
6	F	27	Marine Science	None
7	F	20	Biomedical Sciences	Jr
8	M	18	Undeclared	Fr
9	F	18	Environmental Science	Fr
10	F	20	Environmental Science	So
11	F	19	Nursing	Fr
12	F	18	Undecided	Fr
13	F	18	Pre-Pharmacy	Fr
14	F	19	Pre-Pharmacy	Fr
15	F	20	Biology	So
16	F	18	Environmental Science	Fr
17	F	24	Physical Ed	Jr
18	F	20	Athletic Training	Jr
19	F	19	Biomedical Sciences	So
20	F	45	Masters Nursing	None

Figure 7 NSKS Belief Scale

Realist----------------------------------neutral---------------------------------Instrumentalist
(48) (unaccepted NOS view) (144) (accepted NOS view) (240)

Realist – absolute; theories are either true or false
Instrumentalist – subjective; theories are tools

What is clear is that several of the participants' overall scores did show some improvement in their NOS beliefs by the end of the semester course. Fifteen of the fifty-six participants improved their NSKS scores by 5.0 points or less, four improved by the average gain of 6.0 points while twenty-five improved their score by greater (7-18 points). Therefore, 78% of the participants improved their NSKS scores. For the entire population (N=56) participant fifty-two had an overall increase of 18 points, followed by participant twenty-two with a 15 point increase. In addition, twenty of the original fifty-six participants moved toward the instrumentalist (acceptance of NOS views) end of the NSKS scale with seven coming from the interview participants. The lowest overall (N=56) NSKS pre-test score was 122 (St-17). None of the participants increased their scores in all six NSKS dimensions. The overall average increase within the dimensions was 1.1 points. The remaining twelve either had no change or a decrease in their score. Whether improvement or lack of improvement was in any way influenced by laboratory instruction or outside factors will be presented later in chapter seven.

Table 54 Descriptive Statistics – NSKS Scores – All Participants

Dimension	Pre-Mean Score N= 56	Post-Mean Score N=56	Pre-Mean Score N= 20	Post-Mean Score N=20
Amoral (D-1)	23.643	24.196	23.150	24.350
Creative (D-2)	22.893	23.670	22.550	24.100
Developmental (D-3)	23.625	24.768	24.000	24.700
Parsimonious (D-4)	24.625	26.321	24.550	26.700
Testable (D-5)	24.196	24.982	24.050	24.300
Unified (D-6)	23.643	24.411	23.750	24.750
Overall Score	142.482	148.375	141.650	148.900

Summary of NSKS Interview Scores

As for the interview participants (N=20), 78% improved their NSKS score by the end of the semester (Table 55). Six participants improved their scores by 6.0 points or less, while another twelve improved their scores by more than 6.0 points. Two of the interview participants' NSKS post scores decreased by 2.0 points. Whether the improvements or lack of improvements were in any way influenced by laboratory instruction or other possible factors will be presented later in chapter seven.

Participant fourteen of the interview participants had the lowest overall NSKS pretest score of 132, followed by participant seventeen with 136. Although 78% of the interview participants showed an increase in total NSKS scores, participants one, ten, and nineteen had the largest total score increases of 12 point each. Interview participants two, three, and twelve improved their scores in five of the six dimensions with the majority improving their scores in four of the six dimensions.

Participant six had the highest pre-test score (149) and participants one and nine had the highest post-test scores of the interview participants with both scoring 155 placing them at the instrumentalist (accepting of NOS views) end of the NSKS scale (Figure 7). However, all three of the aforementioned students' pre-test scores placed them at the realist end of the NOS scale indicating that their initial beliefs did improve concerning the NOS. Twelve of the twenty interview participants moved from either a realistic or neutral position in regard to NOS towards an instrumentalist perspective during the course of the semester. This was an above average increase of 9.4 points suggesting a marked improvement in the sophistication of their NOS beliefs.

Table 55 Descriptive NSKS Statistics - Interview Participants

ID	Gender	NSKS Pre	NSKS Post	Difference
1	F	143	155	12***
2	F	144	153	9***
3	F	138	148	10***
4	M	138	149	11***
5	M	144	151	7***
6	F	149	151	2**
7	F	143	152	9***
8	M	147	145	-2*
9	F	147	155	8***
10	F	141	153	12***
11	F	143	149	6**
12	F	138	150	12***
13	F	146	144	-2*
14	F	132	142	10***
15	F	140	145	5**
16	F	143	148	5**
17	F	136	142	6**
18	F	143	148	5**
19	F	140	152	12***
20	F	138	146	8***

* decrease in score
** ≤ 6.0 points gain in score
*** > 6.0 points gain in score

Characterization of Nature of Science Beliefs

Although the NSKS assessment serves the purpose of finding out if, and in what categories, students beliefs are changing, we needed a way to explore how these beliefs changed during the semester. Using a set of probing questions initial and final interviews were conducted to ascertain if at all, whether participant nature of science (NOS) beliefs changed during the semester of laboratory instruction.

Key areas that appeared to provide opportunities for participants to make inferences about their beliefs included the initial and final interviews. The initial interviews lasted approximately 15 – 20 minutes and focused on four of the NSKS dimensions. The final interviews lasted 30-45 minutes and focused on general NOS beliefs. The following discussion will present an overview of the responses by the interview participants to the NOS beliefs probes during the initial and final interviews. The discussion is organized with the use four of the six NSKS dimensions.

Initial and Final NOS Beliefs Interviews

Many of the instruments used in NOS studies originated as objective, pencil and paper assessments which subsequently changed into more descriptive instruments. Researchers argued that traditional paper and pencil assessments are not adequate in fully explaining what one needs to know about students' conceptions of NOS. Researchers responded to this argument by conducting interviews, surveys, and offering open-ended questions (Lederman, et al., 1998). While the quantitative data offer an opportunity to examine and compare participants' understanding of NOS in a generalized way, the interviews offer a chance to investigate and describe more fully the range of participant positions with respect to understanding NOS.

During the initial interview, questions related to four of the six multi-dimensional axes of the NSKS: creative, developmental, parsimonious, and testable were used to probe the participants (Appendices C, F & O). The questions were designed to investigate the participants' NOS beliefs. The interview participants were asked to elaborate on the questions in order to invoke the participants' thoughts about the NSKS variables.   The questions themselves were meant to look at different areas of NOS beliefs within the NSKS.

During the final interview, participants were presented with an ill-structured scenario problem from King and Kitchener (1994). The reflective judgment scenario problem (Appendix F) incorporates the four dimensions from the initial interview with the focus being on the developmental dimension.

The study investigated the changes from the beginning to the end of the semester within four (creative, developmental, parsimonious, and testable) of the six dimensions of NOS beliefs identified in the NSKS. First the overall participant scores were compared to those of the interview subjects. After a comparison between interview subjects and the overall class based on quantitative scores, an attempt was made to briefly look at what might have changed using the qualitative data from the interviews based on the NOS beliefs within each variable.

Responses to the Initial and Final NOS Beliefs Probes

On the subsequent pages portions of the initial and final interview responses are presented and discussed concerning the participants' NOS beliefs. The interview probes were designed using the NSKS variables discussed in chapters two and three. Each variable interview probe will be presented and discussed separately.

Creative Dimension

In the current NOS literature the dimension relating to the creativity involved in scientific endeavors is viewed on a continuum that ranges from viewing scientific knowledge as a totally lifeless, rational, and orderly activity to viewing it as an endeavor that requires human imagination and creativity through the invention of explanations based on observations. In addition this dimension considers whether scientific models and theories are a product of the human imagination and whether they accurately represent reality. According to Rubba and Anderson (1978) scientific knowledge is a product of the human intellect. The invention of scientific knowledge requires as much creative imagination as does the work of an artist, composer, or a poet. Scientific knowledge represented by models and theories exemplifies the creative spirit of the scientific inquiry process.

Within this dimension the overall participant (N=56) creative pre-test mean was 22.98 while the post-test mean was 23.67 (Table 54) with 17 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 22.55 and 24.10, respectively with 14 participants improving their score. This was also a category that quantitatively showed a below average increase of 0.80 points when compared to the overall average increase of 0.96 (N=56). The participant (N=56) with the highest pre-post score change of 11 points as well as the highest post score was student 52 with a score of 32. This moved the student from the realist end of the NSKS scale to the instrumentalist end by the end of the semester.

Initially 60% of the interview participants (N=20) scores (ST 1-5, 7, 10-12, 14, 17, and 19) suggested they held naïve (realist) views that scientific knowledge is not a product of human imagination. However, by the end of the semester only 25% of the participants' NSKS scores (ST 6, 8, 12, 15, and 17) fell in the realist range. The initial NSKS scores of 15% of the interview participants (ST 6, 8, and 16) fell in the neutral range suggesting they held a combination of naïve and expert beliefs concerning the role creativity plays in the nature of science. By the end of the semester 25% of the participants (ST 2-3, 7, 11, and 16) scored in the neutral range. The initial scores of five of the participants (St 9, 13, 15, 18, and 20) suggested they held an appropriate view (instrumentalist) on the role that creativity plays in the nature of science. Ten participants (ST 1, 4-5, 9-10, 13-14, and 18-20) scored in the instrumentalist range by the end of the semester.

However, for the majority of interview participants the overall increase in post creative scores was above the average with an average increase of 1.55 points (Table 56). The highest pre-post score change within the interview participants of 6 points were students 10 and 11. In addition student 10 had the highest post score of 28. This moved the student from the neutral section of the NSKS scale to the instrumentalist end by the end of the semester. Approximately 60% of the interview participants improved their score on the “creative” dimension moving them into a higher range on the NSKS scale. This suggests that a small portion of the participants are moving away from a realist view that science does not require creativity to a more instrumentalist view.

Although some increases were observed quantitatively with ten of the twenty interview participants, the difference in their understandings is best reflected in the initial interview responses in Table 57. In order to query participants, understanding of the creative dimension of NOS the initial interview question asked participants to respond to the following: “whether scientific theories and models are products of the human mind and may or may not accurately represent reality.” This question assessed participants’ understanding that scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world and developed into scientific theories and models. That scientific models and theories are created from human minds and may or may not accurately represent reality.

Generally several of the interview participants (ST 6, 8, 10, 12, 14, and 16-19) agreed in some part that theories and models are products of the human mind, may or may not model aspects of reality and are needed to assist in understanding scientific knowledge. Other participants (ST 2-5, 7, 11, 15, and 20) agreed that theories and models are products of the human mind and come close to being copies of reality. While some participants (ST 1, 9, and13) did not believe that scientific theories and models were products of human imagination but based on facts and represent reality. Participants often credited theories and models solely to the accumulation of new observations or data and/or the development of new technologies. However, one participant (ST 12) considered change that results from reinterpretation of existing data from a different perspective.

Table 56 Descriptive NSKS Statistics - Creative Dimension

ID	Pre	Post	Difference
1	23.00	26.00	3.00***
2	23.00	24.00	1.00***
3	21.00	24.00	3.00***
4	23.00	25.00	1.00***
5	23.00	25.00	2.00***
6	24.00	22.00	-2.00*
7	21.00	24.00	3.00***
8	24.00	20.00	-4.00*
9	25.00	26.00	1.00***
10	22.00	28.00	6.00***
11	18.00	24.00	6.00***
12	19.00	22.00	3.00***
13	25.00	26.00	1.00***
14	22.00	25.00	3.00***
15	25.00	20.00	-5.00*
16	24.00	24.00	0.00*
17	21.00	23.00	2.00***
18	25.00	25.00	0.00*
19	22.00	25.00	3.00***
20	25.00	25.00	0.00*

* decrease in score or no change
** ≤ 0.96 points gain in score
*** > 0.96 points gain in score

When comparing participants' initial interview comments with their initial NSKS scores for the creative dimension of NOS some of the participants' scores mirror their reflections while others did not. For instance participant 1 had an initial score in the realist range and reflected that range in her interview statements that theories and models are based on facts and not products of the human mind. While participants 2-5, 7, and 11 all had initial scores in the realist range but their interview comments suggested that theories and models are products of the human mind and come close to being copies of reality. Participant twelve had an initial NSKS score in the realist range however during the interview suggested that theories and models are products of the human mind, may or may not model aspects of reality and are needed to assist in understanding scientific knowledge. Participant thirteen had an initial NSKS score that reflected an instrumentalist view yet in her initial interview she held the belief that scientific theories and models accurately represented reality and were not products of the human mind. These discrepancies between NSKS scores and interview statements could be attributed to several factors such as: distracted during the administration of the NSKS resulting in incorrect bubbling of answer choice or interpretation of the NSKS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 57 Participants' Interview Reflections - Creative (N=20)

Initial NOS Beliefs Interview Question-1-Creative
There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statements: Scientific theories and models are products of the human mind and may or may not accurately represent reality.
Quotation Comments
ST 1: **"**False, theories are based on facts. For instance theories have been tested and show consistent results. Therefore, a fact is something that is proven by testing."
ST 2: "I believe that the theories and models are based on some reality. The human mind questions and tries to figure out what happened. Scientist question what is proposed and try to disprove the theory. Sometimes this changes the way science presents an idea. It is a product of the mind, but was stimulated from reality."
ST 3: "I think that theories do originate from human minds. Someone has to discover and create theories. I do think that they can accurately represent reality."
ST 4: "I think the models are products of the human mind and are reflective of our best understanding of science. Therefore, they represent reality as accurately as can be reflected at the current time. Theories and models are subject to change as information and knowledge evolves."
ST 5: "Yes, models and theories are produced by the human mind. They represent some aspects but not all things are truly revealed. So scientists make the best guess as to how it applies."
ST 6: "They are products of the human mind. But, they help one understand the concepts. Theories might not accurately or perfectly describe the actual concept but it's the best replication one has to help in understanding the concept. For instance, when one views the atomic models and orbital's via diagrams. The diagrams may not reflect the actual atom, but it's the best thing that we have to represent it. That is our reality."
ST 7: "More or less, scientific theories begin as products of the human mind. However the ultimate goal of a theory is to become a fact and be able to represent reality."

Continued on next page

Table 57 (Continued)

ST 8: "I believe the statement is true. We cannot always replicate a scientific theory into a perfect model."
ST 9: "Theories have been proven, so they can apply to some aspects of reality."
ST 10: "I think it has to do with the human mind and the way that we interpret scientific knowledge. For the most part theories and models are based on observations and experiments performed by several scientists. When science is replicated by others then it becomes part of a theory. So, in that way it's not just a product of the human mind, it's only a product of the human mind in the way we interpret it."
ST 11: "Theories and models are accurate but they are also products of the human mind. Theories and models are created after someone conducts an experiment."
ST 12: "It all depends on how someone interprets the information. It may be accurate and it might not be accurate. If one scientist looks at scientific data from an experiment and a different scientist looks at the same data their own knowledge and opinions will be reflected in the theories that they make and the explanations they give. So theories and models may be products of the human mind and may or may not be accurate."
ST 13: "I think that scientific theories and models do accurately represent reality. They are based on evidence and not just made up from the human mind."
ST 14: "True, theories are produced by the human mind. However, there is plenty room for error as it does not accurately represent reality."
ST 15: "Yes and no. One may never know for sure if theories and models are accurate or whether they represent reality."
ST 16: "Yes. For instance one scientist starts with a research concept and then others may research the same topic and add knowledge to support or not support it. It's developed in the human mind but it may somewhat accurately represent what we know. For example the atomic theory, we haven't totally disproved it."
ST 17: "True enough as theories and models are products of the human mind but based on physical evidence."
ST 18: "I agree. There are scientific theories from the 17th century that we look at and wonder what we were thinking at the time. However, it gave one a basis to prove if it was correct or incorrect. So, they might be accurate for the time until someone can prove that they were incorrect."
ST 19: "Yes they are products of the human mind. But when scientists make theories they are based on evidence-based reasoning and are generally accurate until proven false."
ST 20: "Although many scientific laws have eventually been proven many theories are yet to be proven. It is through the great imagination of brilliant minds that we have any scientific facts at all."

Developmental Dimension

In the current NOS literature the developmental dimension of scientific knowledge is viewed as operating on a continuum that ranges from viewing scientific knowledge as absolute, "set in stone" to viewing it as changing and dynamic. According to Rubba and Anderson (1978) scientific knowledge is never "proven" in the absolute and final sense. Scientific knowledge is limited by the justification process rendering it as probable. Scientific beliefs that appear to be true at one time may be assessed differently when additional evidence is available. Formerly accepted scientific beliefs should be judged in their historical context.

Within this dimension the overall participant (N=56) developmental pre-test mean was 23.62 while the post-test mean was 24.76 (Table 54) with 28 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 24.00 and 24.70, respectively with 7 participants improving their score. This was also a category that quantitatively showed an above average increase of 1.14 points when compared to the overall average increase of 0.96 (N=56). This above average increase occurred in 19 of the 56 participants, and 6 of the 20 interviewed participants' scores. The participant with the highest pre-post score change of 8 points as well as the highest post score was student 29 with a score of 31. This moved the participant from the realist end of the NSKS scale to the instrumentalist end by the end of the semester.

However, for the interview participants the overall increase in post NSKS developmental scores (Table 58) was below average with a 0.70 point average increase. The highest pre-post score change within the interview participants was participant 14 with a 5 point increase (20 to 25). This moved the participant from the neutral section of the NSKS scale into the instrumentalist range by the end of the semester. Participants 2 and 15 had the highest post scores each with 27 remaining in the instrumentalist range (Figure 7). Approximately 45% of the interview participants improved their score on the "development" dimension. This gain suggests that some participants are moving toward the belief that scientific knowledge is not "set in stone" which represents a more instrumentalist point of view.

Initially 35% of the interview participants (N=20) scores (ST 3-7, 14, and 18) suggested they held the naïve (realist) view that scientific knowledge is "set in stone".

However, by the end of the semester only 15% of the participants' NSKS scores (ST 5, 13, and 18) fell in the realist range. The initial NSKS development scores of 20% of the interview participants (ST 12, 16, and 19-20) fell in the neutral range suggesting they held a combination of naïve and expert beliefs concerning the tentativeness of scientific knowledge. By the end of the semester 30% of the participants (ST 3-4, 7, 17, and 19-20) scored in the neutral range. The initial scores of nine of the participants (ST 1-2, 8-11, 13, 15, and 17) suggested they held an appropriate view (instrumentalist) that scientific knowledge is tentative and evolving. Eleven participants (ST 1-2, 6, 8-12, and 14-16) scored in the instrumentalist range by the end of the semester.

Table 58 Descriptive NSKS Statistics - Developmental Dimension

ID	Pre	Post	Difference
1	26.00	26.00	0.00*
2	26.00	27.00	1.00***
3	22.00	24.00	2.00***
4	23.00	24.00	1.00***
5	22.00	22.00	0.00*
6	22.00	25.00	3.00***
7	23.00	24.00	1.00***
8	26.00	25.00	-1.00*
9	26.00	26.00	0.00*
10	25.00	25.00	0.00*
11	25.00	25.00	0.00*
12	24.00	26.00	2.00***
13	25.00	22.00	-3.00*
14	20.00	25.00	5.00***
15	25.00	27.00	2.00***
16	24.00	26.00	2.00***
17	25.00	24.00	-1.00*
18	23.00	23.00	0.00*
19	24.00	24.00	0.00*
20	24.00	24.00	0.00*

* decrease in score or no change
** ≤ 0.96 gain in score
*** > 0.96 gain in score

Although increases were observed quantitatively with some of the interview participants, the difference in their understandings is best reflected in the interview responses in Table 59. In order to query participants, understanding of the developmental dimension of NOS in relation to the tentativeness of scientific knowledge, the initial interview question asked the participants to react to the following statement: “Scientific knowledge is a changing and evolving body of concepts and theories.” This question assessed participants’ understanding that scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations.

The majority of interview participants (ST 1-2, 4-20) agreed part that scientific knowledge is a changing and evolving body of concepts and theories. Only one participant (ST 3) felt that science was exact with set rules and laws and it was possible as new things were discovered that scientific concepts could change. Participants often credited the changes in scientific knowledge to the accumulation of new observations or data and/or the development of new technologies. However, one participant (ST 6) considered change that results from reinterpretation of existing data from a different perspective.

When comparing participants’ initial interview comments with their initial NSKS scores for the developmental dimension of NOS some of the participants’ scores mirror their reflections while others did not. For instance several participants (4-7, 14, and 18) had initial scores in the realist range and yet in their interview statements suggested that scientific knowledge does evolve and change over time. Other participants (ST 12, 16, and 19-20) had initial scores in the neutral range but their interview comments suggest they hold the belief that scientific knowledge does evolve and change over time. The remaining participants (1-2, 8-11, 13, 15, and 17) had initial scores in the instrumentalist range that correlated with their interview reflection that scientific knowledge does evolve and change over time. These discrepancies between NSKS scores and interview statements could be attributed to several factors such as: distracted during the administration of the NSKS resulting in incorrect bubbling of answer choice or interpretation of the NSKS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 59 Participants’ Interview Reflections - Developmental (N=20)

Initial NOS Beliefs Interview Question-2-Developmental
There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statement: Scientific knowledge is a changing and evolving body of concepts and theories.
Quotation Comments
ST 1: “I agree. Theories change when knowledge is advanced. At one point the world had no knowledge of evolution, or antibiotics and now they do through scientific research and developments.”
ST 2: “I believe that is accurate. Scientific knowledge changes due to new technology. This new technology spawns new theories and new twists on old theories. Therefore scientific knowledge is always changing.”
ST 3: “First science is often referred to as being very exact with set laws and rules, which I believe is true. However, I would also imagine that as new things are discovered different concepts may be introduced.”
ST 4: “I definitely agree. I think scientific knowledge evolves. I don't feel that everything in this universe is understood or currently clear.”
ST 5: “Yes, I believe that scientific knowledge is changing, but not so immediately like the next day. The change might be over a period of months to years. ”
ST 6: “I would say yes. Scientific knowledge is always changing and evolving. Scientist can develop new ways to think about old knowledge. From this develop different theories.”
ST 7: “I believe that scientific knowledge is and will always be changing.”
ST 8: “Yes I think scientific knowledge is evolving in the sense that more facts, concepts, and theories are added and discovered over time. In other words, some old concepts can be tested and proven false. For instance, when they believed that everything was made of the elements of earth, fire, water, and air. We now know this to be false because of new scientific knowledge and concepts.”
ST 9: “Yes, newer theories/concepts are being discovered all the time. Because our world continues to evolve, therefore so does science.”
ST 10: “I agree. We could discover something that would change our views about some entire body of knowledge as a whole. I think scientific knowledge will always evolve.”
ST 11: “Yes, experiments show new findings when they are conducted and show new things which weren’t known before.”
ST 12: “Yes because new scientific knowledge can add to current theories. Scientists can develop new theories through their research.”
ST 13: “I agree because it seems like scientific knowledge is changing all the time when scientists find new evidence and add to theories.”

Continued on next page

Table 59 (Continued)

ST 14: "True. Changes in scientific knowledge are always occurring. Changes in concepts and theories occur when scientist develop better explanations."
ST 15: "Yes, new discoveries are constantly being made."
ST 16: "Yes. Scientific knowledge has been evolving since the beginning of time. With the development of new technologies scientific knowledge has been evolving."
ST 17: "I agree completely. There are constantly new developments changing what we know to be true."
ST 18: "Yes, for instance someone just discovered a new element. Everyday scientists are discovering new things."
ST 19: "Yes, science is changing everyday. However, the new things we learn are usually from things that have happened over a gradual period of time."
ST 20: "Yes there are always new discoveries. It is ever changing and ever evolving but there are still many scientific standards and benchmarks that hold fast."

Parsimonious Dimension

In the current NOS literature on the parsimonious dimension, evolving scientific knowledge is viewed as operating on a continuum that ranges from the view that scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity. According to Rubba and Anderson (1978) scientific knowledge tends toward simplicity but not the disdain of complexity. Scientific knowledge is comprehensive as opposed to specific. There is a continuous effort to develop a minimum number of scientific concepts to explain the greatest number of possible observations. The ultimate goal of science is to develop an understanding of the natural universe which is free of biases.

Within this dimension the overall participant (N=56) pre-test mean was 24.62 while the post-test mean was 26.32 (Table 54) with 36 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 24.55 and 26.70, respectively with 10 participants improving their score. This was also a category that quantitatively showed an above average increase of 1.70 points when compared to the overall average increase of 0.96 (N=56). This above average increase occurred in 33 of the 56 participants, and 15 of the 20 interviewed participants' scores. The gain on the “parsimonious” dimension is an indicator that some participants are moving toward an instrumentalist view that scientific knowledge attempts to achieve simplicity of explanation and away from a realist view that it attempts to achieve complexity.

However, for the majority of interview participants (Table 60) the overall increase in post parsimonious scores was above the average of 1.70 points.   The highest pre-post score change within the interview participants was participant 15 with an increase of 6 points. This moved the student from the realist section of the NSKS scale to the instrumentalist end by the end of the semester. In addition participant 5 had the highest post score of 31. With approximately 45% of the participants improving their score on the “parsimonious” dimension this suggests that some of the participants are moving towards the belief that scientific knowledge attempts to achieve simplicity of explanation rather than complexity.

Initially 25% of the interview participants (N=20) scores (ST 2, 4, 10, and 14-15) suggested they held naïve (realist) view that scientific knowledge attempts to achieve complexity of explanation and that it is specific as opposed to comprehensive. However, by the end of the semester only 5% of the participants’ NSKS scores (ST 14) fell in the realist range. The initial NSKS scores of 35% of the interview participants (ST 1, 3, 8, 13, and 16-18) fell in the neutral range suggesting they held a combination of naïve and expert beliefs concerning the parsimonious nature of science. By the end of the semester 10% of the participants (ST 10 and 17) scored in the neutral range. The initial scores of eight participants (ST 5-7, 9, 11-12, and 19-20) suggested they held an appropriate view (instrumentalist) concerning the parsimonious nature of science. Seventeen participants (ST 1-9, 11-13, 15-16, and 18-20) scored in the instrumentalist range by the end of the semester.

Table 60 Descriptive NSKS Statistics - Parsimonious Dimension

ID	Pre	Post	Difference
1	24.00	27.00	3.00***
2	22.00	27.00	5.00***
3	24.00	27.00	3.00***
4	23.00	26.00	3.00***
5	26.00	31.00	5.00***
6	27.00	25.00	-2.00*
7	27.00	29.00	2.00***
8	24.00	26.00	2.00***
9	27.00	29.00	2.00***
10	21.00	24.00	3.00***
11	29.00	25.00	-4.00*
12	25.00	29.00	4.00***
13	24.00	25.00	1.00***
14	21.00	23.00	2.00***
15	23.00	29.00	6.00***
16	24.00	26.00	2.00***
17	24.00	24.00	0.00*
18	24.00	26.00	2.00***
19	25.00	29.00	4.00***
20	27.00	27.00	0.00*

* decrease in score or no change
** ≤ 0.96 gain in score
*** > 0.96 gain in score

Although increases were observed quantitatively with a majority of the interview participants, the difference in their understandings is best reflected in the interview responses in Table 61. In order to query participant' understanding of the parsimonious dimension of NOS in relation to the simplicity rather than complexity of scientific knowledge, the initial interview question asked the participants to react to the following statement: “The ultimate goal of science is to gather all the complex facts about natural phenomena.” This question assessed participants' understanding that scientific knowledge tends toward simplicity, is comprehensive, and there is an effort to develop a minimum number of concepts in order to develop an understanding of the natural world which is free of biases.

Several of the interview participants (ST 3, 5, 9-13, and 20) suggested that the ultimate goal of science was not to gather all the complex facts but to understand them and how they apply to the world. Other participants (ST 6-8 and 15-19) believed that the ultimate goal of science was to gather all the complex facts as well as understand how they applied to the world. The remaining participants (ST 1-2, 14, and 17) felt that the ultimate goal of science was to gather all the complex facts about natural phenomena. Participants often credited the goal of science solely to the exploration and understanding of the world/natural phenomena. However, a few of the participants (ST 14) considered the gathering of complex facts over theories as the goal.

When comparing participants' initial interview comments with their initial NSKS scores for the parsimonious dimension of NOS some of the participants' scores mirror their reflections while others did not. For instance participants 2, 4, and 14 had initial scores in the realist range and reflected that range in their interview statements that that the ultimate goal of science was to gather all the complex facts about natural phenomena. While participant 15 had an initial score in the realist range but suggested that the ultimate goal of science was to gather all the complex facts as well as understand how they applied to the world. Participant 10 had an initial NSKS score in the realist range however during the interview suggested that the ultimate goal of science was not to gather all the complex facts but to understand them and how they apply to the world. Other participants (ST 5, 9, 11-2, and 20) had initial NSKS scores that reflected an instrumentalist view and reflected those views in their interview comments. These discrepancies between NSKS scores and interview statements could be attributed to several factors such as: distracted during the administration of the NSKS resulting in incorrect bubbling of answer choice or interpretation of the NSKS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 61 Participants' Interview Reflections - Parsimonious (N=20)

Initial NOS Beliefs Interview Question-3- Parsimonious
There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statement: The ultimate goal of science is to gather all the complex facts about natural phenomena.
Quotation Comments
ST 1: "That's true. Except I think it's sort of a fruitless goal. We will never know everything. But, that's what we're aiming for."
ST 2: "I believe that is the ultimate goal in one fashion or another."
ST 3: "I do not know enough to absolutely know whether this is right or wrong. However, my feeling is that science does not only want to gather facts, but also analyze them and know what they mean. So gathering facts of natural phenomena is one thing, but also applying it to life is another."
ST 4: "I would say yes, that is a good description of scientific goals. Naturally occurring things can be tested with hands on experimental techniques."
ST 5: "No, I do believe that we need to gather all the natural forms."
ST 6: "To gather everything about the world we live in and try to figure things out. How everything works and how it's all interconnected and how it relates to each other."
ST 7: "I agree science is about understanding the world and its' make-up."
ST 8: "True, and to explain these facts."
ST 9: "No. Science also involves other sources that you wouldn't find naturally."
ST 10: "I don't necessarily believe that. I think that science is to gather the facts about everything. The purpose of science is to gather knowledge about medicines, things for the future, different kinds of tools, and whatever we need to know. I don't think it necessarily is natural phenomena."
ST 11: "No, the goal of science is to keep gaining new knowledge. So the world in its evolution can keep going on."
ST 12: "No because science is not only used to figure out natural phenomena it is also conducted for everyday purposes like making medicine."
ST 13: "I think that the ultimate goal of science is to explore ideas and develop theories. Also to find out what is real and not real and how things work, and not just about natural phenomena."
ST 14: "True. Facts, I believe are more important than theories. Although science is full of theories there are plenty of facts to back up natural phenomena."
ST 15: "Yes, and to understand it."
ST 16: "Well, I don't think we'll ever gather all the facts about natural phenomena, but ultimately yes, I would say that's the goal."
ST 17: "Yes. I'm trying to think of a type of science that doesn't deal with that but even the biological sciences do, because living creatures are natural phenomena too."

Continued on next page

Table 61 (Continued)

ST 18: "Yes, I agree with that. I think the reason people study science is to understand why things are the way they are. Why the sky is blue is always a constant question. They want to figure out why things are the way they are."
ST 19: "Yes, I would say this is the goal of science because it's to find how things work and you need to do this by consistently gathering facts."
ST 20: "I believe the ultimate goal of science is to understand the function and actions of the world we live in - how and why everything occurs the way that it does. How can we live with it or use it to make things better."

Testable Dimension

In the current NOS literature the testable dimension is viewed as operating on a continuum that ranges from the view that scientific knowledge needs not to be capable of experimental test as opposed to it is capable of empirical tests. According to Rubba and Anderson (1978) scientific knowledge is capable of public empirical tests. Scientific knowledge's validity is established through repeated testing against accepted observations. Consistency among results is required, but not a sufficient condition for the validity of scientific knowledge. There is no one way to do science therefore there is no universal step-by-step scientific method.

Within this dimension the overall participant (N=56) testable pre-test mean was 24.20 while the post-test mean was 24.98 (Table 54) with 13 participants improving their score. The pre- and post-mean scores of the interviewed participants (N=20) were 24.05 and 24.30, respectively with 10 participants improving their score. This was also a category that quantitatively showed a below average increase of 0.78 points when compared to the overall average increase of 0.96 (N=56). The participant (N=56) with the highest pre-post score change of 10 points as well as the highest post score was student 52 with a score of 34. This moved the student from the neutral end of the NSKS scale to the instrumentalist end by the end of the semester.

Initially 35% of the interview participants (N=20) scores (ST 2, 5, 7, 13-14, and 17-18) suggested they held naïve (realist) views that scientific knowledge needs not to be capable of experimental test and the scientific method does offer the real truth. However by the end of the semester only 15% of the participants' NSKS scores (ST 4, 5, and 17) fell in the realist range. The initial NSKS scores of 15% of the interview participants (ST 4 and 15-16) fell in the neutral range suggesting they held a combination of naïve and expert beliefs concerning the role that empirical evidence and the scientific method plays in the nature of science. By the end of the semester 30% of the participants (ST 2-3, 12-13, 16, and 18) scored in the neutral range. The initial scores of ten of the participants (ST 1, 3, 6, 8-12, and 19-20) suggested they held an appropriate view (instrumentalist) on the role that empirical evidence and the scientific method plays in the nature of science. Eleven participants (ST 1, 6-11, 14-15, and 19-20) scored in the instrumentalist range by the end of the semester.

However, for the majority of interview participants (Table 62) the overall increase in post testable scores was above the average increase of 0.79 points. The highest pre-post score change within the interview participants of 6 points were students 10 and 11. In addition student 10 had the highest post score of 28. This moved the student from the neutral section of the NSKS scale to the instrumentalist end by the end of the semester. Approximately 20% of the participants improved their score on the "testable" dimension. This suggests that a small portion of the participants are moving away from a realist view that scientific knowledge needs not be capable of empirical tests to a more instrumentalist point that scientific knowledge is capable of empirical tests.

Although some increases were observed quantitatively with ten of the twenty interview participants, the difference in their understandings is best reflected in the initial interview responses in Table 63. In order to query participants, understanding of the testable dimension of NOS the initial interview question asked participants to respond to the following: “The scientific method will eventually let people learn the real truth about the natural world and how it works.” This question assessed participants' understanding that scientific knowledge is based on and/or derived from observations of the natural world, there is no universal step-by-step scientific method, and science cannot answer all questions.

Table 62 Descriptive NSKS Statistics - Testable Dimension

ID	Pre	Post	Difference
1	25.00	25.00	0.00*
2	23.00	24.00	1.00***
3	27.00	24.00	-3.00*
4	24.00	23.00	-1.00*
5	21.00	22.00	1.00***
6	25.00	25.00	0.00*
7	22.00	26.00	4.00***
8	26.00	25.00	-1.00*
9	26.00	25.00	-1.00*
10	27.00	26.00	-1.00*
11	25.00	26.00	1.00***
12	26.00	24.00	-2.00*
13	22.00	24.00	2.00***
14	22.00	25.00	3.00***
15	24.00	25.00	1.00***
16	24.00	24.00	0.00*
17	19.00	22.00	3.00***
18	23.00	24.00	1.00***
19	25.00	26.00	1.00***
20	25.00	25.00	0.00*

* decrease in score or no change
** ≤ 0.96 gain in score
*** > 0.96 gain in score

Several of the interview participants (ST 1, 3, 6, 10-11, 14, 16, and 20) agreed in some part that scientific knowledge is based on and/or derived from observations of the natural world and science cannot answer all questions. However, none of the aforementioned participants reflected on the aspects of the scientific method. Only two participants (ST 5 and 7) mentioned that the scientific method was a tool and could not give us all the scientific knowledge about the world. Other participants (ST 8-9, 12, 15, and 17-19) interview statements reflected a realist view with the belief that the scientific method will eventually let people learn the real truth about the natural world and how it works. Some participants credited the scientific method with the all the current scientific knowledge.

When comparing participants' initial interview comments with their initial NSKS scores for the testable dimension of NOS few of the participants' scores mirror their reflections. For instance several participants (2, 17, and 18) had initial scores in the realist range and reflected that range in their interview statements that the scientific method will eventually let people learn the real truth about the natural world and how it works. While participants 4 and 16 had initial scores in the neutral range which are reflected in their interview comments suggesting that some things will not be made clear by the scientific method and others will. Other participants (1, 3, 6, 10-11, and 20) all had initial NSKS scores in the instrumentalist range however their interview statements reflected a combination of beliefs concerning the testable dimension including that we will never know the real truth about everything and that the scientific methods allows for advances in scientific knowledge. Participants 5 and 7 had initial scores reflecting realist views however their interview statements suggested that the scientific method was just a tool and it does not give us all the scientific knowledge about the world. The initial NSKS scores for four participants (8-9, 12, and 19) reflected an instrumentalist view however their interview reflections suggested they believed that the scientific method will eventually let people learn the real truth about the natural world and how it works. These discrepancies between NSKS scores and interview statements could be attributed to several factors such as: distracted during the administration of the NSKS resulting in incorrect bubbling of answer choice or interpretation of the NSKS questions and/or answer selection as well as their personal experiences in the chemistry lecture and laboratory course during the semester.

Table 63 Participants' Interview Reflections - Testable (N=20)

Initial NOS Beliefs Interview Question- 4- Testable
There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statement: The scientific method will eventually let people learn the real truth about the natural world and how it works.
Quotation Comments
ST 1: "I don't think there will ever be a time where we know absolutely everything about the world and how it works. Although we make advances in our knowledge of the world all the time using the scientific method the world is always changing."
ST 2: "I believe eventually through persistence humans will be able to figure out how the natural works in scientific terms. However, I don't know if the world will be ready to accept what science will offer."
ST 3: "I don't have enough personal experience yet to make an absolute choice. Scientific method is about obtaining scientific results, but I am not sure whether it will let us learn about the real truth of the world."
ST 4: "Depends on your definition of "eventually". I think that some things won't be made totally clear by scientific method any time soon. However some things could become clearer in the very near future."
ST 5: **"**No, the scientific method is a nice tool, but can not give us all the knowledge."
ST 6: "It might and it might not. We keep learning more and it definitely helps. It starts us on the right track for questioning it and finding out as much as we can."
ST 7: "I believe that if the knowledge is out there we may be able to acquire it. However some things may never be discovered using the scientific method like the big bang theory."
ST 8: "Yes. Through observation and use of the scientific method one can learn truths of the natural world."
ST 9: "Yes, because that's what all science is based on."
ST 10: "Well, despite how much the scientific method is used to support science, I still think that because much of science is based on theory that it won't necessarily be the real truth."
ST 11: "There is no real truth. No one really knows how the world works as new things are discovered everyday. However we do gain new knowledge the world with the scientific method."
ST 12: "Yes because it is how we have learned what we know so far. Therefore unless a more advanced method of thinking is established then the scientific method offers a perspective on how it works."

Continued on next page

Table 63 (Continued)

ST 13: "I think that the scientific method helps one explain and understand more about how the world works and why."
ST 14: "No, the scientific method may try to teach people the truth about the natural world, but other factors may stand in the way."
ST 15: "Yes if they are willing to learn the real truth."
ST 16: "I wouldn't say it's necessarily the real truth because again, it's about theory. The scientific method helps us learn a lot about the natural world and how it works, but not the complete real truth. For example there's many species we haven't discovered in the ocean."
ST 17: "I agree. I think the only opposing argument is in the world of theology but you can't really argue it once they have all the facts."
ST 18: "Yes, I agree with this because the scientific method is way of analyzing situations. If everyone follows the method then the data will be consistent. Each scientist might look at the data differently, but they will all have used the same standard."
ST 19: "Yes the scientific method could possibly tell us the truth about the world and how it works. It is a step by step way of proving how something works."
ST 20: "The real truth is probably far too difficult for most people to understand. But most people can have a basic understanding of how the natural world works. I am not sure what my definition of the real truth is."
ST 20: "The real truth is probably far too difficult for most people to understand. But most people can have a basic understanding of how the natural world works. I am not sure what my definition of the real truth is."

Final NOS Interviews

During the final interview, participants were presented with an ill-structured scenario problem from King and Kitchener (1994). The reflective judgment scenario problem (Appendix F) incorporates some aspects of the four NSKS dimensions from the initial interview with the focus being on the developmental (tentativeness of scientific knowledge) and testable (empirical basis) dimensions.

The following NOS characteristics served as a basis of comparison during the analysis of the post NSKS scores and final NOS interview: (1) Scientific knowledge is tentative since it is subject to change with new observations and with the reinterpretations of existing observations; (2) Scientific knowledge is empirically based because it is based on and/or derived from observations; (3) Scientific knowledge is subjective due to prior experiences and beliefs of scientists. Scientific knowledge is theory-laden as interpretations of data are filtered through existing theories; and (4)

Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena while scientific models are based on inferences to represent and understanding of a mechanism or relationship and do not necessarily represent the actual phenomena.

The overall average score for the NSKS at the beginning of the semester course for all participants (N=56) was 142.482 indicating most participants NOS beliefs fell in the unaccepted NOS views range. By the end of the semester, the overall average score for all the participants was 148.375 indicating a slight shift from non accepted views (realist) to a blend of neutral and instrumentalist views of NOS.

The interviewed participants' overall average score (N=20) for the NSKS at the beginning of the semester course was 141.650 indicating most participants held neutral NOS belief. Initially 70% of the interview participants (N=20) NSKS scores (ST 1, 3-4, 7, 10-12, and 14-20) suggested they held naïve (realist) NOS views. However by the end of the semester 85% of the participants' NSKS scores (ST 1-12, 15-16, and 18-20) fell at the beginning of the instrumentalist range. By the end of the semester, the overall average score for all the interviewed participants was 148.900 placing them at the edge of neutral and instrumentalist views of NOS. For the majority of interview participants (ST 1-5, 7, 9-12, 14, 17, and 19-20) the overall increase in post NSKS scores was above the average increase of 5.9 points (Table 55). The highest score was 155 earned by 2 participants (ST 1 and 9) indicating acceptance of NOS views and the lowest score was 142 scored by 2 participants (14 and 17) in the realist range. Again it is worth noting that for the post-assessment overall score, 17 of 20 students scored in the range of acceptance of NOS views with one participant (13) scoring in the neutral range and the remaining 2 scoring in the realist range. Therefore the majority of the participants scored in the acceptance of NOS views range by the end of the semester (Table 55).

Although increases were observed quantitatively with seventeen of the twenty interview participants, the difference in their understandings is best reflected in the final interview responses in Table 63. In order to query participants, understanding of NOS the initial interview question asked participants to respond to the following: "Some scientists believe that explanations of chemical phenomena, such as atomic theory, are accurate and true descriptions of atomic structure. Other scientists say that we cannot know whether or not these theories are accurate and true, but that scientists can only use such theories as working models to explain what is observed. This scenario problem probes participants' understanding that scientific knowledge is tentative, has an empirical basis, the role a scientist's subjectivity and creativity plays, and theories and models are based on inferred explanations and may or may not represent reality.

Scientific knowledge, while reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change. Several of the interview participants (ST 4, 6-7, 10-12, 14-16, and 18-20) illustrated their belief in the tentativeness of scientific knowledge in their final interview comments (Table 64). The participants reported that scientific knowledge changes because of new observations or evidence and there were many questions still unanswered. The remaining participants did not mention the tentativeness of scientific knowledge in their responses.

Science's necessary reliance on empirical evidence is what distinguishes it as a way of knowing from other disciplines. Science is at least partially based on observations. In relation to the empirical basis of NOS 50% of the participants (4, 6, 9-12, 14, 16, and 19-20) identified scientific knowledge such as theories as being derived from observations or evidence. The remaining participants did not directly mention evidence or observations in their reflections.

According to Lederman, et al., (2002) scientific knowledge is theory-laden. Scientists' theoretical commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work. Science is influenced and driven by currently accepted scientific theories. In the final interview of several participants (ST 1-2, 6, 12, 16, and 18-20) suggested that science is theory-laden and that a scientist's beliefs play a role in science. Participants one and sixteen mentioned that scientists can and do disagree and neither are necessarily correct or incorrect. Participant three felt conflicted over scientists' beliefs about theories. She tended to support the view that scientists believe that explanations of chemical phenomena are accurate and true descriptions. The remaining participants mentioned theories but not the influence that scientist have on scientific theories.

Theories are inferred explanations for observable phenomena. Scientific theories are often based on a set of assumptions or axioms. Theories serve to explain large sets of seemingly unrelated observations. Scientific models are created to describe aspects of a theory and are useful in giving predictions and explanations. Scientific models based on available data, and are not copies of reality. The final interview statements of 70% of the participants (ST 4, 6-12, 14-17, and 19-20) agreed with the second statement that scientists can only use such theories as working models to explain what is observed. However one participant (ST 13) described theories as being accurate and true.

When comparing participants' final interview comments with their final NSKS scores few of the participants' scores mirror their reflections. For instance two participants (14 and 17) had final NSKS scores in the realist range however reflected instrumentalist views in their interview statements that theories are working models and scientific knowledge is tentative. While participant thirteen had a final NSKS score in the neutral range but reflected a realist view in her interview comments suggesting that theories are accurate and true. Other participants (3-4, 8, 11, 15-16, 18, and 20) all had final NSKS scores at the low end of the instrumentalist range. The majority of the aforementioned participants (4, 8, 11, 15-16, and 20) reflected a moderate to higher level of thinking and tended to agree with the second statement that we cannot know whether or not these theories are accurate and true, but that scientists can only use such theories as working models to explain what is observed. As stated earlier participant thirteen was conflicted and supported the first part of the statement that theories are accurate and true descriptions of scientific knowledge. The remaining participants (1-2, 5-7, 9-10, 12, and 19) had final NSKS scores reflecting a higher instrumentalist view. However several participants (1-2, and 5) held more moderate views of NOS in their interview statements while the remaining participants (7, 9-10, 12, and 19) reflected a higher level of acceptance of NOS views.

Table 64 Final Interviews – Nature of Science (N=20)

Final NOS Interview Question
Some scientists believe that explanations of chemical phenomena, such as atomic theory, are accurate and true descriptions of atomic structure. Other scientists say that we cannot know whether or not these theories are accurate and true, but that scientists can only use such theories as working models to explain what is observed. What do you think about this statement? How did you come to hold that point of view or answer? On what do you base that point of view or answer?
Quotation Comments
ST 1: “I think the statement shows that scientists can disagree and neither one of them are necessarily incorrect. The goal of science is to learn more about scientific knowledge. So, I think that both of these scientists are correct in believing what they believe until somehow it’s disproven.”
ST 2: “I really think that we use theories to help explain current scientific knowledge. If the theory is disproven we need to be able to go back to the beginning of the theory and reevaluate. We will never really know until we prove or disprove it.”
ST 3: “I think it is conflicting what scientists think about theories. I think theories are not a law. It seems a theory offers a little more room to maneuver. It would be difficult for me to say one is correct and one is not correct. I would need to know more about each person’s case. I do agree more with the first scientist.”

Continued next page

Table 64 (Continued)

ST 4: "I agree with the second statement that theories can be used as working models. This is because our understanding of how the universe works is still evolving. There are many questions that are still unanswered and scientific knowledge is always changing."
ST 5: "Both statements could be true. However, we don't have all the scientific knowledge yet. Exact truth in science is not fully formed."
ST 6: "I lean more toward using theories as working models. As some scientists say we don't know if they are accurate and true but the models represent to the best of our ability what we consider to be true from what we observed. Scientific knowledge is changing. We don't know if we'll ever absolutely understand everything and all the variables. There are still unknown information that may result in changes in theories."
ST 7: "I agree that theories are used as models. Not all scientific knowledge can be proved or disproved. One must have some kind of support/evidence."
ST 8: "I agree with the second statement that theories can be used as working models of what could be. I think a theory could be accepted as some part of the truth but it is still a theory and not completely a fact. Example of fact? I am 5 foot 7. Example of theory? Evolution."
ST 9: "I can see the truth in both statements. I would probably be grouped in the category where you can't know whether or not theories are accurate and true, but that you use the theories as working models to explain what is observed. However, some theories have been around for a long time and have not been disproven."
ST 10: "I think many concepts in science involve the use of a theory with a working model to explain the theories and/or what we've observed. This is because scientific knowledge is always changing. Things that were considered factual may now be considered completely or partially incorrect."
ST 11: "I agree with the second statement. We can't know whether theories are true or false. Science is changing all the time. There is always room for error."
ST 12: "Theories are considered by some to be true until someone disproves them. The second statement suggests that one can explain what is observed by using a model. For instance Lewis-Dot structures show the electrons are organized in a certain way. So one can use the model but there eventually there might be evidence that contradicts the theory so one would need a new model. So theories aren't set they can always change if somebody discovers some new evidence."
ST 13: "I think that theories are accurate and true. This we know because of evidence."
ST 14: "Models explain what's being observed from theories. But, I do think that there are things that can be changed in the models as science is not set in stone. I understand that through experiments there's repetition and that's what supports theories."
ST 15: "Theories should be used as working models. The scientific process is not set in stone."
ST 16: "I'm sure there are some scientists that believe that theories are accurate and true. Others say that they're not necessarily accurate and the true because you can't exactly prove it. I would say that I agree with the scientists that believe that theories are working models. One cannot know whether the theories are accurate and true. For instance we can't see the atom itself. We can't say the theory is set in stone. It's just a theory to explain something we presently believe based on some evidence."
ST 17: "Theories are not necessarily accurate or true. I believe they are more of an accepted working model."
ST 18: "Well they might be accurate for the time, but, they're set in stone. For instance 100 years from now scientist could replace the current knowledge of the atomic theory with new knowledge. Therefore it's not like it'll always be accurate. For now it is."

Continued on next page

Table 64 (continued)

ST 19: "Well, theories are based off evidence. So theories can be accurate and true, but they can also be proven wrong if new evidence is discovered. Scientists would use the theories as working models to explain what is observed. Even if they don't believe it's true or accurate they can still use it to disprove the theory."
ST 20: **"**I think the second statement is more accurate. Over time they have added to the atomic theory as new structures have been discovered. They've done further tests and discovered that things were different than they thought them to be. So, I think models depict that uncertainty."

Discussion

Changing NOS Beliefs

RQ1. What range of NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

The overall average score for the NSKS at the beginning of the semester course for all participants (N=56) was 142.482 indicating most participants NOS beliefs lie in the unaccepted NOS views. Among them, the highest score was 158 indicating acceptance of NOS views and the lowest score was 122 suggesting non acceptance of NOS views. For the pre-assessment overall scores, 13 of 56 students scored above 147 indicating an acceptance of NOS views while 20 of 56 participants scored below 141 indicating initial non acceptance of NOS views. The majority of participants scored from 141-147 considered the neutral range indicating they held some of the accepted and non accepted NOS views but not all the views.

The interviewed participants' overall average scores for the NSKS at the beginning of the semester course was 141.650 indicating most participants held neutral NOS belief. Among them, the highest score was 149 indicating acceptance of NOS views and the lowest score was 132 suggesting non acceptance of NOS views. For the pre-assessment overall scores, only 1 of the 20 interviewed participants scored above

147 indicating an acceptance of NOS views while 8 of 20 participants scored below 141 indicating an initial non acceptance of NOS views. The majority of participants (11) scored from 141-147 considered the neutral range indicating they held some of the accepted and non accepted NOS views but not all the views.

In general, the initial findings indicate that the participants of the study did not possess an adequate understanding of NOS at the beginning of the semester. Various studies since the 1960s' have concluded that misconceptions concerning the NOS among students are common (Moss, 2001; Brickhouse, et al., 2000; Walker, et al., 2000; Griffiths & Barry, 1993; Mackay, 1971; Colley & Klopfer, 1963).

In the current literature on NOS the creativity dimension is viewed as operating on a continuum that ranges from viewing scientific knowledge as a totally lifeless, rational, and an orderly activity to viewing it as an endeavor that requires human imagination and creativity through the invention of explanations based on observations. In addition this dimension considers whether scientific models and theories are a product of the human imagination and whether they accurately represent reality. The initial NSKS scores of the participants (N=56) resulted in 26.8 % of the participants beginning the semester with instrumentalist views of the role creativity plays in the nature of science while 60.0% held realist views. Only 25% of the interview participants (N=20) initially scored in the instrumentalist range for this NOS dimension. In the initial interviews 20% of the participants believed that scientific models and theories are products of the human imagination and may or may not represent reality.

Generally students possess misconceptions on the role creativity plays in obtaining scientific knowledge. Studies show that in general students do not believe that scientific knowledge is a product of human imagination (Lederman & Abd-El-Khalick, 2000; Lederman, 1999). Lederman's study (1999) concluded that the 10th grade students believed that creativity and imagination played a limited role in the development of scientific knowledge. Lederman and Abd-El-Khalick's study (2000) found that 70% of the college students did not refer to creativity or imagination or models or theories in their explanations. Walker, et al., (2000) reported that students in their senior year of college perceived science as a rote and clinical process.

In the current literature on NOS the developmental dimension is viewed as operating on a continuum that ranges from viewing scientific knowledge as absolute, "set in stone" to viewing it as changing and dynamic. The initial NSKS developmental scores of the participants (N=56) resulted in 37.5 % of the participants beginning the semester with instrumentalist views about the role development plays in the nature of science while 35.0 % held realist views. Nine of the interview participants (N=20) initial NSKS development scores fell in the instrumental range. In the initial interviews 95% of the participants believed that scientific knowledge changes and evolves over time.

Some students hold misconceptions pertaining to the developmental nature of science. Studies have shown that a portion of students hold the misconception that the truth of scientific knowledge is beyond doubt and does not change over time (Walker, et al., 2000; Meichtry, 1993). However, other studies have shown that students believed in that scientific knowledge is tentative (Moss, 2001; Lederman, 1986).

In the current literature on NOS the parsimonious dimension of science is viewed as operating on a continuum that ranges from the view that scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity. The initial NSKS scores of the participants (N=56) resulted in 44.6 % of the participants beginning the semester with instrumentalist views while 32.1% held realist views concerning the parsimonious nature of NOS. Eight of the interview participants (N=20) initial NSKS parsimonious scores fell in the instrumental range. In the initial interviews 40% of the participants believed in some part that the ultimate goal of science is not to gather all the complex facts but to understand them and how they apply to the world.

Studies suggest that students believe that scientific knowledge is specific rather than comprehensive (Lederman, 1986; Rubba and Anderson, 1978; Mackay, 1971). Another study suggested that scientists follow the scientific method (Lederman & Abd-El-Khalick, 2000).

In the current literature on NOS the testable dimension is viewed as operating on a continuum that ranges from the view that scientific knowledge needs not to be capable of experimental test as opposed to it is capable of empirical tests. Plus that there is no one way to do science therefore there is no universal step-by-step scientific method. The initial NSKS scores of the participants (N=56) resulted in 48.2 % of the participants beginning the semester with instrumentalist views while 28.6 held realist views concerning the testable nature of NOS. Ten of the interview participants (N=20) initial NSKS scores fell in the highly sophisticated level for this dimension. In the initial interviews 30% of the participants believed that the scientific method was just a tool and that it does not give us all the scientific knowledge about the world.

According to McComas and Olson (1998) scientists require replicability and truthful reporting. A large majority of students in a study performed by Lederman and Abd-El-Khalick (2000) demonstrated inadequate views of the empirical NOS.

According to Sandoval (2003) there are broadly consistent findings from NOS studies. Most learners appear to believe that scientific knowledge is an accumulation of facts about the world, rather than explanations about the world created by scientists. Learners seem to believe that the ideas that scientists generate and test are descriptions of the actual world. They tend to see experimentation as a straightforward process of proving ideas right or wrong as well as that experiments yield answers to questions directly. A majority of learners have a hierarchical view of the relationship between hypotheses, theories, and laws based upon their degree of certainty rather than their scope and purpose. In other words, learners view hypotheses as guesses, theories as well-tested hypotheses, and laws as indisputably proven theories. Learners seldom see scientists as creative, except in a limited sense of needing to be clever to devise experiments. They do not recognize that scientists use their imaginations to generate theoretical ideas. In addition, learners tend to view historical scientific knowledge as uniformly wrong and current scientific knowledge as right, rather than viewing scientific knowledge developmentally.

RQ1a. Do students' NOS beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

By the end of the semester, the overall average score for all the participants (N=56) was 148.375 indicating a slight shift from non accepted views to neutral views of NOS. The highest score was 169 indicating an acceptance of NOS views and the lowest score was 118 in the range of non acceptance of NOS views. Again it is worth noting that for the post-assessment overall score, 16 of 56 students scored in the neutral range of NOS views while 5 participant's scores remained in the unaccepted NOS views range. The majority of the participants (35) scored in the accepted range of NOS views. The results also indicate that participants' NSKS post-assessment scores ranged from 118-169. This suggests that NOS beliefs can improve even if only minimally over a course of a semester. The possible impact that instruction may have had on the changes is discussed in chapter seven.

By the end of the semester, the overall average score for all the interviewed participants (N=20) was 148.900. The highest score was 155 earned by 2 participants indicating acceptance of NOS views and the lowest score was 142 also scored by 2 participants in the range of realist-neutral NOS views. Again it is worth noting that for the post-assessment overall score, 13 of 20 students scored in the range of acceptance of NOS views with the remaining 7 scoring in the neutral range. Therefore the majority of the participants scored in the acceptance of NOS views range by the end of the semester. Once again this suggests that NOS beliefs can improve even if only minimally over a course of a semester. The possible impact that instruction may have had on the changes is discussed in chapter seven.

In a longitudinal study performed by Ryder, et al., (1999) undergraduate science majors were found to change their overall NOS beliefs. Students showed development in their ideas about the relationship between data and knowledge claims, the lines of scientific inquiry, and science as a social activity. Another longitudinal study performed by Moss, et al., (2001) with pre-college students' examined their understanding of the nature of science at the beginning and the end of the academic year. Only minimal changes were noted by the end of the study in

Lederman et al., (1997) state that the important question concerning an individual's understanding of NOS should center on the limits of one's understandings. The current study highlighted the limits of participants' understandings via the descriptions and dialogue presented in the previous sections. Portions of the reflective passages during interviews were presented on the basis of the model of NOS using the NSKS dimensions. A goal of this study was to communicate, often in participants' own voices, key comments which are representative of their NOS beliefs.

In this study the creativity of scientific knowledge is described as being created from the human mind and logical reasoning. This creation is based on observations and inferences of the natural world. The final mean score (N=56) for the overall understanding of the creative dimension was 23.67 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 30.4% of the participants (N=56) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. The final mean score (N=20) for the overall understanding of the creative dimension was 24.10 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 50% of the participants (N=20) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 75% of the interview participants (N=20) reflected positive beliefs concerning the role creativity plays in NOS. Therefore by the end of the study, participants in both groups showed improvement in their creativity NOS views.

The creative and imaginative nature of scientific knowledge is explained by Lederman, et al, (2002) as being empirical. The development of scientific knowledge involves making observations. In addition, generating scientific knowledge involves human imagination and creativity. It involves the invention of explanations and theoretical objects. These scientific objects are functional theoretical models rather than copies of reality. By the end of a study by Khishfe and Lederman (2006) only 5% of the study population still demonstrated naïve views concerning the role creativity plays in NOS. Some of the participants in this study acknowledged a role of creativity in the form of human imagination, and some made connections between creativity, inference, and subjectivity. According to Ziman (1995), pattern recognition is linked to subjectivity and is a mainstay of all scientific knowledge and practice.

Historically and by definition in this study the developmental dimension views scientific knowledge as uncertain and always changing. With regard to the developmental nature of science, it was found that the participants did possess a better understanding of the tentativeness of scientific knowledge by the end of the semester. The final mean score (N=56) for the overall understanding of the developmental dimension was 24.77 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 39.3% of the participants (N=56) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 57.1% of the participants (N=56) reflected instrumentalist beliefs concerning the role development plays in NOS. The final mean score (N=20) for the overall understanding of the developmental dimension was 24.70 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 35% of the participants (N=20) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 45% of the interview participants (N=20) reflected instrumentalist beliefs concerning the role development plays in NOS. Therefore by the end of the study, participants in both groups showed improvement in their developmental NOS views.

Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes. A moderate percentage of the participants in this study understood that scientific knowledge is subject to review and change and that today's scientific laws, theories, and concepts may have to be changed in the face of new evidence. By the end of a study by Khishfe and Lederman (2006) only 5% of the study population still demonstrated naïve views of the tentativeness of scientific knowledge. In a study by Brickhouse et al., (2000), approximately 47% of the college students interviewed believed that theories do not change while 90% of the participants in Abd-El Khalick and Lederman's (2000) study did not seem to believe that scientific knowledge is tentative. In addition Walker et al. (2000) stated some high school and college students in their study thought that science theory is static. However, the students in both Lederman's (1986) and Moss, et al., (2001) studies believed that science knowledge is tentative.

By definition in this study the parsimonious dimension views scientific knowledge as being comprehensive as opposed to specific and tends toward simplicity. With regard to the developmental nature of science, it was found that some participants did possess a better understanding of the parsimonious nature of scientific knowledge by the end of the semester. The data shows that the final mean score for the overall understanding of the parsimonious aspect of science was the highest among the dimensions. The final mean score (N=56) for the overall understanding of the parsimonious dimension was 26.32 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 46.4% of the participants (N=56) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 80.4% of the participants (N=56) reflected instrumentalist beliefs concerning the role parsimony plays in NOS. The final mean score (N=20) for the overall understanding of the parsimonious dimension was 26.70 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 50% of the participants (N=20) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 80% of the interview participants (N=20) reflected instrumentalist beliefs concerning the role parsimony plays in NOS. Therefore by the end of the study, approximately 80% of the participants in both groups exhibited informed parsimonious NOS views.

Some of the participants disagreed that there is a continuous effort in science to develop a minimum numbers of laws and concepts to explain the greatest possible number of observations. Furthermore only a minority of the participants knew that scientific knowledge is comprehensive as opposed to specific. More supported the belief that scientific knowledge is specific as opposed to comprehensive.   The poor performance of the participants in the parsimonious dimension corresponds with the result obtained from Lederman's (1986) studies where Grade 10 students were found to hold misconceptions of the parsimonious subscale.

By definition in this study the testable dimension views scientific knowledge as being empirical and based on observations using the senses and tools/instruments with a variety of methodologies.   With regard to the testable nature of science, it was found that some participants did possess a better understanding of the testable aspects of scientific knowledge by the end of the semester. The final mean score (N=56) for the overall understanding of the testable dimension was 24.98 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 25% of the participants (N=56) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 55.4% of the participants (N=56) reflected instrumentalist beliefs concerning the role testability plays in NOS.   The final mean score (N=20) for the overall understanding of the testable dimension was 24.30 and a wide range of levels of understanding were exhibited for this dimension. From the data it is clear that although 25% of the participants (N=20) experienced an increase in overall belief range for this dimension of NSKS, the changes were not complete as to improve the NOS beliefs in all participants. By the end of the semester 55% of the interview participants (N=20) reflected instrumentalist beliefs concerning the role testability plays in NOS. Therefore by the end of the study, approximately 50% of the participants in both groups exhibited improvement in their testable NOS views.

Scientists conduct investigations for a variety of reasons. Different types of questions propose different types of scientific investigations. Different scientific fields utilize different methods, central theories, and standards to advance scientific knowledge and understanding. There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions using their prior knowledge, persistence and creativity. Scientific knowledge is gained in a range of ways including analysis, observation, theory, journal research of prior investigations and experimentation (McComas, et al., 1998). By the end of a study by Khishfe and Lederman (2006) half of the study population improved their empirical NOS views.

The final NOS interviews revealed that some of the participants still held several misconceptions pertaining to various aspects of NOS while others improved. Overall, some participants by the end of this study acknowledged that scientific knowledge is subject to change, recognized that scientific knowledge involves human imagination, there is no universal scientific method, scientific knowledge has an empirical basis, there are areas of scientific knowledge that are more certain than others, and models of theories do not necessarily represent reality. The findings suggest the need to foster a better understanding of NOS.

Summary

In summary the overall findings of the study (N=56) in answering research question -1, sub-question-a was as follows: Do students' NOS beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

1. Noticeable increase in posttest scores with a statistically significant large effect size of 1.00.
2. The mean gain scores are lowest for the *amoral* dimension and highest for the *parsimonious* dimension.
3. The mean gain score for overall increased by 5.89 points moving from a realist view towards an instrumentalist view of NOS.
4. The mean gain scores for five of the NSKS dimensions and the overall score are significant at $p \leq 0.05$.
5. The mean gain score for the *amoral* dimension is not significant at $p \leq 0.05$.

In summary the findings related to the interview participants of the study (N=20) in answering research question -1, sub-question-a was as follows: Do students' NOS beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

1. Noticeable increase in posttest scores with a statistically significant large effect size of 1.00.
2. The mean gain scores is lowest for the *testable* dimension and highest for the *parsimonious* dimension.
3. The mean gain score for overall increased by 7.25 points moving from a realist view towards an instrumentalist view of NOS.
4. The mean gain scores for three of the NSKS dimensions and the overall score are significant at $p \leq 0.05$.
5. The mean gain score for the *amoral, developmental*, and *testable* dimensions are not significant at $p \leq 0.05$.

Not unexpectedly, given the literature on NOS beliefs, the participants (N=56) in the study showed a minimal but significant change in their overall NOS beliefs and in five of the six dimensions the exception being the amoral dimension. This lack of development may not be so surprising since the amoral dimension related to scientific knowledge may be influenced by the participant's own views of moral judgments and prior experiences learning science.

Overall, minimal gains were made for the interview participants (N=20) in general within the NSKS dimensions. The participants overall had quantitative scores that were mixed with only three of the six dimensions showing increases. Slightly better results were obtained from the entire population (N=56) quantitatively in terms of increased sophistication of NOS beliefs. The participants (N=56) had increases within five of the six dimensions.

With the interview participants, it seemed they either held the belief or not, as minimal to moderate growth could be seen qualitatively within the interviews over time. Although increases were seen quantitatively, these may well be insignificant. It seems apparent that some participants have very naïve (realist) NOS beliefs while most possess neutral NOS beliefs and a few surprisingly hold instrumentalist beliefs. The naïve views are to be expected since the development of NOS beliefs is normally seen after encountering NOS instruction and during the college years. Even then many students fail to fully accept NOS views.

Chapter seven presents the findings of the study's second research question sub-question 2-a, and 2-b. The characterization of epistemological and NOS beliefs and any changes in those beliefs that may have resulted from laboratory instruction will be presented. The combination of interviews, reflective questionnaires, and quantitative measures will provide a glimpse into participants' beliefs during the course of a semester. This will provide a glimpse of the participants’ overall beliefs concerning the laboratory aspects of the semester course. The results are discussed and related back to the key laboratory education literature as well as the NOS and personal epistemological beliefs literature.

Chapter Seven: Laboratory Instructional Features

Introduction

Chapter seven characterizes the findings of the instructional features of the study's' second research question, sub-question 2-a, and 2-b. The characterization of laboratory instruction with the quantitative and qualitative results from the Student Evaluation of Laboratory Instruction Questionnaire as well as the results of the analyses of the participant's responses to interview probes will be presented. This will provide a glimpse of the participants' overall beliefs concerning the laboratory aspects of the semester course.

This study was of an exploratory nature to lay a foundation for focusing on more specific features of epistemological and NOS reasoning in light of specific instructional features (pre-lab, laboratory work, or post-lab) for future research. The results are discussed and related back to the key laboratory education as well as the NOS and personal epistemological beliefs literature.

Method of Analysis

This analysis was conducted in a multi-layered, multi-stage process, through reading, and sorting participants' responses to laboratory instruction questions, both general in nature and specific to the course. The analyses below are organized by the responses from the participants to the Student Evaluation of Laboratory Instruction Questionnaire (Appendix E) and the final interviews. The first part of the analysis presents the participants' (N=56) reflections on the laboratory instructional features (e.g., pre- and post- laboratory activities, laboratory work) through the use of the student questionnaire (section 1) and the final interview (N=20) responses. In addition the responses to the final interview questions that evaluated participants' views on several other aspects of the laboratory instruction such as; the role they played in promoting their own learning, the skills obtained during the laboratory course, and the role and significance of the laboratory notebook and scientific analysis. The second part of the analysis presents participant (N=56) responses to the second section of the student questionnaire probing their perceptions of the pre-post laboratory experiences. The third part of the analysis presents the participants' (N=56) reflective and final interview responses (N=20) to their believed learning gains using Bloom's Taxonomy. The last section of this analysis presents the participants (N=56) reflective and final interview responses (N=20) to whether the instructional features influenced their epistemological or NOS beliefs. The interview participants' epistemological beliefs analysis was performed using the EBAPS dimensions (axes): structure of knowledge, nature of knowing and learning, real-life applicability, evolving knowledge, and source of ability to learn with the three laboratory instructional features. The reflective responses were evaluated using the six NSKS dimensions: Amoral, creativity, developmental, parsimonious, testable, and unified. The final NOS interview was evaluated using the three laboratory instructional features. The aforementioned dimensions (axes) served as the major theme codes giving a framework from which first-order themes originally derived from the participants' verbatim quotations or raw data themes could be analyzed. Within each dimension (axis), the responses to interview (N=20) and reflective questions from section one of the student questionnaire (N=56) regarding NOS and personal epistemological beliefs at the beginning and end of the semester are presented. The intent of this analysis is to expand the theoretical understanding of the dimensions (axes) of personal epistemology in science and the continuum of beliefs, as expressed in context. Illustrative quotes have been selected from the interviewed participants as representative of the range of beliefs along the continuum. The demographics for all the participants (N=56) is presented in Appendix P. Table 64 presents a demographic overview of the interview participants with their participation identification number. Quotes are identified with the letters ST followed by the participants' identification number (Table 65). Table 66 presents the descriptive statistics of the CCI, NSKS, and EBAPS scores for the interview participants.

The main research questions that guided this portion of the study were:

RQ2. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

RQ2a. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their personal epistemological beliefs about science (development) during the semester general chemistry laboratory course?

RQ2b. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

Characterization of Participants' Reflection of Laboratory Instruction

Chemistry is a laboratory science; therefore chemistry instruction would not complete without some laboratory component. But in a discipline as wide-reaching as chemistry is, the natural questions are what should be taught and how it should be taught. Learning chemistry can take place in the chemistry laboratory. The chemistry laboratory is a venue almost unique to chemistry learning, and it can provide another dimension to the instructional goal of promoting student learning. McComas (1991) points out that while other subjects or academic domains, such as, architectural drafting, computer programming, drama, finance, and home economics, involve students interacting with materials, it is the science laboratory that is most closely associated with “experimentation, problem solving and questioning”.

Table 65 Demographic Statistics - Interview Participants

ID	Sex	Age	Major	College Year
1	F	19	Pre-Pharmacy	Fr
2	F	21	Psychology	So
3	F	21	Biomedical Science	Jr
4	M	24	Electrical Engineering	So
5	M	22	Environmental Science	Jr
6	F	27	Marine Science	None
7	F	20	Biomedical Sciences	Jr
8	M	18	Undeclared	Fr
9	F	18	Environmental Science	Fr
10	F	20	Environmental Science	So
11	F	19	Nursing	Fr
12	F	18	Undecided	Fr
13	F	18	Pre-Pharmacy	Fr
14	F	19	Pre-Pharmacy	Fr
15	F	20	Biology	So
16	F	18	Environmental Science	Fr
17	F	24	Physical Ed	Jr
18	F	20	Athletic Training	Jr
19	F	19	Biomedical Sciences	So
20	F	45	Masters Nursing	None

Laboratory instruction is a cornerstone of many science programs as it allows students to be actively involved in their learning. Effective laboratory instruction requires engaging the minds of the students so that they can think about the laboratory instructional experience in such a way as to evaluate their understanding in relation to what is experienced (Domin, 2007). This involves creating opportunities for reflection (Tien et al., 2007), as well as argumentation (Driver, 1995; Osborne et al., 2004) such as with the reflective laboratory instructional questionnaire used in this study (Appendix E). According to the National Research Council (2006), both are necessary, and to be effective they must be explicitly linked to a specific laboratory experience. When to implement these opportunities for maximal effect depends on the instructional methods or style used.

Table 66 Descriptive Statistics - Interview Participants' Scores

ID	CCI	EBAPS Pre	EBAPS Post	NSKS Pre	NSKS Post
1	72	2.70	3.13	143	155
2	76	2.35	2.55	144	153
3	81	2.38	2.97	138	148
4	67	2.70	2.62	138	149
5	86	1.88	2.08	144	151
6	63	2.37	3.12	149	151
7	63	2.32	2.77	143	152
8	72	2.83	3.22	147	145
9	45	2.53	2.60	147	155
10	72	2.05	3.45	141	153
11	58	2.80	2.98	143	149
12	63	2.63	2.78	138	150
13	49	2.63	2.48	146	144
14	65	2.48	3.02	132	142
15	76	2.98	3.12	140	145
16	77	2.85	3.55	143	148
17	65	2.50	2.45	136	142
18	76	2.63	2.77	143	148
19	67	2.52	2.87	140	152
20	58	2.65	2.80	138	146

The laboratory instructional features of this study discussed in chapters two and three include: pre-laboratory, laboratory work, and post-laboratory. Pre-laboratory work usually involves expectations or requirements that students prepare on their own time prior to the actual laboratory work. Pre-laboratory activities can stimulate students to think, recall prior information, practice basic calculations, learn the safety procedures, or check that experimental procedures have been read and understood. Laboratory work allows students to develop practical skills by learning to use the tools and conventions of science, work as a member of a scientific team, add to their understanding of the nature of science (NOS) as well as experience the ambiguity and complexity of empirical work. Post-Laboratory activities are the student's opportunity to report and reflect on what occurred during laboratory work. Post-laboratory work usually involves writing up the laboratory experiment, performing calculations using data from the experiment, comparison of class data, discussion of the results between teams, answering open-ended writing assignments and performing analysis of data and errors. All of these instructional features can encourage students to connect and revise prior knowledge, thereby leading to an improved grasp of the topic, and improve motivation and learning.

Participant Reflections of Laboratory Instruction

Section one of the Student Evaluation of Laboratory Instruction Questionnaire was used to evaluate participants' beliefs on how helpful they found each of the instructional components and the pedagogical features with respect to their understanding and necessity of the laboratory learning experience. This section of the reflective student questionnaire (Appendix E) was used to assess participants' reactions to the three major instructional components (e.g., pre-laboratory, laboratory work, and post-laboratory) of laboratory instruction implemented during the semester course. The three instructional components were sub-divided into the five main pedagogical tools or approaches used during the course (e.g., pre-laboratory – lab manual, quiz, questions/flowcharts, discussion, and technology). The results for all the participants (N=56) and the interview participants (N=20) are presented in Tables 67and 68, respectively. The participants reflected further by responding to the probe question concerning the instructional methods used in this course and how they compared with other science laboratory courses they had experienced.

The vast majority (65%) of participants (N=56) clearly indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. Strong participant support was shown for the post-laboratory with 59% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material. The pre-laboratory was ranked third with 44% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material.

Table 67 Participants' Laboratory Instructional Preferences

Instructional Category	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Pre-laboratory	3.0%	13.0%	40.0%	16.0%	28.0%
Lab Work	2.0%	5.0%	28.0%	23.0%	42.0%
Post-laboratory	4.0%	6.0%	33.0%	24.0%	33.0%

N=56

The interview participants (N=20) ranked the three instructional features the same as all the participants (N=56) with laboratory work being the most essential, followed by post-laboratory, and lastly pre-laboratory. The majority (83%) of interview participants clearly indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. Once again, strong participant support was shown for the post-laboratory with 72% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material. The pre-laboratory was ranked third with 46% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material.

Table 68 Interview Participants' Laboratory Instructional Preferences

Instructional Category	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Pre-laboratory	5.0%	14.0%	35.0%	22.0%	24.0%
Lab Work	3.0%	5.0%	9.0%	19.0%	64.0%
Post-laboratory	7.0%	5.0%	16.0%	22.0%	50.0%

Reflective Comments of Laboratory Instructional Preferences

Participant comments were generally positive. Some of the participant (N=56) reflective comments are listed in Table 69. The majority of the participants commented that certain aspects of the pre-laboratory such as the generating of a procedural flow chart were beneficial while some of the pre-laboratory questions were unnecessary. The laboratory manual, laboratory notebook, and the technology tools were commented on by the participants most often in their reflective comments. The laboratory manual was viewed as quite useful and detailed enough for effective use by the participants. The laboratory notebook received more positive responses from the participants as the semester progressed whereas a few participants felt that recording their "real-time" data during laboratory work could have been easily recorded on regular notebook paper. This type of naïve comment may suggest that some participants did not have the prior experience in their other laboratory courses with practicing "real-time" data collection in a permanent document or understand the importance of recording data as it occurs.

Students repeatedly stated that they used a wider range of technology-enhanced equipment (e.g., Blackboard, MBL) than they would normally use. The technology-enhanced approach allows students to perform several trials which are more of a challenge when using traditional bench laboratory methods due to time constraints.

As for the post-laboratory the majority of the participants' reflections were positive except for the few that it was not crucial to their learning. This type of novice response suggests that some students either did not like to write or understand the importance of analyzing and reporting scientific data to share with the scientific community. However, a majority of the participants offered positive overall comments concerning the laboratory instructional methods as noted in Table 69.

During the actual lab work, participants' minds are engaged not on the underlying theories and principles, but on the procedural aspects of the activity. The cognitive demand placed on working memory in trying to understand and follow the given methods allows for little, if any, cognitive resources to be devoted toward thinking about the concepts involved in the activity. Participants partaking in a MBL laboratory activity were most cognitively engaged while they were in the laboratory conducting the activity. This is indicated by the use of the terms 'frustrating' and 'challenging' to describe the activities. These terms indicate that participants were, at some point in the lab work, in a state of cognitive dissonance which they had to think through to reestablish cognitive equilibrium.

In the case of laboratory instruction, a majority of the participants in this study perceived understanding to develop outside of the laboratory, after the lab work was completed, when they had the opportunity to reflect on what they had done while others felt the post-lab was not crucial and simply a review of the material. The aforementioned attitudes reflect both those of novice and expert participants. The post-lab analysis included the writing of the laboratory report that related to specific concepts addressed during a specific laboratory activity. For laboratory instruction, the post-lab activity is crucial for conceptual development; it may be the only opportunity the students get to reflect on what was done in the lab. Research by Keys (2000) has shown that the process of laboratory report writing can stimulate science learning provided that “the students actively deliberated and reflected on science content as part of the writing process itself.”

Table 69 Participants’ Reflections - Instructional Methods (N=56)

Instructional Issue	Reflective Written Comments
Pre-lab	**ST-6** “The pre-lab assignment helps out the most. Writing the procedural flowchart really helped me understand the process.” **ST-9** “I think making the procedural flowcharts really help me. The flowcharts offer a clearer picture of what I am going to be doing before I get into the lab. However, I could have done without some of the pre-lab questions.” **St-16** “I feel that some of the procedures for completing the pre-lab were a bit overly extensive, such as creating a flowchart for each procedure.”
Laboratory Manual	**ST-30** “I think that the instruction manual is very thorough and helpful compared to other ones.” **ST-49** “I really like the detail of the lab manual.” **ST-53** “The lab manual background and instructions seem to be better than the ones I used in high school.”
Laboratory Notebook	**ST-1** “I do not feel the lab notebook is necessary----simple notebook paper would do.” **ST-12** “The laboratory notebook set-up is how it is used in other labs. It is a good way of organizing the chemistry lab information.” **ST-18** “Well, I have never used a lab notebook before and I really don’t think it helps. It just makes everything twice as much work.” **ST-28** “The lab notebook can be easily formatted and organized…easy to look up data/analysis from previous labs.” **ST-54** “The lab notebook is an organized way to record data and observations.”
Technology	**ST-7** “I think the instructional methods used to assist students in lab are all very helpful. Blackboard is a great tool. MBL useful but frustrating.” **ST-8** “Using Blackboard and having online discussions. It was nice to see how other classmates viewed the lab and the data collected. It also was a quick way of clarifying questions.” **ST-26** “The technology is way more present in this course than others I have experienced. This is crucial for majors in the scientific field.”
Post-Lab	**ST-24** “Post lab is very important to analyze and understand what we did.” **ST-26** “Post lab I don’t think is that crucial to the concepts except for review purposes.” **ST-50** “Post labs are needed to evaluate your data and understand the meaning of the lab.”

Continued on next page

Table 69 (Continued)

Overall	**ST-4** "I believe the pre-lab and post-lab activities are vital to the lab. It gives the participant a better understanding of the experiment to be performed." **ST-45** "Overall I find the instructional methods have accelerated my learning compared to my other lab classes." **ST-49** "I feel in the lab you almost are forced to learn the material through constant exposure. This helps me learner better, I've not had this before." **ST-53** "I had never been exposed to these instructional methods in any of my prior science laboratory activities. In my past science labs, we never performed any pre-lab activities or even maintained a laboratory notebook. Our technology was also severely limited, and post-labs were pointless to say the least. I am glad to apply these new methods to my lab work because now I feel like I'm actually retaining information and learning from the activity, as opposed to just going through the motions."

Final Interview Discussion - Instructional Methods

Final Interview Questions One and Two

Final interview questions one and two were used as a tool to determine which instructional feature (pre-laboratory, laboratory work, or post-laboratory) the participants considered were the most effective and least effective in promoting their learning during the semester course. As discussed in the chapter seven introduction as well as chapters two and three the instructional features are divided into three general methods pre-laboratory, laboratory work, and post-laboratory. Table 70 summarizes the interview participants' overall responses (%) to final interview questions one and two. Tables 71 and 72 presents the interview participants' extended responses to questions one and two.

By the end of the semester course two of the three instructional features, laboratory work (40%) and post-laboratory (40%) were selected by the participants as the most effective in promoting their learning during the semester course while the pre-laboratory instructional feature (65%) was selected as the least effective.

Table 70 Final Interview - Laboratory Instructional Feature

Instructional Category	Most Effective	Least Effective
Pre-laboratory	15.0%	65.0%
Lab Work	40.0%	5.0%
Post-laboratory	40.0%	25.0%
Other	5.0%	5.0%

N=20

Question One – Most Effective Instructional Feature

In order to query participants' views concerning the instructional features (pre-lab, laboratory work, or post-lab) they were asked which feature they found to be most effective in promoting their learning during the course (Table 71).

The pre-laboratory was identified by only 15% of the interview participants (ST 7, 14, and 19) as being the most effective instructional feature. These participants stated in the final interview that the pre-laboratory feature offered them a preview of what concepts and methods were to be encountered during the laboratory work thereby decreasing their frustration levels. This supports Barnes and Thornton's, (1998) study that if students are better prepared prior to attending lab, then they will be able to improve their rationale behind the laboratory processes being presented. They found that students in their study felt that the pre-laboratory made performing the lab and writing the post-lab report easier. Students that do not prepare may be unable to fully engage in the completion of the laboratory work and thereby reduce their opportunity to learn. Students from Wyatt's (2003) online pre-labs study indicated satisfaction with the pre-lab exercises. However, the majority of participants in this study indicated that they found the pre-laboratory activities to be the least essential to their learning.

Participants (1-2, 9-10, 12-13, 17, and 20) indicated that laboratory work allowed them to experience the different aspects of the topic whether it was use of the equipment, teamwork, or to see how things really occurred. Laboratory work allowed the participants to complete or use a procedure in a given situation in chemistry laboratory and take the new information gained to solve different types of problems. This supports Byers (2002) views that laboratory work remains essential to the development of a range of practical skills as well as offering the learner an opportunity to understand what scientist do. On the other hand often students involved in laboratory learning only manipulate equipment and do not get around to manipulating the ideas (Gunstone & Champagne, 1990).

The post-laboratory engaged 40% of the participants (ST 4-6, 8, 11, 15-16, and 18) in reflecting on everything they experienced from the pre-laboratory and laboratory work together. The participants emphasized the connection between post-laboratory analysis and understanding concepts introduced in the pre-laboratory activities. It served as a tool for organizing, clarifying and synthesizing their thoughts. The post-laboratory activities lead those participants to an improved understanding of the material presented. This supports the idea that communicating science with clarity and understanding is crucial to science students (Koprowiski, 1997; Rivard, 1994). According to Herrington (1997) the act of writing a post-laboratory report should allow students opportunities to organize, develop, and explain scientific concepts. Writing a post-laboratory report helped connect data, scientific equations, and scientific knowledge with their observations performed during the laboratory work.

Participant three felt all of the instructional features were effective to her learning during the course. She believed that each offered a different but useful perspective to her learning experience. The literature suggests that if designed properly the entire laboratory experience has the potential to play an important role in attaining cognitive skills (Hofstein, et al., 2004).

Table 71 Participants' Reflections – Effective Instructional Methods (N=20)

Final Interview Question-1	
What instructional feature (pre-lab, laboratory work, or post-lab) was the most effective in promoting your learning in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST-7:** **"**I think all of them worked together effectively. But if I had to choose I would pick the pre-lab. I wouldn't struggle in lab when I did the pre-lab." **ST-14:** "I would say the pre-lab. The pre-lab offered a lot of background information. I definitely never went to lab without my pre-lab done. So the pre-lab helped me so I was prepared." **ST-19:** **"**Well, it's hard to decide between the pre-lab and the actual lab itself because the pre-lab prepared you to perform the lab. I'd say probably the pre-lab as it offered one an overview."
Lab Work	**ST-1:** "The laboratory work because it gave me a chance to actually physically do things. This allowed me to see how the concepts applied and how it effects real world situations." **ST-2:** "The laboratory work itself because you had to apply all of the concepts and ideas to the actual hands on experience in order to get the experiments to follow through and get results." **ST-9**: "Probably the actual laboratory work because it put everything to use. You allowed you to see how the concepts applied. I also thought the pre-lab was really helpful because it gave you a heads-up beforehand. However, actually performing it was the most helpful." **ST-10**: "Definitely the laboratory work because you it offered a real time experience." **ST-12:** "The laboratory work was the most effective. It was easier to understand the material when we performed the lab. The instructor would go over the pre-lab before we performed the lab in order to clarify and questions. The post-lab I thought was also effective. It allowed you to analyze what one did during laboratory work." **ST-13:** "The laboratory work because when we did the experiments it allowed one to see how the concepts applied."
Lab Work	**ST-17:** "The laboratory work as it allowed you to actually do it yourself. I learn best with hands-on-experience. I get better grades doing the work." **ST-20:** "I'll say laboratory work. Well, because that it gave me hands-on visual learning. It allowed me to apply the pre-lab concepts. I could actually see what happened, how it happened, and why it happened."

Continued next page

Table 71 (Continued)

Post-Lab	**ST- 4:** "I think the post-lab. After performing the lab and actually analyzing the data I could look back over the experience and all the processes that we performed during the lab. This is when I gained the most knowledge and understanding of what we were doing during the lab." **ST-5:** "I would say both the laboratory work and the post lab. If I had to pick between the two I would pick the post lab as it was more effective. The post-lab allowed one to understand the data, proper use of the formulas and how everything tied together." **ST-6:** **"**If I had to pick one out of the three I would pick the post lab. The post-lab because you could tie all the results together and explained why things occurred. Although the pre lab and lab work are obviously important but the post lab is most important because it brings everything you did together." **ST- 8:** "I would have to say the post lab. After I did the pre lab I didn't know a lot about the concepts, but I had a better idea after the lab work. But when I did the post lab I was able to evaluate everything and learn the most and see what happened during the lab work." **ST-11**: "The post lab was the most effective. The post-lab allowed me to go back and look at the data and to analyze everything." **ST-15**: "Post lab was the most effective. It forced me to sit down and understand what occurred during laboratory work. Performing the formal write ups helped organize and analyze the data." **ST-16:** "I would have to say post-labs. After the lab experience one could understand the data performing the post-lab analysis." **ST-18:** "I would say the post-lab. I would be confused until we had a pre-lab discussion. Once we had performed the lab I gained a clearer understanding of the concepts. However, my overall understanding occurred during the post–lab analysis."
Overall	**ST-3:** "For me I found all equally effective depending on the experiment. For some of the labs I initially learned more from doing the pre-lab and bench work. While during other labs I learned more from the actual final analysis."

Question Two – Least Effective Instructional Feature

In order to query participants' views concerning the instructional features (pre-lab, laboratory work, or post-lab) they were asked which feature they found to be least effective in promoting their learning during the course (Table 72).

The pre-laboratory was identified by 65% of the interview participants (ST 2, 4-6, 8, 11-13, 15-18, and 20) as being the least effective instructional feature. These participants stated in the final interview that the pre-laboratory feature increased their frustration levels. They felt that the pre-laboratory activities did little to offer a perspective of what to expect and limited understanding of the concepts. Others felt that the pre-laboratory activities were time consuming and unnecessary. These views may in part appear to be due to time management issues. According to Johnstone and Al-Shualli (2001) many students ignore the importance of pre-laboratory preparation because they feel that they can survive without performing it. Pre-laboratory activities ease the transition into the new experiences by allowing students to familiarize themselves with the experiment. In addition the students may gain a clearer understanding of what is expected of them during laboratory work (Koehler & Orvis, 2003; McKelvey, 2000; Nicholls, 1999). Effective preparation may result in reducing anxiety and increasing student confidence.

Only one participant (ST 14) indicated that she found laboratory work to be the least effective. She stated that she felt more comfortable with book and written style learning than hands-on. Here the participant lacked an awareness of the aim of laboratory work. Firsthand laboratory science experience is seen as a key way to improve students' understanding and appreciation of the way science works however other studies show that laboratory activities provide little improvement in understanding the methods of science (National Research Council, 2006; Driver, et al., 1996 Lederman, 1992; Gunstone & Champagne, 1990; Tobin, 1990).

Twenty-five percent of the participants (ST 1, 3, 9-10, and 19) found the post-laboratory to be the least effective instructional tool. These participants suggested that the post-laboratory experience was too repetitive and extra work. In some cases if the participant did not understand the point of the pre-laboratory and laboratory data collected during laboratory work so they felt lost when attempting to analyze the results. Students need to learn how to negotiate scientific understanding by communicating those understandings within the context of scientific discourse (Prain & Hand, 1996).

The post-laboratory analysis gives students an opportunity to engage in authentic discourse, make connections between their findings and the relevant science concepts while learning to reflect, synthesize and generate new ideas (Keys, 2000; Keys et al., 1999).

Table 72 Participants' Reflections – Least Effective Instructional Methods

Final Interview Question-2	
What instructional feature (pre-lab, laboratory work, or post-lab) was the least effective in promoting your learning in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST-2: "**The pre-lab because you were more worried about getting it done rather than understanding it. You had to turn in your pre-lab the day you performed the lab. You could turn it in late but you would get points deducted." **ST-4: "**I would have to say the pre-lab. Initially going into a lab, the pre-lab was always the most difficult to me. I would have to seek some help. I think working with a partner or in a team during a pre-lab sharing made things a little bit easier." **ST-5:** "The pre-lab because you really don't know exactly what you are going to be doing or what type of technology you are going to be using. Even though the formulas were there they weren't effective until after performing the labs." **ST-6:** "If I had to pick one it would be the pre-lab. Simply because you are doing it before discussing it. Most of the time you do the pre-lab on your own. It wasn't until the pre-lab discussion that we ended up understanding." **ST-8:** "If I had to choose it would be the pre-lab. I learned more doing the lab and post-lab. Pre-lab was helpful but not as helpful as the others." **ST-11: "**Probably the pre-lab because I hadn't done any of the laboratory work yet or so it was harder for me to get the correct answers. I found them all very effective but the pre-lab was probably the least effective because it was harder for me to do it without actually doing the lab work first." **ST-12:** "The pre-lab because some of the questions I understood them better after performing the lab." **ST-13:** "Probably the pre-lab. Once we did the laboratory work and then the post-lab we understood more about the pre-lab." **ST-15:** "The pre-lab. I tried to "slide by" but not understanding held me back during the lab work. I remember asking my lab partner for help so she explained it to me as we went through the lab. She also helped me with the post-lab and then the pieces came together." **ST-16:** "I have to say it would be pre-lab. Even though I don't think it wasn't entirely non-effective. Well because when you're first learning about the concepts or what the subject is you're like feeling it out. The laboratory work allows you to view the concepts in actions and the post-lab helps one understand."

Continued next page

Table 72 (Continued)

Pre-Lab	**ST-17:** "The pre-lab. It gave you a background but I don't think it was a 100% necessary. It was good coming into the lab knowing a little bit about what you had to do but I don't think anyone would have been that much worse off without it." **ST-18:** "I'd say the pre-lab. I don't do well when I just read the material. I like more of a hands-on approach. So, for me it was harder to just read it and be able to understand it right away." **ST-20:** "I'll have to say the pre-lab. The post-lab really pulls together everything that you've learned. The concepts that you've experienced in the pre-lab work do help you somewhat understand what you're going to be doing, how you're going to be doing it, and why you're going to be doing it. The post-lab helps you completely understand. It helps you analyze the ideas of what was really happening and why it happened and it really puts it together for you. You know, it really allows things that you may not have realized or recognized before, or thought about before come to life."
Lab Work	**ST-14:** "I would say the lab work. The lab work is probably what most of my classmates would find most effective because it's hands-on. However I'm more of a book learner. But, I would say that the pre-lab was the most effective and then the post-lab because that's what tied everything together. The lab work was kind of just like a visual aid."
Post-Lab	**ST-1**: "I'd say the post-lab. The pre-lab helped me to initially understand the information and what I was going to be doing. The lab work helped me to demonstrate it so I could understand it better and the post-lab just reiterated it." **ST-3:** "I would say the post-lab. Although, it is still important I'm not discounting it at all. This is probably because if I didn't already understand the concept in the pre-lab and didn't get it after performing the lab then the post lab would be more difficult for me. Sometimes I could look back and say oh that's why this occurred. But it is more important for me to get it first and then I could apply my knowledge." **ST-9:** "The post-lab. Even though it was somewhat effective. I guess it was just me. After I was done with the experiment I wanted to move on to the next. The post-lab just seemed as if we were repeating the information." **ST-10:** "The post-lab. The pre-lab gave you an overview of the lab. The post-lab was repetitive." **ST-19:** "The post-lab. Sometimes it confused me. I would think I knew what I was doing. However, when I would get to the post-lab I did not understand. I would get confused instead of getting any clarity."
Overall	**ST-7:** "I don't think any of the instructional features were least effective. The pre-lab gave me an initial understanding, the lab work was hands-on learning and the post-lab helped me understand the other two."

Final Interview Question Three - Promoting Learning

Final interview question three was used as a tool to determine what the participants thought they could have done differently to promote their learning during this semester course. The major response themes from the participants were spending more time on the course and/or on the pre-laboratory activities. Table 73 presents some of the interview participants' extended responses to question three.

Participants' self-efficacy and ability to self-regulate may have influenced their accomplishments and persistence when performing the laboratory tasks. According to Bandura (1977), self-efficacy beliefs influence performance accomplishments and the persistence demonstrated in the pursuit of challenging tasks. In addition, self-efficacy has been shown to have a mediating role on student achievement. Participants' perceptions of self-efficacy influenced their instructional activity choices. They may have avoided those laboratory instructional tasks in which they lacked confidence and engaged in laboratory tasks in which they expected to experienced success. Educational psychology studies describe the ability to take responsibility for and to self-direct one's learning as self-regulation of learning (Zimmerman, et al., 1992; Zimmerman, 1990). Participants that actively controlled their study time, study environment, and persistence were more successful in accomplishing the tasks.

Table 73 Interview Participants' Reflections – Promoting Learning

Final Interview Question-3
What could you have done differently to promote your learning?
Quotation Comments
ST 2: "I needed more time as chemistry is a complicated and difficult subject. I'm not a science and math person. In the beginning of the semester I was taking 15 credit hours and I was working 30 hours. I ended up having to drop one of my classes and my grades did get better. If I had more time I would actually do all of the reading. I would look for key words to answer the questions and find the relationship between the concepts and data."
ST 3: "I think of I was on top of the material. I mean I always did things as best as I could and tried to be as detailed as possible when preparing for class. You really had to understand the first steps otherwise you did not understand the later steps. Additionally, when I was not sure about a question or problem I would research it online. I would always try to figure out things on my own before I asked the professor. I would look for things online and really look at the question before I just gave up."
ST 5: "The major strategy that I used to promote my learning involved reading the material. I had taken an introductory chemistry course and adapted that to what I was doing in lab. There were technical issues, not only blackboard, but time issues."
ST 6: "I needed to spend more time on preparing. I did all of the bookwork. I should have gone over the pre-lab more before and after performing the lab. Performing the post-laboratory reports allowed me to reread and I understood those more."
ST 7: "I think if I would have read more it would have helped. I took notes but I needed to devote more time."
ST 8: "I should have done more background reading before the lab. Time was also a big factor. Strategies I used to study for the lab included doing the pre lab to the best to my ability and studying for the quiz. I would just read."
ST 15: "I could have tried to understand the pre-lab. I slacked off a little when it came to doing the pre-laboratory activities. Especially if I didn't understand. I tried to get by without doing much work. I do the same thing in other classes."
ST 16: "I would have to say try harder on the pre-labs. The pre-labs were kind of like going in blindly. Sometimes I had to review the lectures before I did the pre-lab. So I guess I should have tried harder on the pre-labs. For instance I should have read the sections in the laboratory manual and go over the laboratory PowerPoint slides on the Blackboard site. Unfortunately I didn't."
ST 17: "I could have spent more time on preparing for lab. I really didn't get to focus a whole lot on my other classes as this class took up so much time. Strategy for studying was reviewing the course work and reading."
ST 19: "I usually don't watch the lectures before the lab. So if I'd watch the lectures before or read the material then it probably would have made the lab easier. I don't really think I have a learning strategy. I just do what I'm told to do. Sometimes tutoring helped and when we would email each other back and forth. However, this campus only offers tutoring twice a week for one hour each time".

Final Interview Question Four – Laboratory Skills

Final interview question four was used as a tool to determine what the participants' believed were the most important skills they learned in the semester chemistry laboratory course. The major response themes from the participants were use of laboratory equipment and technology, trial and error, analysis, and time management/organization. Table 74 presents some of the interview participants' extended responses to question four.

Laboratory experiences should aim to encourage learners to gain the following: manipulative skills, observational skills, the ability to interpret experimental data, and the ability to plan experiments (Johnstone & Al-Shuaili, 2001). This supports the participants' views on the skills they gained during the course such as: being able to make observations, the proper use of laboratory equipment/tools, improved organization and being able to analyze the information obtained during laboratory work.

Table 74 Interview Participants' Reflections – Laboratory Skills

Final Interview Question-4
What is (are) the most important skill(s) you learned in chemistry laboratory?
Quotation Comments
ST 1: "Learning how to use the laboratory equipment probably as improper use can affect the experimental results. In addition, how to use the computer lab software."
ST 2: "Triple checking your work is an important skill. You want to properly measure so that your data is accurate and precise."
ST 3: I think really looking at what is going on during the laboratory work. Learn that you really need to follow the instructions and if you don't do it right to do it again. Use trial and error and if you make a mistake just repeat the trial and avoid making the same mistake. Critical thinking is an important skill."
ST 4: "One of the most important skills was learning how to properly use the equipment."
ST 5: **"**The most important laboratory skill was how to use the laboratory equipment and technology."
ST 6: **"**I would say performing the analysis and pulling the concepts together."
ST 7: **"**Following the directions and proper use of the laboratory equipment are important skills. They are important because when you do not properly use the equipment the accuracy of the data is impacted."
ST 8: "Probably learning to become more organized was the most important laboratory skill I learned during the course. I became better at organizing the information and analysis."
ST 15: "The most important skills were the use of trial and error, using Excel, and how to analyze data."
ST 17: "The most important laboratory skill I learned was time management."
ST 19: "The most skills involved learning how to use the laboratory tools and organization. Organization is the key skill to this course. You must understand the prior material before you could move on to the next activity."
ST 20: "I would say the hands-on experiments, the safety skills, proper use of the equipment and the analytical processing."

Final Interview Question Nine – Laboratory Notebook

Final interview question nine was used as a tool to determine what the participants' believed the role and significance of the laboratory notebook is in any scientific workplace. What is a laboratory notebook? In the context of this chemistry laboratory course, the lab notebook was viewed as a history of the work accomplished during the semester.

Each participant recorded the work they performed for lab assignments, carefully recording what they did and learned along the way. The major response themes from the participants on why one might want to keep a laboratory notebook were to provide a record of why and how experiments were performed, real time data collection, for interpreting results, and providing information to others. Table 75 presents some of the interview participants' extended responses to question nine. The use of laboratory notebooks as a tool is supported by the participants' interview responses. A number of the participants advocated the necessity in the course as well as in the scientific workplace. However, several felt the laboratory notebook was time consuming and repetitive.

The use of laboratory notebooks as an instructional tool is supported by a number of researchers who advocate writing in science to enhance student understanding of scientific content and processes, as well as general writing skills (Bass, Baxter & Glaser, 2001; Keys, Prain, Hand & Collins, 1999; Rivard & Straw, 2000). The information written into a laboratory notebook is used for several purposes. The most important is that the pages of the laboratory notebook preserve the experimental data and observations with unambiguous statements of "the truth" as observed by the scientist (Kanare, 1985). The major goal is to write with detail and clarity so that other scientists can pick up the laboratory notebook and repeat. Students need to realize that the laboratory notebook is the prime source of information when one is required to write an analysis (Aschbacher & Alonzo, 2004).

Table 75 Interview Participants' Reflections – Laboratory Notebook

Final Interview Question-9
Describe the role and significance of the laboratory notebook in any scientific workplace (e.g. classroom, research laboratory, hospital, pharmacy)
Quotation Comments
ST 2: "The lab notebook is an essential tool for anyone involved in a science field. It allows one to record raw data and maintains a train of thought of what happened during the experience. As a psychology major I found it was easier to use a notebook."
ST 3: "I definitely understand the purpose of a lab notebook is to have everything written down and recorded for future use. The role or significance I can understand in a hospital as you are dealing with a patient and there could be confusion if one did not record the information. However, sometimes I just wanted to burn this lab notebook and say can't we just write it on a piece of paper. But I understand the significance of it as it is really important to have everything recorded. The difference between writing it in a lab notebook rather than just on the piece of paper is that one could lose the piece of paper."
ST 4: "Well, the significance I think would be recording the real time data and observations that you make whether it is in the classroom or, lab, or hospital or pharmacy. One can go back after you've left a certain situation to see what you've written down and help you evaluate a situation at a later time."
ST 5: **"**The notebook is the first one I have done. One reason to keep a notebook is to avoid future mistakes. "
ST 6: "The role is to keep track of all of your data as it is very important so you can look back to look at your data and your procedures. It is a summary of what you learned and what you experienced. The difference is if it was just recorded on regular paper you could misplace the papers thereby losing the data."
ST 7: **"**It's a notebook in which you can write down all of your observations and perform calculations. It is an important way to keep your notes all together so if you need to refer back to your data it is easily accessible."
ST 9: "In the classroom it's important and significant so you can go back and refer to your work. After you're done doing the laboratory you can see what you've done and process the information. For the research laboratory, their main goal is so after they're done performing the experiment they can go back for specific details, see if there were mistakes and where the mistakes might have occurred."
ST 11: "The laboratory notebook helped me as I could refer back to it throughout the semester. You can use it for future experiments such as in a research hospital so one can see the differences and similarities in their results."
ST 12: "The lab notebook is used to record data and observations. It helps with post-laboratory activities such as analysis. The uses are the same for a research laboratory or hospital. Recording information in the notebook improves the accuracy."
ST 15: **"**I think it is a very organized way to keep track of what you are doing. It is very important as you want to see why you did something and evaluate what went right and wrong."
ST 17: "I guess I can see the point in using it in the classroom more so than in a research lab or in a hospital. Several students didn't know the structure as we had never used a lab notebook. I think it is good to use it in the classroom as a tool."

Continued next page

Table 75 (continued)

ST 18: “The purpose was to record your data. I think it gives you practice for the future. I know in the field that I’m looking at there are all types of government forms you have to fill out. So, I think it gives you practice efficiently recording what you were doing and the results. It also allows others to see what you’re doing. Therefore if they wanted to continue where you left off they would have some guidelines and initial results so they could pick up from there and continue on.”
ST 19: “The lab notebook is where you record data and observations. Research labs and hospitals also need to record information. This allows them to keep patient information organized and written down accurately for future evaluation.”
ST 20: “To have a place where you can record significant data and findings. This is necessary so that one can later utilize the information for further clarification.”

Final Interview Question Ten –Scientific Analysis

Final interview question ten was used as a tool to determine what the participants’ believed the role and significance of the scientific report or analysis is in any scientific workplace. The goal of scientific writing is effective communication. A good scientific report does more than present data; it demonstrates the writer's comprehension of the concepts behind the data. In the scientific community, one of the most basic goals is the development and application of new knowledge. Writing scientific reports and papers is the easiest and most effective way to share the information with the scientific and medical community. However, scientific papers come under great examination as they are reviewed, tested, and retested time and time again. Published scientific papers act as influential vessels in an attempt to validate the researcher’s data and interpretations. In time the results may become accepted as scientific fact.

Each participant prepared post-laboratory reports. As discussed in chapters two and three there were three types of laboratory reports: the basic laboratory report (BLR), the formal laboratory report (FLR), and the laboratory notebook (LNB).The major response themes from the participants were to share one’s results with others in the scientific community, and learn from the results.   Table 76 presents some of the interview participants' extended responses to question ten.

Scientific analysis in the form of laboratory reports should give learners the ability to think, talk, and write scientifically. Effective scientific communication requires learners to use scientific language to reflect the scientific process. Several of the participants viewed scientific analysis as a method to relive and reflect on the laboratory work thereby bringing structure to their thinking. Frequently participants talked about how the laboratory analysis as a way to revisit to laboratory work and put everything in perspective. Keys (2000) findings suggest that scientific writing promotes scientific thinking by helping learners to explore relationships between evidence and knowledge claims.

Table 76 Interview Participants' Reflections – Scientific Analysis

Final Interview Question-10
Describe the role and significance of the scientific laboratory report/analysis in any scientific workplace. (e.g. classroom, research laboratory, hospital, pharmacy)
Quotation Comments
ST 2: "The report is significant in research as it lays out the experimental results and discussion. It allows others performing the same type of research to read and learn from other research. In this course it forced you to explain and hopefully understand the overall experience."
ST 3: "It relates what the scientist did through the entire process. It offers an analysis of the results. The report discusses what the results could possibly mean and discuss any potential error. It is an all encompassing way to analyze information and present it to others. For research it is useful if they are doing similar work."
ST 5: "You would be presenting your results to other scientists."
ST 6: "The lab report is important because it presents an analysis of your data. This allows one to understand the results and explain what may have gone wrong. It pulls everything together. The report is important as it allows others to read and learn from the results. It's a way to learn and share with the science community."
ST 7: "The significance of the report is so you and others have an understanding of the results, what you performed, and summarize your conclusions."
ST 8: "I think it is very important to organize your data and results into a report. It describes what happened so when others read it they can learn from what you did."

Continued next page

Table 76 (continued)

ST 10: "In the classroom I think it is good practice. For the real world their important if you're going into anything where people relied on your reports and your analysis. I think the reports are practice for the real world. Reports and analysis are always important, but specifically for science."
ST 11: "The analysis is useful to others in the same field. It assists those who read it by showing the results in a clear concise format. "
ST 12: "The lab report is a way to "wrap it all up". Your research is presented in a special format that everyone else can read. This allows others to see what you've done and learn from it."
ST 15: "In the classroom it is very important as it allows for conclusions to be drawn. The research lab would do it in order to share their results with others. The report is used in the same manner at a research hospital or pharmacy. It is used to publish findings to help the scientific community as a whole."
ST 17: "The research experience is worthless without being able to analyze the data and report the results."
ST 20: "The report is a way to provide information and allow access to data that you have found during the process. It is a method that allows you to share and disseminate knowledge to other people about your work. Then others that may be working in the same area or interested in what you're working on may gain insights. When you share that knowledge other people may be able to learn from your experience."

Reflections of Pre-Post Laboratory Experiences

Section two of the Student Evaluation of Laboratory Instruction Questionnaire probed students' perceptions regarding the following four aspects of laboratory work: achievement in conducting the experiment, difficulty of doing the experiment, enjoyment in doing the experiment, and understanding the experiment. Each of the aforementioned topics included three self-explanatory statements, except the difficulty topic, which had four. (Appendix E) Participants were asked to choose one statement for each topic that best described their own position regarding that topic.

The questionnaire results were tabulated so that participant responses (choosing statement A, B, C, or D) could be expressed as a percentage. Table 77 shows the results of the questionnaire concerning participants' preferences for the instructional method of teaching experiments in the laboratories.

As can be seen from Table 77, 55% of the participants reported they felt a sense of achievement when they participated in a pre-lab discussion prior to performing the experiment, while 34% indicated that they felt a sense of achievement when they performed the experiment first and then participated in a post-lab discussion. A small percentage (11%) felt there was no clear difference.

The sense of achievement for those preferring to perform the experiment first may derive in part from participants' overcoming the attitude of having to have the "right" answer and rising to the challenge of the difficulty they initially experienced with the experiments to being able to perform the activity with minimal assistance. For those participants their enjoyment of the laboratory experience improved over the course of the semester.

Table 77 Reflections Pre-Post Laboratory Experiences Statements (N=56)

Topic and Statements*	Percentage (%)
Achievement	
A. Experiment first	55
B. Explanation first	34
C. No difference	11
Difficulty	
A. Experiment first	72
B. Explanation first	5.0
C. No difference	14
D. Same difficulty	9.0
Enjoyment	
A. Experiment first	21
B. Explanation first	60
C. No difference	19
Understanding	
A. Experiment first	33
B. Explanation first	48
C. No difference	19

*Appendix E

From Table 77, 72% of the participants indicated that it was more difficult to perform an experiment before it was discussed especially when it came to the methods and equipment which many were not familiar with due to lack of laboratory experience. Approximately 14% of the participants felt at the beginning of the semester it was a challenge to perform an experiment prior to a discussion but eventually preferred to perform the experiment first and follow-up with a post-lab discussion. A small percentage (2.0%) felt it was more difficult to perform an experiment after it was discussed, while 9.0% indicated there was no clear difference.

Early in the semester when the participants began laboratory experiments without a detailed pre-laboratory discussion their difficulties were noticeable as the laboratory manual was not designed to be used independently. In several experiments, the laboratory manual states “instructor will demonstrate” so when the participants asked to be shown, they were usually directed to a step in the procedure, to the diagrams or to a mock set-up of the laboratory equipment at the front of the laboratory. This pushed some of the participants to act more independently while completely frustrating others. However, many of the participants appeared to gain independence to varying levels as the semester progressed.

As can be seen from Table 77, 60% of the participants indicated that they enjoyed the laboratory experience better if they participated in a pre-lab discussion prior to performing the experiment, while 21% indicated that they enjoyed lab better when they performed the experiment first and then participated in a post-lab discussion. A small percentage (19%) felt there was no clear difference.

Many participants, if not most, were willing to obtain the raw data and then leave the laboratory as quickly as possible as indicated by the preference (60%) of performing the experiment after a detailed pre-lab discussion. Enjoyment during the laboratory work period may contribute to the participants’ achievement and understanding. Creating enjoyment is one way to avert the “take the data and run” scenario. Performing the experiment prior to a discussion allows participants more time to ask questions and think thereby contributing to an improved understanding of the concepts underlying the laboratory activity.

As indicated in Table 77, 48% of the participants indicated that they understood better if they participated in a pre-lab discussion prior to performing the experiment, while 33% indicated that they understood better when they performed the experiment first and then participated in a post-lab discussion. A small percentage (19%) felt there was no clear difference.

There are several factors that could explain the understanding results if one considers Bloom's Taxonomy (Jalil, 2006). When the experiment is discussed prior to performing it, the instructor is addressing higher levels of learning (e.g., analysis), without addressing the knowledge level (1^{st} level), in a proper way. This means that some participants may not know what the instructor is talking about when the discussion connects the theory to practice. Some participants may misunderstand leading to misconceptions. Here some participants preferred acting as receivers of information demonstrating they were able to repeat experiments. This preference may have been due to one or a combination of the following: lack of prior experience in laboratory problem solving, cook-book laboratory experiences, or personal lack of confidence

Performing the experiment first would be considered the natural process of learning as one begins with observation which is the first level in Bloom's taxonomy–knowledge. When the experiment is performed first and then discussed this promotes better visualization of the underlying concepts of that experiment. This approach may facilitate critical thinking, encourage use of prior knowledge, and assist them in seeking additional information. The participants had to think more independently, make judgments, and interpret the laboratory manual. When participants are allowed to discover answers on their own, retention improves, and deeper understanding develops (Jalil, 2006).

Reflective Assessment - Bloom's Taxonomy

Section three of the reflective questionnaire was used as a tool to estimate learning gains or outcomes due to laboratory instruction. Bloom's cognitive taxonomy separates into six major domains: knowledge, comprehension, and application all considered lower-order cognitive skills, and analysis, synthesis, and evaluation, higher-order cognitive skills. This taxonomy was applied to the analysis of the reflective self-assessment questionnaires and interviews. The questionnaire gave more quantitative data and the interviews more qualitative information.

In the study participants (N=56) completed a self-evaluation of their overall learning gains/outcomes in the cognitive domains of Bloom's Taxonomy due to the laboratory instruction. The questionnaire question in general was formulated as follows: "Which description best describes the kind of learning/understanding you have gained by doing this laboratory activity?" The participants were given the Bloom categories in the cognitive domains: knowledge, comprehension, application, analysis/synthesis, and evaluation to characterize their learning gains/outcomes. To assist the participants in understanding the meaning of each domain, keywords were provided. Two examples are: knowledge (to recall, describes, identifies facts, term or phenomena) and analysis (to analyze, troubleshoot, and distinguish concepts through reasoning). The participants evaluated their own learning gains/outcomes on the scale: nothing, a little, some, a lot, or very much for each of the cognitive domains. Table 78 summarizes participants' overall self-assessments of the cognitive domains.

Table 78 Participant Assessment of Laboratory Cognitive Domains

Cognitive Domains	Overall Average Choice
Lower Order	
Knowledge	D - a lot
Comprehension	D – a lot
Application	C - some
Higher Order	
Analysis	C - some
Synthesis	B – a little
Evaluation	B – a little

It is clear that, with regard to knowledge, and comprehension there are no differences between the overall average participant selections of “a lot” and is supported by the data in Table 79 for all six lab activities. The application category was rated “some” overall by the participants and is supported by three of the selected laboratory activities noted in Table 79. Regarding the higher-order categories of analysis, synthesis, and evaluation, the ratings made by the participants varied depending on the activity and instruction. The average overall choice for the category of analysis was “some” which is supported by the data in Table 79 with three of the six selected activities. This rating suggests that the participants felt they gained more in the area of analysis from the technology-based, micro-computer based (MBL) laboratory activities. In regard to the categories synthesis and evaluation participants selected “very little” as their overall average choice. Participants indicated there was little to no gain in their learning at the synthesis and evaluation level during lab activity 3 (Matter Lab) or activity 7 (Molecular Shapes). However, participants did have to compare, contrast, and justify solutions in lab activity 3 and 7 but not to the extent they had to in other activities.

Table 79 Laboratory Activities in Terms of Bloom's Taxonomy

Cognitive Domain	Laboratory Activity					
	2 *DP	3 ML	4 CRS	7 MS	8 *TE	9 *MV
Knowledge	RG	RG	RG	RG	RG	RG
Comprehension	RG	RG	RG	RG	RG	RG
Application	RG	SRG	SRG	SRG	RG	RG
Analysis	RG	SRG	SRG	SRG	RG	RG
Synthesis	RG	SRG	RG	SRG	RG	SRG
Evaluation	SRG	NRG	SRG	NRG	SRG	SRG

RG indicates skill required-gained as identified by participants
SRG indicates skill somewhat required-gained as identified by participants
NRG indicates skill not all required-gained as identified by participants
*Technology-Based (MBL) activities

Reflections - Laboratory Learning – Bloom's Taxonomy

Knowledge involves lower-order thinking and includes those behaviors that emphasize the recognition or recall of ideas, material, or phenomena (Domin, 1999). This involves such skills as: defining terms, identifying objects, or stating procedural steps. Remembering, recalling, and recognizing knowledge is essential for further development of meaningful learning as the aforementioned knowledge is used in more complex tasks. Recognizing knowledge involves retrieving from long-term memory in order to compare it with presented information. Recalling knowledge involves retrieving it from long-term memory. Instruction at the knowledge level promotes retention of the presented material in much the same form as it was taught (Anderson & Krathwohl, 2001). The student's role at the knowledge level is to read, listen, observe, take notes, recall information, as well as ask and respond to questions. Some of the keywords used to evaluate participants' comments were to learn, remember, and to understand. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of knowledge. The participants recalled, remembered, and/or recognized chemistry knowledge. For example, participants recognized their knowledge of chemical reactions and steps in how to use instruments, organize data tables, and repeat density calculations.

Comprehension also involves lower-order thinking and includes those behaviors that emphasize the grasping the understanding of the meaning of informational materials (Domin, 1999). This involves skills such as: explaining a concept, interpreting a graph, or generalizing data. When the goal of instruction is to promote knowledge transfer the focus shifts to comprehension (Anderson & Krathwohl, 2001). The student's role at the knowledge level is to read, listen, observe, take notes, recall information, as well as ask and respond to questions. Some of the keywords used to evaluate participants' comments were to explain, to describe, and to understand. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of comprehension. The participants constructed meaning from the laboratory instruction through graphic, oral, and written communication. For instance, participants could give examples, restate in their own words, and explain experimental concepts. Here the participants built connections between "new" knowledge to be gained to prior knowledge. This new knowledge is integrated with existing cognitive frameworks and mental models (Anderson & Krathwohl, 2001).

Being able to interpret, exemplify, classify, summarize, infer, compare and explain knowledge is essential for further development of meaningful learning. During comprehension students may begin to convert information from one form to another. For instance, when a student converts a graph into words involves interpretation skills while exemplifying occurs when a student can give a specific example of a concept. Inferring involves finding patterns while comparing involves detecting similarities and differences between two or more ideas. Classifying, inferring, and comparing occur when a student recognizes something belongs to a certain category as in knowing the differences between elements, compounds, and mixtures. Explaining occurs when the student can construct a cause-and-effect model of a system such as correlating the colors of spectral lines with their wavelengths.

Application is considered by some to be lower order thinking and by others to be the lowest level of higher order thinking. For the purpose of this study it was considered as the transitional level from lower to higher level thinking. Application involves lower-order and higher-order thinking and includes those behaviors that emphasize the ability to used learned material in new and concrete situations (Domin, 1999). To apply knowledge means completing or using a procedure in a given situation. This involves skills such as: problem solving, utilizing concepts in novel situations, and constructing graphs. Some of the keywords used to evaluate participants' comments were to apply, to solve, and to predict. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of application. The participants constructed meaning from the laboratory instruction by being able to execute and/or implement a task with some degree of understanding of the problem and the procedure. For instance, participants felt confident in applying the learned concepts to other situations and the mathematics. Here the participants learned information in new and concrete situations to solve problems. This new ability to be able to apply knowledge is used with other cognitive processes such as understand and create (Anderson & Krathwohl, 2001).

Analysis is the lowest level of higher order thinking and includes those behaviors that emphasize the ability to breakdown material into its component parts (Domin, 1999). Analysis of knowledge involves identifying pertinent data, identifying inconsistencies, and establishing relationships between items. Learning to analyze is considered one of the most important objectives in science instruction. Some of the keywords used to evaluate participants' comments were to distinguish, to analyze, and to differentiate. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of analysis. The participants constructed meaning from the laboratory instruction by being able to distinguish the relevant from irrelevant parts and determine how the elements of a situation fit or function within a structure relating to chemistry. For instance, participants felt confident in being able to analyze scientific error, differentiate the difference between types of chemical reactions, and to distinguish molecular shapes due to their experiences during laboratory instruction. Here the participants used the cognitive processes of differentiating, organizing, and attributing of new information in terms of relevance or importance (Anderson & Krathwohl, 2001).

Synthesis involves higher order thinking and includes those behaviors that emphasize the ability to put parts together to form a new whole (Domin, 1999). Synthesis of knowledge can involve checking consistencies, formulating a hypothesis, proposing a plan for an experiment, or proposing alternatives. Synthesis involves students making judgments based on criteria and standards using the cognitive processes of checking and critiquing (Anderson & Krathwohl, 2001). Criteria factors include consistency, effectiveness, efficiency, and quality. The standards can be either qualitative or quantitative. Checking includes detecting fallacies within a product by determining whether a product has internal consistency. For instance when a student tests whether data supports a hypothesis or conclusion or whether presented material contains parts that contradict one another. Some of the keywords used to evaluate participants' comments were to create, to design, and to compare. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of synthesis. The participants constructed meaning from the laboratory instruction by being able to distinguish the relevant from irrelevant parts and determine how the elements of a situation fit or function within a structure relating to chemistry. For instance, participants felt confident in being able to create a strategy to determine what errors occurred in trials, speculate why certain unexpected results occurred that did not support the hypothesis, and making judgments on whether the data supports the chemistry concepts due to their experiences during laboratory instruction.

The final higher-order thinking domain, evaluation includes those behaviors that emphasize the ability to judge the value of material based on definite criteria (Domin, 1999). Evaluation of knowledge can include judging the value of data, judging the value of experimental results, and justifying conclusions. Evaluation involves students putting or reorganizing material together resulting in a coherent whole or new pattern that allows them to build a model of chemistry phenomena. At this level students may judge the value of material based using one or all of the following cognitive processes: generating, planning, and producing (Anderson & Krathwohl, 2001). For instance when a student tests whether data supports a hypothesis or conclusion or whether presented material contains parts that contradict one another. Some of the keywords used to evaluate participants' comments were to justify, to conclude, and to compare/contrast. Table 80 presents some examples of the participants' reflective comments concerning the cognitive domain of evaluation. For instance, participants compared and contrasted class experimental data, justified the resulting end product(s), and generated conclusions due to their experiences during laboratory instruction.

Table 80 Participants' Reflections on Cognitive Domains (N=56)

Cognitive Domain	Reflective Written Comments
Knowledge	**ST 7:** "I did gain knowledge on how to use instruments and determine an unknown substance." **ST 11**: "I can recall how to figure density; how to organize a table." **ST 12:** "I can describe how you would balance redox reactions." **ST 53:** "I learned how to recognize chemical reactions in the lab. The experiments showed the information in a more visual, illustrated process."
Comprehension	**ST 8:** "Participating in the experiment allows me to better understand and explain in my own words what was done." **ST 16:** "I could easily explain to someone the differences between elements, compounds, and mixtures." **ST 26:** "Performing experiments isn't crucial for knowledge as much as comprehension. Experience is important for comprehension." **ST 53:** "I was able to comprehend the correlation between the colors of spectral lines and their wavelengths."
Application	**ST 11:** "Applying all of the different theories and formulas to actual problems." **ST 45:** "I feel confident that I can predict whether chemical reactions will happen or not." **ST 52:** "I learned to apply the concept of the Law of Conservation of Mass to the experiment and real life." **ST 54:** "I can solve the enthalpy equations and can calculate heat and temperature changes."
Analysis	**ST 12:** "I now hold the ability to analyze various chemical reactions and determine whether they are a certain classification of reaction." **St 45:** "I know how to analyze the shape of the molecule to determine hybridization and determine polarity." **ST 53:** "I was able to distinguish the shapes and geometry of certain molecules by analyzing the number of bonds, lone pairs, and electron groups." **St 54**: "I learned to analyze my error which occurred during the experiment."
Synthesis	**St 15:** "Create a strategy to figure out what went wrong in the first trial." **ST 19:** "I believe I can design experiments to collect and analyze raw data." **ST 43:** "I was able to speculate as to why certain unexpected results occurred." **ST 45:** "This lab not only supports the ideal gas law, but paves my way to learning other gas laws such as Boyles' or Charles."
Evaluation	**ST 9:** "I was able to compare and see the differences between different chemical reactions." **ST 11:** "Comparing information from all the groups in the class." **ST 12:** "I can justify why each substance got separated from the mixture the way it did." **ST 53:** "I was able to compare previous measured data to the experimental data and draw appropriate conclusions."

Final Interview Question Eleven - Bloom's Taxonomy

Final interview question 11 was used as a tool to determine which three of the six cognitive domains in Bloom's Taxonomy did the interview participants feel they utilized most often during the semester course. As discussed in the previous section Bloom's

Taxonomy is divided into six domains further classified into two levels of thinking: lower-order (knowledge, comprehension, and application) and high-order (analysis, synthesis, and evaluation). Table 81 summarizes the interview participants' responses to the interview question concerning which three cognitive domains that they utilized most often in the semester course. Table 82 presents some examples of participants' responses when asked to expand on their original answer and explain why and during which instructional feature they felt they used those particular cognitive domains the most.

By the end of the semester course 85% of the interview participants identified the cognitive domain of application as the skill that was used most often during the semester course. This domain is the transitional level from lower-order to higher-order thinking in Bloom's Taxonomy model. Participants indicated that application skills were used most often during laboratory work and post-laboratory analysis for performing calculations and writing laboratory reports. Application allowed the participants to complete or use a procedure in a given situation in chemistry laboratory and take the new information gained to solve different types of problems.

Eighty percent of the interview participants identified comprehension as the second domain used most often during the semester course. Comprehension a lower-order thinking skill was necessary for pre-laboratory and laboratory work in order to grasp the meaning of and classify informational materials.

Table 81 Descriptive Statistics of Interview Participants (N=20)

<table>
<tr><th colspan="7">Final Interview Question-11</th></tr>
<tr><th colspan="7">Which three of the six learning skill levels in Bloom’s Taxonomy did you utilize most often in this course?</th></tr>
<tr><th>ID</th><th colspan="6">Bloom’s Taxonomy - Cognitive Domains</th></tr>
<tr><th></th><th>Knowledge</th><th>Comprehension</th><th>Application</th><th>Analysis</th><th>Synthesis</th><th>Evaluation</th></tr>
<tr><td>1</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>2</td><td></td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>3</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>5</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>8</td><td>X</td><td>X</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>9</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>10</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>11</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>12</td><td>X</td><td>X</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>13</td><td></td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>14</td><td>X</td><td>X</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>15</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>16</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>17</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>18</td><td></td><td></td><td>X</td><td>X</td><td></td><td>X</td></tr>
<tr><td>19</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td></tr>
</table>

The cognitive domain of knowledge was identified by 60% of the participants as the third skill level used most often during the semester course. The lower-order thinking domain of knowledge requires retrieving relevant knowledge from long-term memory. As suggested by the participants, knowledge is essential during the pre-laboratory and laboratory work components of instruction in order to perform more complex tasks as the semester progressed.

By the end of the semester course the three higher-order thinking domains were identified as being used the least by the participants. Forty-five percent of the interview participants identified the cognitive domain of analysis as the higher-order thinking skill used most often during the semester course. This domain requires the breaking down of materials into component parts and determining how they relate to one another and the overall purpose in chemistry. Participants indicated that analysis skills were used most often during post-laboratory analysis for performing calculations and writing laboratory reports. Analysis allowed the participants to examine the information (data) to develop conclusions by making inferences and using evidence to support their conclusions.

The interview participants identified the cognitive domain of synthesis as the skill used the least (5.0%) during the course of the semester. Synthesis requires a student to apply knowledge and skills to produce alternatives. During the semester course participants did indicate that they had to create strategies and speculate about unexpected results (data).

Twenty-five percent of the interview participants felt they often used the cognitive domain of evaluation during the semester course. This domain required the participants to reorganize their models into a functional whole. Participants indicated that evaluation skills were necessary for post-laboratory analysis.

Table 82 Interview Participants' Reflections - Bloom's Taxonomy

Final Interview Question-11
Which three of the six learning skill levels in Bloom's Taxonomy did you utilize most often in this course?
Quotation Comments
ST-2: "I would have to say comprehension, application, and analysis. In every lab report we had to describe and interpret our results. We had to classify and arrange our results so that whoever picked up our notebooks could understand."
ST-4: "I think you use all six of them to a certain level. I believe that comprehension, the understanding of information and grasping the meaning was used a lot from lab to lab. Application was used writing lab reports. You had to demonstrate understanding of the data, perform calculations, and be able to draw conclusions from what you observed. Analysis involved breaking down what you did in order to report the information."
ST-5: "Knowledge you would get from the course lectures, which corresponded to the lab. So by watching the power-point lectures from the lecture and lab helped one understand what was going on in lab. Comprehension would involve further understanding during the laboratory work which reinforced the material visually showing you what was happening. Application because of the calculations that we have to do in lecture then actually applying that in the lab."
ST-6: "Knowledge, application, and comprehension were used. There are some things you have to memorize but you have to understand the application so you can apply it. One also gained an understanding of the information by tying it all together."

Continued next page

Table 82 (continued)

ST-9: "Knowledge as it included collecting and examining information. Knowledge was gained from the pre-lab. Application was used performing calculations. We also had to be able to classify such as when identifying types of chemical reactions. Analysis was the major component of the post-lab. This included analyzing your results and categorizing everything."
ST-10: "When you write a post-lab report you're evaluating all the experimental data. Comprehension was necessary because in order to perform the lab you had to have some understanding of the concepts. You also had to able to apply the formulas and calculations to gain an overall understanding."
ST-12: "You have to know certain terms that are used in the labs. You have to know what the formulas are and how they are used. You have to know how to collect data. Comprehension, you have to know how to interpret your data and discuss it. For instance when you're doing the post-lab you have to analyze what you did during the experiment. You have to explain the data and organize your results into tables."
ST-16: "Comprehension because it helped you understand the theories behind the lab. It helps in grasping the meaning of what you did. Application is to apply the collected information to what you already know. Synthesis helped me to understand the material from before and apply it to the next lab."
ST-18: "Application it was used in the pre-lab and during laboratory work. You would apply the pre-lab to the experiment. The analysis involved using equations that dealt with the lab. You'd take the data that you got from the experiment and evaluate it. Evaluation included taking the experimental data as a whole and being able to draw a conclusion."

Characterization of Participants' Epistemological Reflections

Epistemology and Instructional Methods

Section one, question eight of the Student Evaluation of Laboratory Instruction Questionnaire was used to evaluate participants' beliefs concerning what they learned, if anything about epistemological beliefs with respect to the laboratory instructional methods. This section of the reflective student questionnaire (Appendix E) was used to assess participants' reactions to the three major instructional components (e.g., pre-laboratory, laboratory work, and post-laboratory) of laboratory instruction implemented during the semester course with the EBAPS dimensions (structure of knowledge, nature of knowing and learning, real-life applicability, evolving knowledge, and source of ability to learn). The results for all the participants (N=56) and the interview participants (N=20) are presented in Tables 83 and 84-93, respectively.

Evidence from the reflective open-ended responses on the student questionnaire indicated that some participants (N=56) perceived epistemological messages in their instruction (Table 83). For the EBAPS dimension, structure of scientific knowledge participants' reflections suggests that they believe scientific knowledge to be structured and connected. For the EBAPS dimension, nature of knowing and learning scientific knowledge participants' reflections suggest that they believe that learning scientific knowledge requires making connections with prior knowledge. For the EBAPS dimension, real-life applicability of scientific knowledge participants' reflections suggests that scientific knowledge is relevant and visible in our daily lives. For the EBAPS dimension, evolving scientific knowledge participants' reflections suggests that they believe scientific knowledge to not set in stone, that error occurs and results do not always match the concepts. For the EBAPS dimension, source of ability to learn scientific knowledge participants' reflections suggest that scientific knowledge can be learned by anyone through practice and one learns by doing.

Table 83 Participants' Reflections - Epistemology - Instructional Methods

EBAPS Variable	Reflective Written Comments What have you learned, if anything, concerning your epistemological beliefs about science with respect to the instructional methods?
Structure of Scientific Knowledge	**ST-27:** "That knowledge of scientific principles and definitions help during instruction. As the course progresses I see how scientific knowledge is highly structured and connected from one lab to the next." **ST-46:** "I have learned that chemistry is more than explosions. That it is the building blocks for everything. Scientific knowledge is connected from one topic to the next." **ST-52:** "I've learned that chemistry involves large quantities of hands-on work and descriptive observations. These observations are connected to the science concepts." **ST-53:** "I believe scientific knowledge is attained through a series or process. Through these activities we can make connections between the concepts and data."

Continued next page

Table 83 (Continued)

Nature of Knowing & Learning Science	**ST-9:** "I have learned how to analyze the lab results and other information by working actively through the material. I gather the information in combination with the results to form a well thought out conclusion." **ST-49:** "I have learned that two different instructors could explain the same concept two different ways but still be correct. That I have to relate what I learn in lab to my prior knowledge." **ST-50:** "Knowing what the lab is all about is very essential in order to be able to comprehend the material and then apply it to prior knowledge. Being able to analyze the results assists in synthesizing and creating other ideas. Being able to evaluate your results and summed it up involves constructing one's own understanding." **ST-53:** "The instructional methods facilitated my understanding of this aspect of chemistry by compartmentalizing it in various successive sections. For instance during the laboratory work I used my prior knowledge to construct understanding about the new material encountered." **ST-54:** "I have learned that it is very important to have pre and post labs. They allow you to reflect before and after the laboratory work. It is important that the instructor allow you to do things on your own. In other words construct your own understanding."
Real-life Applicability of Science	**ST-11:** "It is a phenomenal event for chemistry is happening everywhere and at every moment. Being able to see the chemistry concepts working in everyday life makes them more relevant." **ST-13:** "I've taken chemistry before and but this course has increased my perspective on how chemistry is seen in our daily life."
Evolving Scientific Knowledge	**ST-7:** "I have learned that there is no exact, right answer in science. That science is always changing and the laboratory results may or may not support the current knowledge." **ST-8:** "From this course I have learned that science has error but strives to be a precise and accurate as humanly possible. However, it changes and does not always occur as predicted." **ST-15:** "Experiments do not always go according to plan. For instance some of the predictions did not concur with some of the results. This supports the idea that science is not set in stone." **ST-16:** "I have learned that science can often require many attempts/experiments to obtain supportive results. Sometimes you have to repeat an experiment if it does not go according to plan or if you want to try a different method. The results do not always support the science concepts as error does occur."

Continued on next page

Table 83 (continued)

Evolving Scientific Knowledge	**ST-45:** "I learned why some % yields are above or below 100%. This supports my belief that the results from laboratory experiments are not exact and error is anticipated. The results obtained should be repeatable." **ST-52:** "I've learned that chemistry involves performing and recording of specific observations such as viewing whether a change or no change occurs during the procedure. The results may or may not support the scientific concepts."
Source of Ability to Learn Science	**ST-4:** "Through practice I learned that I can apply the concepts from lecture to lab." **ST-11:** "I feel that I have achieved my goal when I perform experiments and understand the results. I enjoy learning new concepts and theories involving chemistry." **ST-15**: "Fun is an important part of "instructional methods" especially in learning science. The more interesting the subject the more likely one is to remember and understand the information. Performing the lab and then analyzing the results improves my understanding." **ST-49:** "You can learn science if you do it. After I have performed the experiment I understand a concept much more easily."

N=56

Final Interviews - Epistemological Beliefs and Instructional Methods

During the final interviews, five questions related to the multi-dimensional axes of the EBAPS: structure of scientific knowledge, nature of knowing and learning science, real-life applicability of science, evolving scientific knowledge, and source of ability to learn science were used to probe the participants views on which instructional feature influenced their beliefs (Appendices B & N). The interview participants were asked to elaborate on the questions in order to invoke the participant's thoughts about the EBAPS variables and the instructional feature (e.g., pre-laboratory, laboratory work, and post-laboratory). These answers can often display different epistemological categories within one question. This suggests that one cannot fully isolate these variables and only search for evidence in the participants' reflections and interviews.

Structure of Scientific Knowledge

Strong support was shown by 45% of the participants (N=20) indicating that they found the post-laboratory work to be the most effective in influencing their epistemological beliefs about the structure of scientific knowledge (Table 84). Moderate participant support was shown for the laboratory work with 30% indicating that it had a moderate influence on their laboratory experience and understanding of the structure of scientific knowledge. Three participants (15%) indicated that none of the instructional features influenced their beliefs for this dimension. The pre-laboratory was ranked fourth with 10% suggesting that it had influenced their beliefs about the structure of scientific knowledge.

Table 84 Instructional Feature – Structure of Scientific Knowledge

Instructional Category	Most Effective
Pre-laboratory	10.0%
Lab Work	30.0%
Post-laboratory	45.0%
Other	15.0%

N=20

Evidence from the final interview responses indicated that some participants (N=20) perceived epistemological messages in their instruction (Table 85). For the EBAPS dimension, structure of scientific knowledge interview participants' suggested that they believe scientific knowledge to be structured and connected. Participants 9 and 12 identified the pre-laboratory as the instructional method that influenced their beliefs about the structure of scientific knowledge because it assisted in making connections between the concepts and the rest of the laboratory experience. The participants (ST 1, 3, 15, and 18-19) selecting the laboratory work as having the most influence on their structure of scientific knowledge beliefs expressed that during laboratory work they could begin to tie all the concepts from the pre-laboratory together with what occurred during the lab. The majority of the participants (ST 4-5, 7-8, 11, 14, 16-17, and 20) described the post-laboratory feature as having the most influence on their structure of scientific knowledge views. These participants felt that the post-laboratory experience allowed them to see how all the concepts and results from the pre-lab and laboratory work was structured and connected improving their understanding. Three participants (ST 2, 6, and 10) expressed that none of the instructional methods influenced their beliefs concerning this dimension. They identified prior science learning experiences as having a major influence.

Table 85 Structure of Scientific Knowledge - Instructional Methods

Final Epistemological Beliefs Interview Question-1	
Structure of Scientific Knowledge – What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Structure of Scientific Knowledge in this course?	
Instructional Issue	Quotation Comments
Pre-laboratory	**ST 9**: “The pre-lab as I could begin to see how the concepts discussed were connected to the overall lab concepts.” **ST 12:** The pre-lab because it connected and related the concepts to the lab to be performed.”
Laboratory Work	**ST 1:** “The laboratory work because you are actively engaged in learning and connecting the results to the concepts.” **ST 3: “**The laboratory work as you could see how it connected to the pre-lab concepts.” **ST 13:** “The laboratory work because I could tie the material from the pre-lab to what happened during the lab.” **ST 15:** “The laboratory work as it clarified the gray areas.” **ST 18:** “The laboratory work because you could make connections with the pre-lab.” **ST 19:** “The laboratory work because you can observe the connections. ”
Post-Laboratory	**ST 4:** “The post-lab because you’re connecting concepts that you’ve learned from previous labs.” **ST 5: “**The post lab this is we here you actually try and connect the information.” **ST 7:** “The post lab because it connects the pre-lab and laboratory work concepts together. So you can see how it is connected.”

Continued next page

Table 85 (continued)

Post-Laboratory	**ST 8:** "The post lab. After you evaluated the data you could see the bigger picture of how everything was intertwined." **ST 11:** "The post lab as it helped me put it all together." **ST 14:** "The post-lab because you attempt to understand why things work the way they do and draw a conclusion." **ST 16:** **"**Post-lab because it helped strongly connect everything." **ST 17:** "The post lab because it tied it all the concepts together." **ST 20:** "All three of them influenced that belief. However I would choose the post-lab."
Overall	**ST 2:** **"**I don't believe so I think I understood in elementary school I've always been taught that theories should be proven 3rd grade teacher beat into our heads." **ST 6:** "Not one in particular. When I developed the belief a long time ago when I was first studying science I guess." **ST 10**: "None of the instructional methods. I just started taking kind of some more hands-on science classes."

N=20

Nature of Knowing and Learning Scientific Knowledge

Strong support was shown by 50% of the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs about the nature of knowing and learning scientific knowledge (Table 86). Moderate participant support was shown for the post-laboratory with 25% indicating that it influenced their laboratory experience and understanding of the nature of knowing and learning scientific knowledge. One participant indicated that none of the instructional features influenced her beliefs for this dimension. The pre-laboratory was ranked third with 20% suggesting that it had a moderate influence on their beliefs.

Table 86 Instructional Feature – Nature of Knowing and Learning Science

Instructional Category	Most Effective
Pre-laboratory	20.0%
Lab Work	50.0%
Post-laboratory	25.0%
Other	5.0%

N=20

Evidence from the final interview responses indicated that some participants (N=20) perceived epistemological messages in their instruction (Table 87). For the EBAPS dimension, nature of knowing and learning scientific knowledge interview participants' suggested that they believe connecting prior scientific knowledge with new concepts is important. Four participants (ST 2, 8, 10, and 20) identified the pre-laboratory as the instructional method that influenced their beliefs about the nature of knowing and learning scientific knowledge because it allowed them to connect their prior knowledge with the new knowledge being presented during rest of the laboratory experience. The majority of the participants (ST 3-7, 11-12, 14, 17, and 18) selected the laboratory work as having the most influence on their nature of knowing and learning scientific knowledge beliefs. They expressed that during laboratory work they could apply and begin to tie all their prior and current concepts together with what occurred during the lab. A few participants (ST 1, 15-16, and 19) described the post-laboratory feature as having the most influence on their nature of knowing and learning scientific knowledge views. These participants felt that the post-laboratory experience allowed them to take all their scientific knowledge gained from the pre-lab and laboratory work as well as their prior knowledge and construct their own understanding. One participant (ST 9) expressed that none of the instructional methods influenced her beliefs concerning this dimension. She suggested that everyone has their own method of learning that works for them.

Table 87 Nature of Knowing and Learning Science - Instructional Methods

Final Epistemological Beliefs Interview Question-2	
Nature of Knowing and Learning in Science – What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Nature of Knowing and Learning in Science in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST 2:** “The pre lab as I had to construct my own understanding and think outside the box.” **ST 8: “**Pre lab because you need to relate the new things you learn to the previous material.” **ST 10:** “Probably the pre-lab as that is where you’re first introduced to the new material and you build on what you’ve done previously.” **ST 20:** “Pre-lab.”
Lab Work	**ST 3:** “I think the lab work was the most effective for me. I wanted to be able to spit out more than facts and really understand.” **ST 4**: “I would say the lab work because you use real world situations to relate to what you see and what’s going on during the labs.” **ST 5:** “The laboratory work influenced my beliefs. Using my prior knowledge helped me understand while doing the lab.” **ST 6:** “The lab work because as things occur you have to be able to think the results through.” **ST 7:** “The lab work is when you are actually constructing knowledge as you work and begin to understand.” **ST 11:** “Laboratory work because it helped me to expand my knowledge learning.” **ST 12**: “The lab work really helped in explaining the concepts.” **ST 14: “**I would say the lab work. Prior knowledge and experiences were important.” **ST 17**: “The lab work as it actually allowed you to build on the lecture material.” **ST 18:** “It would be the laboratory work because even if you had prior experiences or knowledge you’re still learning a new concept. It allowed you to use the new concept.”
Post-Lab	**ST 1:** “The post-lab because it that summarizes most of your findings in order to show your understanding. You use prior science knowledge.” **ST 13:** “I would say the post-lab because you have to put the knowledge together and draw a conclusion.” **ST 15:** “Post lab because it forced you to use the information from the experiment and relate it to the concepts.” **ST 16:** “Post-lab. It required some learning and understanding on my own. It involves using prior knowledge.” **ST 19:** “I think the post-lab because you’re trying to answer and understand why and what happened in lab.”
Overall	**ST 9:** “None of the methods. I’ve always felt some people learn better by memorizing and others understand better by rewriting or rephrasing it in their mind.”

N=20

Real-Life Applicability of Scientific Knowledge

Strong support was shown by 65% of the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs about the real-life applicability of scientific knowledge (Table 88). Minimal participant support was shown for the post-laboratory with 15% indicating that it somewhat influenced their laboratory experience and understanding of the nature of knowing and learning scientific knowledge. Three participants indicated that none of the instructional features influenced their beliefs for this dimension. The pre-laboratory was ranked fourth with one participant suggesting that it had influenced her beliefs.

Table 88 Instructional Feature – Real-Life Applicability

Instructional Category	Most Effective
Pre-laboratory	5.0%
Lab Work	65.0%
Post-laboratory	15.0%
Other	15.0%

N=20

Evidence from the final interview responses indicated that some participants (N=20) perceived epistemological messages in their instruction (Table 89). For the EBAPS dimension, real-life applicability of scientific knowledge interview participants' suggested that scientific knowledge occurs and is relevant to everyday life. One participant (ST 13) identified the pre-laboratory as the instructional method that influenced her beliefs about the real life applicability of because the activities presented examples in the readings. The majority of the participants (ST 1, 4-5, 8-9, 11-12, and 14-19) selected the laboratory work as having the most influence on their real life applicability of scientific knowledge beliefs. They expressed that during laboratory work certain experiments or demonstrations involved concepts that could be applied to real life such as the atomic theory and how fireworks work. A few participants (ST 6, 10, and 20) identified the post-laboratory feature as having the most influence on their real life applicability of scientific knowledge views. These participants described the post-laboratory instructional method as a way to apply what they had learned in the course to their daily lives. Three participants (ST 2-3 and 7) expressed that none of the instructional methods influenced their beliefs concerning this dimension. They identified prior science learning experiences as having a major influence.

Table 89 Real-Life Applicability - Instructional Methods

Final Epistemological Beliefs Interview Question-3	
Real Life Applicability of Science – What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Real Life Applicability of Science in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST 13:** “Pre-laboratory. As there were examples in the reading.”
Lab Work	**ST 1:** “The laboratory work which included demonstrations of science things that happen in real-life such as fireworks and tire pressure.” **ST 4:** “I think the lab work. We made observations about the chemistry of light, the role of the gas laws to tire pressure, neon lights, and many other things related to real life.” **ST 5:** “The instructional feature that influenced my belief the most was the laboratory work.” **ST 8:** “Probably the lab work. I would see how these processes apply outside of the lab in real life situations.” **ST 9**: The laboratory work. When we did laboratory work we performed activities or experiments where we could see for instance how fireworks are created. ” **ST 11:** “Probably the most influential is laboratory work because it demonstrated the different things that go on during real life such as a chemical reaction or phase change.” **ST 12:** “I would explain like how the laboratory work relates to real life in the post-lab. We were doing with this one lab, in the laboratory where we studied light and how fireworks are made. I think the lab work because when you actually would do it you were actually experiencing the reality.” **ST 14:** **“**I would say the lab work just because that’s when you actually see it.” **ST 15:** “The laboratory work offered us some experiences with materials used in everyday life. We did reactions with dish soap and chemicals used in fireworks.” **ST 16:** “I would say the laboratory work. We had to work with light spectrums, the sun and fireworks. It shows that chemistry is everywhere.”

Continued next page

Table 89 (continued)

Lab Work	**ST 17:** "Laboratory work because it ties in to how things actually happen." **ST 18: "**I'll go with the laboratory work. We had to practice safety just like if we had a job in science or one using chemicals." **ST 19:** I'd say the laboratory work because we would do labs and demonstrations that involved concepts like the science of fireworks."
Post-Lab	**ST 6:** "The post lab because we would be able to see the connections between lab and everyday life. For instance how heat is transferred via your hot water heater." **ST 10: "**Probably the post-lab because you see that it can apply at home." **ST 20:** "Post-lab. I think that's where everything connects together and you gain some insight into how it applies to our life. You realize the difference it really has made."
Overall	**ST 2:** "None of the instructional features applied." **ST 3:** "All of the methods even the course lecture and discussion portion of the lab. I learned this gradually over time that chemistry all around." **ST 7:** "None of the features. I think scientists and people everywhere use it. I believed it before I came into the classroom. "

N=20

Evolving Scientific Knowledge

Strong support was shown by 35% of the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs about evolving scientific knowledge (Table 90). Moderate participant support was shown for the post-laboratory with 25% indicating that it was somewhat effective in influencing their laboratory experience and understanding of the nature of knowing and learning scientific knowledge. Five participants indicated that none of the instructional features influenced their beliefs for this dimension. Once again the pre-laboratory was ranked fourth with 10% suggesting that it had a minimal influence on their beliefs.

Table 90 Instructional Feature – Evolving Scientific Knowledge

Instructional Category	Most Effective
Pre-laboratory	10.0%
Lab Work	35.0%
Post-laboratory	30.0%
Other	25.0%

N=20

Evidence from the final interview responses indicated that some participants (N=20) perceived epistemological messages in their instruction (Table 91). For the EBAPS dimension, evolving scientific knowledge interview participants' suggested that the laboratory experience challenged them to compare the concepts to their results and decide what explanation to believe. Two participants (ST 3 and 9) identified the pre-laboratory as the instructional method that influenced their beliefs about the evolving nature of scientific knowledge as the pre-laboratory involved reviewing the theories that applied and how they had developed and changed over time. The majority of the participants (ST 8, 11, 13-16, and 19) selected the laboratory work as having the most influence on their evolving scientific knowledge beliefs. They expressed that during laboratory work they would consider the theories that applied and compare what they expected to happen with what actually happened. From this comparison some could see that scientific knowledge changes. Six participants (ST 1, 5, 7 12, 18, and 20) described the post-laboratory feature as having the most influence on their evolving scientific knowledge views. These participants felt that the post-laboratory experience allowed them to compare the results to the theories and understand the changes or differences. Several participants (ST 2, 4, 6, 10, and 17) expressed that none of the instructional methods influenced their beliefs concerning this dimension. They identified prior science learning experiences as having a major influence.

Table 91 Evolving Scientific Knowledge - Instructional Methods

Final Epistemological Beliefs Interview Question-4	
Evolving Scientific Knowledge – What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Evolving Knowledge of Science in this course?	
Instructional Issue	Quotation Comments
Pre-laboratory	**ST 3:** “Probably pre-lab as I got a better picture or idea how the concepts for the lab developed.” **ST 9:** “The pre-lab. Reading about the theories and looking back on the different hypotheses showed that scientists changed their minds over time.”
Lab Work	**ST 8:** “The laboratory work. When carrying out the experimental process it can challenge what is considered set in stone.” **ST 11:** “Laboratory work.” **ST 13:** “Laboratory work.” **ST 14:** “Laboratory work because it offered supporting evidence.” **ST 15:** “I always thought science changed over time. However, laboratory work helped validate my belief.” **ST 16:** “The lab work. For example the lab where we studied the Law of Conservation of Mass.” **ST 19:** “I would say the lab work because it would reinforce the concepts about how they change.”
Post-Lab	**ST 1:** “The post-lab helped me decide if something was right or wrong. After I studied the results I could predict why it happened and how the theory might have been contradicted.” **ST 5**: “The post lab. Showed that things can change.” **ST 7:** “It would be the post-lab as you formed conclusions based on your results that did not always match the expected. So science is not set in stone and there are different possibilities.” **ST 12:** “The post-lab most because that’s when you interpret your results. Everybody interprets their results differently so part of it will be somewhat based on their opinion.” **ST 18:** “I would say the post-lab. It gives you the opportunity to evaluate the new concepts and see if there is evidence to support the concepts.” **ST 20:** “I would say post-lab influenced or supported my belief.”
Overall	**ST 2:** “My belief was established in 3rd grade.” **ST 4:** “I’m not so sure if any of them influenced my beliefs.” **ST 6:** My belief was developed when I was a child in early science classes.” **ST 10:** “None of the instructional features influenced me. I held that belief in about 7th grade.” **ST 17:** “None influenced my belief because I have had many science classes.”

Source of Ability to Learn Scientific Knowledge

Strong support was shown by 35% of the participants (N=20) indicating that they found the post-laboratory to be the most effective in influencing their epistemological beliefs about the source of ability to learn scientific knowledge (Table 92). Moderate participant support was shown for the pre-laboratory with 25% indicating that it was moderately effective in influencing their laboratory experience and understanding of the source of ability to learn scientific knowledge. Four participants indicated that none of the instructional features influenced their beliefs for this dimension. The laboratory work was ranked third with 20% suggesting that it moderately effective in influencing their beliefs.

Table 92 Instructional Feature –Source of Ability to Learn

Instructional Category	Most Effective
Pre-laboratory	25.0%
Lab Work	20.0%
Post-laboratory	35.0%
Other	20.0%

N=20

Evidence from the final interview responses indicated that some participants (N=20) perceived epistemological messages in their instruction (Table 93). For the EBAPS dimension, source of ability to learn scientific knowledge interview participants' suggested that they believe anyone can learn science some just have to work harder. Five participants (ST 1-3, 12, and 14) identified the pre-laboratory as the instructional method that influenced their beliefs about the source of ability to learn scientific knowledge because it prepared and assisted them in making connections between the concepts and the rest of the laboratory experience. Four participants (ST 4, 7, 11, and 13) identified laboratory work as having the most influence on their source of ability to learn scientific knowledge beliefs. They expressed that the hands-on experience was an effective way for them to tie all the concepts together. The majority of the participants (ST 6, 8-9, 15-16, and 19-20) described the post-laboratory feature as having the most influence on their source of ability to learn scientific knowledge views. These participants felt that the post-laboratory experience allowed them to apply the concepts and results from the pre-lab and laboratory work thereby improving their understanding. The remaining participants (ST 5, 10, 17-18, and 19) expressed that none of the instructional methods influenced their beliefs concerning this dimension. They identified motivation and effort as having a major influence.

Table 93 Source of Ability to Learn - Instructional Methods

Final Epistemological Beliefs Interview Question-5	
Source of Ability to Learn Science – What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Source of Ability to Learn Science in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST 1:** "The pre-lab because if you just read and do the work anyone can be successful." **ST 2:** "The pre lab because it helped me understand the underlying concepts. You have to be prepared to learn." **ST 3:** "The pre-labs because the concepts are introduced. I had a difficult time if I did not do all of the pre-lab." **ST 12:** "The pre-lab because you could are introduced to the concepts. Plus it doesn't matter if you think you are good at science or not you still can learn by doing the work. **ST 14:** "I would say pre-lab because that is where I gained most of the basic knowledge which helped me to better understand the material."
Lab Work	**ST 4:** "Laboratory work because I learn better when there are hands-on activities." **ST 7:** "Laboratory work because doing the activities helped me to understand the concepts." **ST 11:** "Laboratory work. I would reread the pre-laboratory material and go over the laboratory work data then I would understand what happened." **ST 13:** "Laboratory work influenced my beliefs."

Continued next page

Table 93 (continued)

Post-Lab	**ST 6:** “Post lab because you learn more after experiencing and thinking about it.” **ST 8:** “All of them influenced my beliefs but the post-lab more than the other two. You learn by evaluating your results and drawing a conclusion.” **ST 9:** “The post-lab but I already held the belief that all individuals can learn science.” **ST 15:** “I would say the post lab. It helped to connect my prior knowledge with what I learned during the laboratory work.” **ST 16:** “Post-lab because learning science involves analyzing the information.” **ST 19:** “The post-lab because it really makes you think.” **ST 20:** “Post-lab. When doing the post-lab you are trying to process all the data. You are trying to find out why certain things happened.”
Overall	**ST 5:** “The laboratory work and the post lab. Both features allowed you to learn through experience.” **ST 10:** None of the instructional features. I think it’s based on your effort and motivation.” **ST 17:** “None of the instructional features. I would say anyone can learn science.” **ST 18:** “I do not think any of the features influenced me. I really like learning science.”

N=20

Characterization of Participants’ NOS Reflections

NOS and Instructional Methods

Section one, question eight of the Student Evaluation of Laboratory Instruction Questionnaire was used to evaluate participants’ beliefs concerning what they learned, if anything about NOS beliefs with respect to the laboratory instructional methods. This section of the reflective student questionnaire (Appendix E) was used to assess participants’ reactions to the three major instructional components (e.g., pre-laboratory, laboratory work, and post-laboratory) of laboratory instruction implemented during the semester course with four of the NSKS dimensions (creativity, developmental, parsimonious, and testable). The results for all the participants (N=56) and the interview participants (N=20) are presented in Tables 94-96.

Evidence from the reflective open-ended responses on the student questionnaire indicated that a few participants (N=56) perceived NOS messages in their instruction

(Table 93). For the NSKS dimension, creativity participants' reflections suggest that they believe science involves imagination. For the NSKS dimension, developmental participants' reflections suggest that they believe that scientific knowledge develops over time. For the NSKS dimension, parsimonious participants' reflections suggest that scientific knowledge is tied together by overlapping concepts. For the NSKS dimension, testable participants' reflections suggest that they believe scientific knowledge is gained by multiple trials, observations and error does occur.

Table 94 Participants' Reflections - NOS - Instructional Methods

NOS Variable	Reflective Written Comments What have you learned, if anything, concerning your NOS beliefs about science with respect to the instructional methods?
Creative	**ST-11**: "Science is a phenomenal event because it is happening everywhere and at every moment. You have to use your imagination to gain an understanding." **ST-13:** "I've taken other science courses where we had to design experiments. This course continues to show how chemistry concepts involve imagination."
Developmental	**ST-9:** "I have learned that science requires gathering the information over time to form a well thought out conclusion." **ST-32:** "I have learned that you can perform multiple experimental trials that support a theory for many years and with one opposing test disprove the theory." **ST-45:** "I have learned how to support the Law of Conservation of Mass."
Parsimonious	**ST-5:** "The nature of science is based on many laws and concepts that are tied together." **ST-9:** "I have learned about chemical reactions and the properties that set the different chemicals apart. The rules for this are simple and can be applied to other situations."
Testable	**ST-7:** "I have learned that there is no exact right answer in science." **ST-8:** "I have learned that science is based on trial and error." **ST-11:** "It is much easier to understand the nature of science by doing hands-on lab experiments than by simply reading." **ST-15:** "Predictions did not always correspond with the results." **ST-16:** "Science requires many attempts to obtain results. Sometimes you have to repeat an experiment if it does not go according to plan." **ST-45:** "I learned that laboratory experiments do not always produce expected results." **ST-52:** "I've learned that science involves making multiple observations."

Final Interview – NOS Beliefs and Instructional Methods

During the final interview, one question related to NOS beliefs was used to probe the participants views on which instructional feature influenced their beliefs (Appendices B & N). The interview participants (Table 96) were asked to elaborate on the question in order to invoke the participant's thoughts about NOS and the instructional feature (e.g., pre-laboratory, laboratory work, and post-laboratory). These answers can often display different NOS categories within one question. This suggests that one cannot fully isolate these variables and only search for evidence in the participants' reflections and interviews. Table 95 presents the participants instructional preference in relation to their NOS beliefs.

Table 95 Instructional Feature – NOS Beliefs

Instructional Category	Most Effective
Pre-laboratory	20.0%
Lab Work	70.0%
Post-laboratory	5.0%
Other	5.0%

N=20

Extremely strong support (ST 2-6, 8, 10-12, 14-15, 17-18, and 19) was shown by 70% of the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their NOS beliefs (Table 95). Minimal participant (ST7, 9, 13, and 20) support was shown for the pre-laboratory with 20% indicating that it was moderately effective in influencing their laboratory experience and understanding of NOS. One participant (ST 1) indicated that the post-laboratory feature influenced her NOS beliefs. Only one participant (ST 16) felt none of the instructional features influenced her NOS beliefs. She indicated that the lecture and textbooks influenced her beliefs.

Table 96 Interview Participants' NOS Reflections - Instructional Methods

Final NOS Interview Question-2	
What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the Nature of Science in this course?	
Instructional Issue	Quotation Comments
Pre-lab	**ST 7:** "Pre-laboratory influenced by beliefs but my point of view was formed in earlier science courses." **ST 9:** "The pre-lab included reading over the history of different scientists and any theories they influenced." **ST 13:** "Pre-lab as it offered explanations of theories." **ST 20:** "The pre-lab presented information on the related concepts and theories."
Lab Work	**ST 2:** "Laboratory work because we used the theories and concepts to help explain what was going on just like scientists do." **ST 3:** "Laboratory work because we could repeat reactions and observations to add support to our conclusions." **ST 4:** "The laboratory work because in most cases you're able to visually see what's going on." **ST 5:** "The laboratory work. You have to understand the theory and apply it to results." **ST 6:** "If anything it is the lab work because you get to see it doesn't always happen as expected. There are variables that cause changes." **ST 8:** "Probably the laboratory work. While doing the bench work in the laboratory you distinguish between theory and fact while testing your hypothesis." **ST 10:** "The lab work because sometimes the results do not line up completely with what you thought they would be. So you have to consider if it's wrong or whether you made a mistake." **ST 11:** "Laboratory work because you experience the error that can occur in science." **ST 12**: "The laboratory work because you expect an experiment to produce certain results but when we actually performed it sometimes something completely different happened." **ST 14:** "The lab work." **ST 15:** "The lab work because it is how scientific knowledge is collected, used and interpreted." **ST 17:** "The laboratory work as we could see things as they happened." **ST 18:** **"**I would say the laboratory work." **ST 19:** "Probably the lab work. It reinforced my thinking. For instance we made predictions before performing the lab. Then we would actually do the lab and find out if our predictions were correct."
Post-Lab	**ST 1:** "The post-lab because that is where we discuss the results and whether it supports the theory."
Overall	**ST 16:** "None of the features I was influenced by the course lecture and textbook."

Discussion

Essential Laboratory Pedagogy

RQ2. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

The majority (65%) of participants (N=56) indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. This supports the research that laboratory work can provide learners with a good opportunity to apply their newly acquired knowledge and gain new skills through first-hand experience (Johnstone, 1997; Millar 2002). When learners engage in laboratory work they can test, rethink, and reconstruct their own ideas and thoughts (Cimer, 2007; Kirschner, 1992). Dawe (2003) suggests that positive outcomes may be a result of the learners' gaining ownership over the concepts during laboratory work. The post-laboratory followed with 59% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material. The pre-laboratory was ranked third with 44% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material.

The interview participants (N=20) ranked the three instructional features the same as all the participants (N=56) with laboratory work being the most essential, followed by post-laboratory, and lastly pre-laboratory. The majority (83%) of interview participants indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. The development of interpretation, measurement, observation, and prediction skills are dependent on laboratory work. However, laboratory experiences do not guarantee that the aforementioned skills can be achieved. More emphasis should be placed on what the student should gain from the overall experience. Once again, strong participant support was shown for the post-laboratory with 72% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material. The pre-laboratory was ranked third with 46% indicating that it was either very or extremely essential to the laboratory experience and understanding of the material.

By the end of the semester course two of the three instructional features, laboratory work (40%) and post-laboratory (40%) were selected by the participants (N=56) as the most effective in promoting their learning during the semester course while the pre-laboratory instructional feature (65%) was selected as the least effective.

Fifty-five percent of the participants (N=56) reported they felt a sense of achievement when they participated in a pre-lab discussion prior to performing the experiment, while 34% indicated that they felt a sense of achievement when they performed the experiment first and then participated in a post-lab discussion. A small percentage (11%) felt there was no clear difference.

The study found that 72% of the participants (N=56) indicated that it was more difficult to perform an experiment before it was discussed especially when it came to the methods and equipment which many were not familiar with due to lack of laboratory experience. Approximately 14% of the participants felt at the beginning of the semester it was a challenge to perform an experiment prior to a discussion but eventually preferred to perform the experiment first and follow-up with a post-lab discussion. A small percentage (2.0%) felt it was more difficult to perform an experiment after it was discussed, while 9.0% indicated there was no clear difference.

As indicated 60% of the participants (N=56) indicated that they enjoyed the laboratory experience better if they participated in a pre-lab discussion prior to performing the experiment, while 21% indicated that they enjoyed lab better when they performed the experiment first and then participated in a post-lab discussion. A small percentage (19%) felt there was no clear difference.

Lastly 48% of the participants (n=56) indicated that they understood better if they participated in a pre-lab discussion prior to performing the experiment, while 33% indicated that they understood better when they performed the experiment first and then participated in a post-lab discussion. A small percentage (19%) felt there was no clear difference.

The conventional way of preparing the participants for the laboratory was through pre-laboratory activities. This included encouraging them to read over the potential methods. However, this can overload the students with information resulting in the learner becoming lost in the sequence of ideas. In addition, unless specific tasks are allocated (pre-laboratory) only a minority of students will read the material.

Epistemological Beliefs and Laboratory Pedagogy

RQ2a. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe influenced their personal epistemological beliefs about science (development) during the semester general chemistry laboratory course?

Strong support was shown by the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs. For three out of the five EBAPS (nature of knowing and learning, real-life applicability, and evolving knowledge) laboratory work was ranked as most effective in influencing beliefs. Moderate participant support was shown for the post-laboratory with it being ranked second in influencing overall EBAPS beliefs. Overall the pre-laboratory was ranked third suggesting that it had a minimal influence on participants' beliefs.

Students arrive with existing personal epistemological beliefs that lead to interpretations of instruction, and as these beliefs change, so do the interpretations. The participants in this study may have come to class with preconceptions about science laboratory learning formed from their prior learning experiences. The participants' perceptions of the laboratory learning experience may have hindered their beliefs. Some participants preconceptions were expressed when they described the laboratory experience as a place to reinforce what they learned in lecture or during the pre-laboratory.

According to Hofer (2001), studies have investigated how epistemological beliefs that learners hold about knowledge and knowing affect the learning and instructional process. For example Ryan's (1984) study suggested that there is a relationship between learners' epistemological beliefs and their information-processing strategies as measured by Bloom's taxonomy. Dimensions of epistemological beliefs have been shown to relate to learning and instruction (Schommer, 1990). For instance, one study showed that participants who viewed knowledge as certain were likely to generate unquestionable conclusions (Schommer, 1990). In addition, some were likely to give oversimplified conclusions.

Garret-Ingram findings (1997) were that epistemological beliefs affect learners' use and choice of instructional strategies. This suggests one may need to consider a conceptual framework that includes the role personal epistemology plays in self-regulated learning. Hofer and Pintrich (1997) suggest that learners' beliefs and theories about knowledge may influence their engagement in learning.

Epistemological beliefs have been linked to conceptual change in learning science. Studies about learners' epistemological beliefs about whether science is dynamic or static or a mix of the two predicted their ability to integrate their understanding of a topic and their strategy to use (Davis, 1997; Songer & Linn, 1991). In the Davis study, eighth-grade students with a dynamic view were likely to try to understand science, while those with a static view were more concerned with the memorization of facts. According to Edmondson and Novak (1993) several studies link science epistemological beliefs with science learning and the basic assumption that students' beliefs about the origin and structure of knowing and scientific knowledge are intertwined with their learning of science.

According to Hofer (2001), educational experiences play a role in fostering a belief change. The questions lie in what instructional strategies can best be employed. Little research exists that clarifies the relation between types of instruction and personal epistemological beliefs.

NOS Beliefs and Laboratory Pedagogy

RQ2b. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

Strong support was shown by the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their NOS beliefs. Minimal participant support was shown for the pre-laboratory with it being ranked second in influencing overall NOS beliefs. Overall the post-laboratory was ranked third suggesting that it had a minimal influence on participants' NOS beliefs.

According to Sere, et al., (1998) influences upon students' actions and learning during laboratory work include their images of science (NOS) and their images of learning. Laboratory work might develop learners' conceptual understanding or their skills in planning investigations, or their aptitudes at using standard laboratory procedures in carrying out investigations. However, most learners in educational teaching laboratories often work with knowledge claims already agreed as reliable within the scientific community. For example in this study some of the participants during laboratory work used accepted theories or applied accepted theory in specific contexts. Their ideas about how that knowledge came to be viewed as reliable may have influenced their laboratory work. For all these reasons, participation in labwork involves students in drawing upon their epistemological and NOS understanding. For example in this study, during laboratory work, the participants had to make decisions about the amount of data that would be collected and the conclusions that can be drawn from given data sets. According to Leach et al., (1998) the decisions that learners make about data collection will be influenced by their NOS views of the nature of measurement (testable).

Summary

In summary the overall findings of the study in answering research question -2, sub-question-a and sub-question-b was as follows:

RQ2. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

The majority (65%) of participants (N=56) indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. The interview participants (N=20) ranked the three instructional features the same as all the participants (N=56) with laboratory work being the most essential, followed by post-laboratory, and lastly pre-laboratory.

RQ2a. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe influenced their personal epistemological beliefs about science (development) during the semester general chemistry laboratory course?

Substantial support was shown by the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs. For three out of the five EBAPS (nature of knowing and learning, real-life applicability, and evolving knowledge) laboratory work was ranked as most effective in influencing beliefs.

RQ2b. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work), do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

Extremely strong support was shown by the participants (N=20) with 70% indicating that they found the laboratory work to be the most effective in influencing their NOS beliefs.

Chapter eight presents an overview of the dissertation and a brief summary of the studies findings in relation to each research question. Following this is a general discussion of the limitations of the study and directions for future research.

Chapter Eight: Conclusions

Introduction

Personal epistemological and NOS beliefs research both have had a long history for over 30+ years. Few studies however, have involved college science students' beliefs with instructional features. This study was of an exploratory nature to lay a foundation for focusing on more specific features of epistemological and NOS reasoning in light of specific instructional features (pre-lab, laboratory work, or post-lab) for future research. This study investigated students' epistemological and NOS beliefs and their perceptions of the instructional features as related to those beliefs.

This chapter provides an overview of the dissertation in the following section. This chapter includes a summary of the following: (1) chapter one – introduction; (2) chapter two – literature review related to personal epistemology, NOS, and science laboratory pedagogy; (3) chapter three – research methods; (4) chapter four – quantitative results – results for research question one and sub-questions; (5) chapter five – development of epistemological beliefs - results for research question two and sub-question 2-a; (6) chapter six – development of NOS beliefs – results for research question two and sub-question 2-b; (7) chapter seven – laboratory instructional features – results for sub-questions 2-a and 2-b; (8) significance and implications of study; (9) limitations; (10) suggestions for further research; and (11) concluding remarks.

Overview of the Dissertation

Chapter one presented an overview of personal epistemological and NOS beliefs. This was followed by a discussion of the problem statement, the nature of the study as well as introduce concepts and issues central to the research such as: the nature and development of personal epistemology, the role of student images of science, the nature of chemistry learning, the definitions of personal epistemology and NOS, the possible link between personal epistemological and NOS beliefs, the role of the laboratory instructional environment, and research methodology issues. In addition, the research questions were presented followed by the study's significance for chemistry education research.

This study investigated students' epistemological and NOS beliefs, whether they changed and their perceptions of the instructional features as related to those beliefs. Overall, the study's purpose was to explore and lay a foundation for focusing on more specific features of reasoning related to personal epistemological and NOS beliefs changes in light of specific science laboratory instructional features for future research. In addition, the study explored and laid a foundation for focusing on more specific features of reasoning related to learning and specific science laboratory instructional features for future research.

This study encompassed two large and distinct research fields: personal epistemological and NOS beliefs. However, because the two research fields have not always been predominantly linked, the review of the qualitative results was divided into two separate chapters. Chapter 5 dealt with development of personal epistemological beliefs, while chapter 6 dealt with the development of the nature of science. Research question one and sub questions looked at the initial and final personal epistemological and NOS beliefs of the participants involved in the study. Chapter 4 discussed the quantitative changes of the participants' NOS and personal epistemological beliefs.

The major construct of this study was personal epistemological beliefs a psychological driven concept borrowing from philosophical issues (Schommer, 1994). Hofer and Pintrich (1997) define epistemological beliefs as how learners come to know and the theories and beliefs they hold about knowing. The extent to which these beliefs affect a learner can be the difference between a unsophisticated naive belief about learning at a surface level and a sophistication that involves a deeply divergent thought process that utilizes experience and formal education to a well-developed assimilation of knowledge (Schommer-Aikins, 2004).

The secondary construct for this study NOS involves personal scientific epistemological beliefs. NOS is an area of human enterprise that includes the beliefs and values inherent to scientific knowledge and its development. The consensus view of NOS from science education standards documents includes the following: (1) scientific knowledge has a tentative character; (2) scientific knowledge relies heavily on observation, experimental evidence, and rational arguments; (3) there is no one way to do science; (4) science attempts to explain natural phenomena; (5) laws and theories serve different roles in science; (6) individuals from all countries contribute to science; (7) new scientific knowledge must be reported clearly and openly; (8) science requires accurate record keeping, peer review, and replicability; (9) observations are theory-laden; (10) scientists are creative; (11) the history of science discloses both an evolutionary and revolutionary character; (12) science is part of social and cultural traditions; (13) science and technology impact each other; and (14) scientific ideas are affected by their social and historical milieu (McComas, Almazroa, & Clougii, 1998).

Chapter two was divided into six main sections and consisted of a review of relevant studies in the science education and educational psychological literature focusing on the research questions described in Chapter 1. The research literature included reviews of: (1) models of personal epistemological development; (2) multidimensional models of personal epistemological development; (3) the nature of science; (4) the applicability to college science education; and (5) the laboratory in chemistry education.

The first and second section of the literature review discusses several models of personal epistemological development beginning with a discussion of five major uni-dimensional epistemological models of development followed by a description of two multidimensional models of epistemological beliefs. Uni-dimensional epistemological models and their related theories were described followed by the multi-dimensional models. The uni-dimensional epistemological models suggests that individuals move through a patterned sequence of development while multi-dimensional models suggest that systems of beliefs do not develop through a patterned sequence and are composed of separate dimensions. The models discussed include Perry's scheme of intellectual and ethical development, Belenky's women's ways of knowing model, Baxter-Magolda's epistemological reflection model, King and Kitchener's reflective judgment model, Kuhn's model of reasoning skills, Schommer-Aikins' system of independent beliefs model, and Hofer and Pintrich's epistemological theories model. In addition these two sections provided information on assumptions, and validity and reliability issues related to the theories.

The third section presented a review of the research literature related to student's images of science (NOS). The section begins with a consensus research-based definition of NOS, followed by a discussion of classifying students' images of science in one of three categories: (1) data-focused view; (2) radical relativist view; or (3) theory-data linked view. This is followed by a review of the necessity for cognitive dissonance in order for improved student understanding of NOS as well as an overview of measuring students' NOS beliefs. The connections between NOS and personal epistemology are revisited and expanded from the initial discussion in chapter one. This section of the literature review ends with a discussion of three potential methods used to enhance learners' NOS beliefs; (1) historical, (2) implicit, and (3) explicit-reflective. None of the aforementioned methods were targeted in this study.

The fourth section of chapter two discussed research methodology issues related to the potential instruments used to assess students' NOS and personal epistemological beliefs. The discussion begins with a general overview of current assessment instruments followed by two sections that review instruments currently used to assess the aforementioned beliefs in general and in the domain of science. This review included a basic review of the two assessment instruments used in this study; the EBAPS and the NSKS.

The fifth section relates to the applicability of promoting epistemological growth in the college science classroom through the use of certain pedagogical applications. The discussion begins with an overview of epistemological orientations in learning science followed by a description of assessing epistemological levels in the classroom in order to promote epistemological growth. The remainder of this section discusses the six pedagogical applications identified in the literature that facilitate epistemological growth: (1) learning tasks; (2) expectations; (3) modeling and practice; (4) constructive feedback; (5) learner-centered environment; and (6) respect for student development.

The final section consisted of a review of the literature on science laboratory instruction. This section of the literature review elaborates on the nature of laboratory instruction, epistemological development in laboratory instruction, and the history of laboratory instructional methods. The section begins with a description of the nature of laboratory instruction, how the developmental levels relate to laboratory instruction, and concludes with a discussion of science laboratory pedagogy and instruction. The laboratory instructional methods reviewed included: (1) expository; (2) inquiry; (3) discovery; and (4) problem-based. The laboratory pedagogical approaches discussed were: (1) pre-laboratory; (2) personal response systems; (3) laboratory work; (4) microcomputer-based software; and (5) post-laboratory. The aforementioned pedagogical approaches were used in the study.

Chapter three described the quantitative and qualitative methods used in this study. Blending both methods into a single study is recommended by researchers. Qualitative and quantitative data collection mixed-measures were employed in three phases during this study of fifty-six students in 3 sections of a first semester general chemistry laboratory course. Section one restates the purpose of the study, elaborates on the rationale behind the research questions, and presents an overview of the analysis, design, and methodology.

Section two describes the context and participants of the setting. A sample of 56 undergraduate students at a major University in Florida volunteered and participated in the study. All participants were enrolled in the first semester of a two semester general chemistry laboratory course during the fall semester of 2006.

Section three discusses the research instruments, measures, and techniques which include the: (1) Chemical Concepts Inventory (CCI), (2) Epistemological Beliefs Assessment for the Physical Sciences (EBAPS), (3) Nature of Scientific Knowledge Scale (NSKS), (4) Students' Reflective Assessment of Laboratory Methods, and (5) In-depth semi-structured interviews.

EBAPS was used to generate quantitative data on participants' personal epistemological beliefs. The EBAPS assesses personal epistemological beliefs of science in the following five dimensions: (1) the structure of scientific knowledge; (2) the nature of learning science; (3) the real-life applicability of science; (4) the evolving knowledge of science; and (5) the source of ability to learn science. The EBAPS includes 30 items that are a mix of Likert-type ratings of agreement or disagreement, as well as hypothetical scenario conversations to which students responded using multiple choice answers to indicated how closely their own views match those of the scenario conservation. This instrument was used to answer research question one and sub-question1-b.

The NSKS was used to generate quantitative data on participants' NOS beliefs. The NSKS assesses participants' NOS beliefs in the following dimensions: (1) amoral; (2) creative; (3) development; (4) parsimonious; (5) testable; and (6) unified. The NSKS includes 48 items related to the aforementioned dimensions. The NSKS has a Likert scale forced-response format consisting of five choices from strongly agree to strongly disagree. This instrument was used to answer research questions one and sub-question 1-a.

The student laboratory questionnaire (Students' Reflective Assessment of Laboratory Methods) was used to assess the participants' reactions to the three instructional methods associated with each laboratory activity (e.g., pre-laboratory activities, laboratory work, and post-laboratory activities). Section one of the questionnaire probed the usefulness of each pedagogical feature of laboratory instruction with respect to understanding and necessity of the laboratory learning experience. Section two of the questionnaire probed participants' perceptions regarding the following four aspects of laboratory work: (1) understanding the laboratory work, (2) enjoyment in performing the laboratory work, (3) achievement in conducting the laboratory work, and (4) difficulty in doing the laboratory work. Section three of the questionnaire asked the participants to describe the kind of learning they believed they gained in a particular laboratory activity using Blooms Taxonomy categories.

Semi-structured pre- and post study interviews with a subsample of participants (n=20) from the sample population (N=56) were performed by an outside interviewer. The interviews involved questions and/or statements related to the EBAPS and NSKS dimensions as well as the laboratory instructional features. The audio-taped interviews performed by an outside interviewer were transcribed and coded for themes. The coding themes included the following: (1) EBAPS dimensions; (2) NSKS dimensions; and (3) the laboratory instructional features (pre-laboratory, laboratory work, and post-laboratory).

Section Four identifies the forms of treatment (pedagogy) involved in the laboratory instruction. This section offered an overview of the laboratory environment and pedagogy. Included is a discussion of the three general instructional features used during this study, pre-laboratory, laboratory work, and post-laboratory.

The three pedagogical laboratory instructional features used in this study included: (1) pre-laboratory; (2) laboratory work; and (3) post-laboratory. The pre-laboratory methods included out of class and in class activities ranging from online quizzes to class discussions prior to performing laboratory work. The laboratory work allowed students to engage in real-time laboratory recording of observations using a laboratory notebook, and answer their own questions experimentally while engaging in teamwork. The post-laboratory methods engaged students in looking for trends, critically evaluating class data, work together to negotiate meaning as well as discuss claims and write about their claims by providing supporting evidence.

The last three sections of chapter 3 summarize data collection, describe how the data was analyzed, and describes the potential quantitative and qualitative analysis methods implemented for the study as well the aspects used in monitoring the reliability and validity of the data collection and analysis. Included are a general overview of the phases of data collection and the researcher's role during the study. The data collection process in this study occurred in three phases. The first phase of data collection included the administration of the CCI, EBAPS, and NSKS to all participants. In addition data related to participants' prior chemistry skills and knowledge was collected. The data was analyzed by an outside researcher. Initial interviews were performed by an outside interviewer during phase two with the twenty volunteers from the population sample (n=56) concerning their NOS and personal epistemological beliefs about science. In addition, student laboratory instruction reflections were collected (n=56). In the final phase the NSKS and EBAPS were re-administered (repeated measure) and final interviews (n=20) by an outside interviewer concerning what laboratory instructional strategies students' believed influenced their understanding of the laboratory material, as well as their NOS and personal epistemological beliefs about chemistry.

Descriptive statistics (average dimension mean, effect size) were used to investigate differences between participants' initial and final personal epistemological and NOS beliefs. T-tests for paired samples were used to indicate the statistical significance of any differences. Associations between the pre- and post-assessments were determined using simple correlations.

The interview responses, initial and final of the twenty volunteers were compared and contrasted to their pre-post assessment scores from the NSKS and EBAPS. The interviews were offered as additional support of the validity of the participants' assessment scores.

Chapter four presented a description of the participant sample followed by the presentation of the quantitative analyses of the study's first research question and sub-questions dealing with pre-post assessment changes in NOS and personal epistemological beliefs. The research questions were presented with the quantitative results of the CCI, EBAPS, and NSKS analyses for all the participants (N=56) and of the twenty whom participated in the interviews. The results are discussed and related back to the key literature.

Descriptive statistics (average dimension mean, effect size) were used to investigate differences between participants' initial and final personal epistemological (EBAPS) and NOS (NSKS) beliefs. T-tests for paired samples were used to indicate the statistical significance of any differences. Associations between the pre- and post-assessments were determined using simple correlations.

Chapter five presents a description of the development of the participant's personal epistemological beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-b. The characterization of personal epistemological beliefs with the results of the analyses of the participants' responses to interview probes is presented. The combination of interviews and quantitative measures provided a glimpse into students' initial and final personal epistemological beliefs. The interviews allowed for further probing of beliefs and as extended support to the participants' EBAPS scores. Clarification of any changes in beliefs during the course of the semester and what the participants' believed influenced their beliefs were considered. The five dimensions of the EBAPS were used as coding themes for this analysis. The results are discussed and related back to the key personal epistemological literature.

Chapter six presents a detailed description of the development of the participants' NOS beliefs through the presentation of qualitative analyses of the study's first research question and sub-question 1-a. The characterization of NOS beliefs with the results of the analyses of the participants' responses to interview probes is presented. The combination of interviews and quantitative measures provide a glimpse into participants' initial and final NOS beliefs. The interviews allowed for additional probing of beliefs and as extended support to the participants' NOS scores. Clarification of any changes in beliefs during the course of the semester and what the participants' believed influenced their NOS beliefs were considered. The dimensions of the NSKS were used as coding themes for this analysis. The results are discussed and related back to the key NOS literature.

Chapter seven characterizes the findings of the instructional features of the second research question and sub-questions 2-a, and 2-b. The three pedagogical laboratory instructional features used in this study included: (1) pre-laboratory; (2) laboratory work; and (3) post-laboratory. The three instructional features were used as coding themes for this analysis. The characterization of laboratory instruction with the quantitative and qualitative results from the Student Evaluation of Laboratory Instruction Questionnaire as well as the results of the analyses of the participants' responses to interview probes was presented. This provided a glimpse of the participants' overall beliefs concerning the laboratory aspects of the semester course.

Major Findings of the Study

This study was of an exploratory nature to lay a foundation for focusing on more specific features of epistemological and NOS reasoning in light of specific instructional features (pre-lab, laboratory work, or post-lab) for future research. This study investigated students' epistemological and NOS beliefs and their perceptions of the instructional features as related to those beliefs. The results are discussed and related back to the key laboratory education as well as the NOS and personal epistemological beliefs literature.

The purpose of this mixed method study was to explore whether student's NOS, and personal epistemological beliefs about science (chemistry) changed by the completion of a semester general chemistry course as well as, what laboratory pedagogical practices (e.g. pre- and post-laboratory activities, laboratory work) students' believe influenced those belief changes and influenced their understanding during the semester general chemistry laboratory course. The participants consisted of 56 undergraduate students enrolled in the first semester of a general chemistry laboratory course at a major university in Florida.

The theoretical epistemological perspectives guiding this study were the uni-dimensional theories from models such as Perry (1970) and Baxter Magolda (1992) as well as multidimensional theories from models such as Schommer's (1990) and Hofer & Pintrich, (1997) discussed in chapters 1 and 2. Quantitative and qualitative methods were used to determine NOS and personal epistemological difference scores followed by participant interviews and reflective instructional questionnaires. After determining the scores on the five dimensions of epistemology as measure by the EBAPS, epistemological difference scores were computed. The aforementioned was repeated with the six dimensions of NOS as measured by the NSKS. Qualitative methods were used to expand and elaborate on the participants' epistemological and NOS beliefs in relation to their assessment scores and the three instructional methods (e.g. pre- and post-laboratory activities, laboratory work).

The main research questions that guided this study were:

The first research question and sub-questions lent themselves to quantitative and qualitative data analysis. They are:

Question One

RQ1. What range of personal epistemological and NOS beliefs about science (chemistry) do undergraduate science students have at the beginning of a semester general chemistry laboratory course?

The findings discussed in detail in chapter 4 addressed the first research question of the range of students' personal epistemological and NOS beliefs and whether these beliefs changed by the end of a general semester chemistry laboratory course. The results are discussed and related back to the key personal epistemological and NOS literature.

The overall average score for the EBAPS at the beginning of the semester course for all participants (N=56) was 2.514 while the interview subsample of participants (n=20) was 2.537 indicating a low moderately sophisticated level of epistemological beliefs. Based on the uni-dimensional epistemological models discussed in chapter two the aforementioned initial averages placed the participants in the early multiplicity stage of Perry's model (1970), the transitional knowing level of Baxter Magolda's model (1986), and the quasi reflective thinking level of King and Kitchener's model (1994). The multi-dimensional models of Schommer-Aikins (1990) and Hofer and Pintrich (1997) discussed in chapter two placed the participants at the lower end of the moderate level with their personal epistemological beliefs. This gives support to the personal epistemological studies discussed in chapter two that students depending on their year in college, as well as other factors such as prior knowledge, age, and gender begin with a low level (dualist) to low moderate level (multiplicist) of personal epistemological beliefs. The 2.514 and 2.537 averages support epistemological studies related to science majors that these students range in the 2.5-3.5 sophistication level (Pavelich & Moore, 1996; Wise, Lee, Litzinger, Marra, & Palmer, 2004). Participants' initial EBAPS scores suggested some of their epistemological beliefs were more sophisticated within the EBAPS dimensions of real-life applicability of science (2.7-2.8) and the source of ability to learn science (2.9-3.0). These higher initial dimension scores could be a reflection of their prior knowledge, life experiences, and/or their self-confidence in other science courses. The initial average scores for the remaining three dimensions, structure of scientific knowledge (2.1-2.2), nature of knowing and learning scientific knowledge (2.5-2.6), and evolving scientific knowledge (2.2-2.4) suggested low beliefs. This supports studies suggesting students' views on the structure of scientific knowledge, nature of scientific knowledge, and evolution of scientific as being static and a repertoire of ideas rather than a cohesive view (Linn & Hsi, 2000; Songer & Linn; 1991).

The overall average score for the NSKS at the beginning of the semester course for all participants, including the interview subsample was 142 placing the majority of the participants on the relativist end of the NSKS scale holding non NOS views. Participants' average sub-scores in each of the six NOS dimensions of the NSKS (23-24) suggested non NOS views in every NOS aspect. These initial average scores supports previous studies that students with years of formal science education hold misconceptions regarding NOS (Dagher, et al., 2004; Lederman, et al., 2002; Smith, et al., 2000). Even after years of formal science education, students often view science as a set of unrelated facts, as unchanging knowledge, and as an absolute, objective endeavor that is separate from social influences and personal bias (Abd-El-Khalick & Lederman, 2000; Bell et al., 2003; Halloun & Hestenes, 1998).

On average, 80% of the participants' initial EBAPS overall scores and dimension sub-scores correlated with their interview responses as discussed in chapter 5. In other words, the interview responses and EBAPS scores of the participants reflected the low level of sophistication seen in other studies involving epistemological beliefs. The participants' initial NSKS overall scores and dimension sub-scores correlated with at least 70% of the interview responses as discussed in chapter 6. Therefore the NSKS scores and interview responses in this study reflect the same general naïve perspective of NOS as suggested in other NOS studies. However, a few of the participants' EBAPS and NSKS scores did not support their reflections. Some of the participants' scores reflected unsophisticated beliefs while their interview or questionnaire responses indicated more neutral NOS beliefs. Similar to the findings in prior studies some of the participants in this study assumed scientific knowledge to be factual and certain, based their beliefs on authority rather than argument or evidence, and that there is one scientific method.

What one cannot infer at this point in time is whether these beliefs are enduring over a long period of time or whether some students' beliefs more adaptable than others are. Additional and longer research studies are needed to investigate students' initial beliefs and the effects of instruction on changing those beliefs.

Sub-Question-1a

RQ1a. Do students' images of the nature of chemistry (NOS) change by the completion of a semester general chemistry laboratory course?

The findings discussed in chapters 4 and 6 in detail address this portion of the first research question concerning whether the students' NOS beliefs changed by the end of a general semester chemistry laboratory course. The results are discussed and related back to the key NOS beliefs literature in chapters 2, 4 and 6.

Overall the NSKS results for the total population sample (N=56) showed a significant increase in the following dimensions: creative, developmental, parsimonious, testable, and unified. The participants seemed to struggle with the amoral dimension.

In summary based on the NSKS results: (1) the mean gain scores for the overall test and all dimensions, except for amoral were found to be significant at $p \leq .05$ and (2) the data suggest that instruction had effected a small change in the students' NOS beliefs.

Overall the NSKS results for the interview participants (N=20) showed a significant increase in the following dimensions: creative, parsimonious, and unified. The participants seemed to struggle with the dimensions amoral, parsimonious, and testable. In summary based on the NSKS results: (1) the mean gain scores for the overall test and all dimensions, except for amoral, parsimonious, and testable were found to be significant at $p \leq .05$ and (2) the data suggest that instruction had effected a small change in the students' NOS beliefs. For there to be a probability of a more substantial change in NOS beliefs specific instructional methods related to NOS and a longer period of instruction would be warranted.

At the beginning of the study some participants' held an idealized image of the nature of evidence, laws, and theories as evident in the NSKS scores and initial interview statements. However, by the end of the semester course some of the participants had shifted their non NOS views slightly toward a blend or supporting some NOS views. As discussed in chapters 4 and 6 several participants used the word proof in their interview statements to describe aspects of NOS. This supports other research studies where students used the term proof to describe the fundamental nature of scientific evidence (Dagher et al., 2004; Lederman et al., 2002). Occasionally, students use the word proof to indicate an absolute answer, and to describe directly-observed evidence. Some participants described scientific knowledge as starting from a hypothesis, then becoming a theory, and after several experiments becomes a law. This supports Bell, Blair, Crawford, and Lederman's (2003) study that secondary students rank scientific knowledge in a hierarchy. The majority of the final interviews discussed in chapter 6 correlated with the overall small increase in the participants' NSKS scores. However, a small number of the participants' NSKS scores did not support their reflections. These participants' scores reflected unsophisticated NOS beliefs while their interview or questionnaire responses indicated more moderate beliefs.

What one cannot infer at this point in time is whether these NOS belief changes are enduring or whether some participants are simply more adaptable than others are. Additional and longer research studies are needed to investigate the effects of instruction on NOS belief changes.

Sub-Question-1b

RQ1b. Do students' personal epistemological beliefs about science (chemistry) change by the completion of a semester general chemistry laboratory course?

The findings discussed in chapters 4 and 5 address this portion of the first research question concerning if the students' epistemological beliefs changed by the end of the general semester chemistry laboratory course. The results are discussed and related back to the key personal epistemological beliefs literature in chapters 2, 4 and 5.

Overall the Epistemological Beliefs Assessment of the Physical Sciences (EBAPS) results for the total population sample (N=56) and the interview participants (N=20) showed a significant increase in structure, nature, real life applicability of science, and evolving knowledge. The participants seemed to struggle with the source of the ability to learn science. In summary based on the EBAPS results: (1) the mean gain scores for the overall score and all dimensions, except for the source of ability to learn were found to be significant at $p \leq .05$ and (2) the data suggest that instruction had effected a change in the students' epistemological beliefs.

The majority of the final interview responses correlated with the participants' final EBAPS scores. Improvement in participants' epistemological beliefs was demonstrated by their more mature comments as discussed in chapter 5. However, some of the participants' EBAPS scores did not support their reflections. Some of the participants' scores reflected unsophisticated beliefs while their interview or questionnaire responses indicated more moderate beliefs.

Earlier studies relating to learners' personal epistemological beliefs conducted with college students indicated that their personal epistemological beliefs can change during the college years (Baxter Magolda, 1992; Perry, 1981). A minimal change in personal epistemological beliefs is indicated in this study as discussed in chapters 4 and 5. A semester is hardly enough time to determine if the changes were valid or simply due to chance. Another investigation found that entering college freshmen believe knowledge is certain and provided by authority while college seniors believed that knowledge is complex and tentative and is derived through reason (Perry, 1968). Schommer's (1997) study determined high school students' epistemological beliefs changed over time. These findings add support to this studies results that epistemological beliefs develop over time. However, a student's beliefs about the structure of scientific knowledge may develop independently from his or her beliefs about the stability of scientific knowledge (i.e., evolving). Therefore, examining the dimensions of epistemological beliefs rather than epistemological beliefs as a coherent whole may allow a clearer picture of how beliefs change.

What one cannot infer at this point in time is whether these belief changes are enduring or whether some participants are simply more adaptable than others are. More research studies are needed to investigate the effects of instruction on personal epistemological growth.

The second research question and sub-questions were:

Question Two

RQ2. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe were essential to their understanding during the semester general chemistry laboratory learning experience?

The findings discussed in chapter 7 addressed the second research question of the laboratory pedagogical practices (e.g. pre- and post-laboratory activities, laboratory work) did students believe were essential to their understanding during the semester general chemistry laboratory experience. The results are discussed and related back to the key laboratory education literature in chapters 2, 3 and 7.

The majority (65%) of participants (N=56) indicated that they found the laboratory work to be either very or extremely essential to the laboratory experience and their understanding of the material. The interview participants (N=20) ranked the three instructional features the same as all the participants (N=56) with laboratory work being the most essential, followed by post-laboratory, and lastly pre-laboratory.

Laboratory investigations are viewed as ideal environments for meaningful learning when appropriate instructional techniques are implemented into the curriculum design. For this study, the use of cooperative learning and active learning techniques, such as pre-preparation and post-laboratory small group discussions were implemented to promote higher order thinking and positive attitudes. The aforementioned methods have been identified in studies as effective pedagogical tools (Cooper, 1995, NRC, 1996). The participants in this study identified the laboratory work feature as being essential to their learning and understanding. The participants found the real-life experiences, group discussions and teamwork as meaningful to their learning. This corresponds with research related to laboratory investigations that found discussions played a meaningful role in developing students' understanding of scientific ideas (Driver, et al., 1994; Millar, 2004).

Some of the participants in the study found the laboratory notebook to be quite useful while others found it to be tedious. However, laboratory notebooks are often used as a formative assessment tool. The use of laboratory notebooks as a part of instruction is supported by many researchers who advocate writing in science to enhance learner understanding of scientific content and processes as well as general writing (Keys, et. al., 1999; Shepardson & Britsch, 2000; Bass, et. al., 2001).

The majority of the participants in this study identified the use of the MBLs as worthwhile. They found them easier to use and related to real-life laboratory experiences. MBLs allowed the students to devote more time to observation, reflection, and discussion. Studies suggest that the use of MBLs can support and enhance meaningful learning in scientific inquiry. They assist in a learners' knowledge construction, and help develop concepts and skills such as graphing, collaboration, and scientific reasoning (Pienta, & Amend, 2004; Nachmias & Linn, 1990). The MBL learning environment can assist in increasing the student's ability to analyze and interpret data. Students can repeat experiments thereby generating more data for analysis, manipulate the parameters of investigations, and study graphs by using MBL modeling tools (Pienta, & Amend, 2004; Newton, 1997; Settlage, 1995; Lazarowitz, & Tamir, 1994). However, according to Pienta and Amend (2004) students without an appropriate conceptual understanding of chemistry may fail to observe the phenomenon under investigation. Therefore, MBLs may not promote learning for all students (Atar, 2002).

Post-laboratory was identified by the participants as almost as essential as the laboratory work. However, without the laboratory work the participants felt there was no point to the post-laboratory activities. Some viewed the laboratory report as pointless, particularly in view of their laboratory notebook. Others felt strongly the opposite that the post-laboratory reports were extremely essential as it allowed one to tie together all the information and see the bigger picture. Much of the laboratory work discussion can be expanded into the post-laboratory discussion and analysis. The students had to look for patterns in results and relate data to the underlying chemical concepts. Keys (2000) findings suggest that scientific writing promotes scientific thinking by helping learners to explore relationships between evidence and knowledge claims. The results of this study show that the use of written products such as laboratory notebooks and reports are valuable methods of instruction for the development of scientific reasoning skills and the construction of scientific understandings (Keys, et al., 1999; Keys, 2000; Reid & Shah, 2007). Writing in science is as a way to bridge prior knowledge with new learning, build explanations, and make sense of information.

Participants in this study identified the pre-laboratory as the least essential to their learning and understanding. However, pre-laboratory instruction is introduced as a way to reduce the information overload on students (Reid & Shah, 2007). The pre-laboratory can reduce the amount of time spent on laboratory procedures so more time can be spent on other aspects of the laboratory environment such as, laboratory work. The pre-laboratory activities encourage planning and allow understanding by reducing information overload.

What one cannot infer at this point in time is whether these beliefs about laboratory instruction are enduring or whether some participants are simply more adaptable than others are to the learning environment. More research studies are needed to investigate the effects of laboratory instruction on student understanding.

Sub-Question – 2a

RQ2a. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their personal epistemological beliefs about science (chemistry) during the semester general chemistry laboratory course?

The findings discussed in chapters 5 and 7 addressed this research question concerning what laboratory pedagogical practices if any, did students believe influenced their personal epistemological beliefs about science during the general semester chemistry laboratory course. The results are discussed and related back to the key laboratory education as well as the personal epistemological beliefs literature.

Substantial support was shown by the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their epistemological beliefs. The post-laboratory was ranked close second with the pre-laboratory receiving minimal support as to influencing the participants' beliefs. For three out of the five EBAPS (nature of knowing and learning, real-life applicability, and evolving knowledge) laboratory work was ranked as most effective in influencing beliefs.

As in much of the literature reviewed in preparation for this research study, aspects of the participants' learning beliefs incorporated views about epistemological issues. The participants provided unprompted belief comments about their views throughout their reflective and interview comments discussed in chapters 5 and 7. This epistemological nature of the participants' beliefs was reminiscent of the work by Perry (1970), Baxter Magolda (1992, 2002), Hofer and Pintrich (1997, 2002), and Schommer-Aikins (2002) that recognizes how an individual's epistemological beliefs are also integral to their entire belief system.

Clearly, engaging in lab-based inquiry engages students with epistemological issues. In terms of the first research question and this question, there was some evidence that the participants' epistemological beliefs about science changed over time. Although the changes were not large, participants became more sophisticated in their beliefs about the structure of scientific knowledge, nature of scientific knowledge, real life applicability of science, and how scientific knowledge evolves over the course of instruction. Whether the laboratory work itself or a specific component impacted the change as the participants declared would need further investigation. However, these results parallel the findings of Solomon et al. (1996) that showed that hands-on laboratory science instruction was related to epistemological awareness. In this case, the participants did become more sophisticated in their overall beliefs. Of course, this potential explanation for the change needs to be tested in additional studies that compare laboratory hands-on science with other more traditional science instruction. Work in this area suggests that students in constructivist learning environments develop more sophisticated epistemological stances than do those in traditional learning environments (Smith et al., 2000).

The participants' epistemological beliefs also incorporated many views about self knowledge and these beliefs were often perceived by the study's participants as. Such findings suggest that epistemological beliefs may into the area of self reflection. The fact that the participants' beliefs were threaded with epistemological references may be due to the fact that the methodology of the study allowed for interlinked concepts to be discussed.

The results of this study suggest that laboratory instructional methods and educational experiences can have an effect on learners' epistemological development. Even with the short training on critical-thinking during the laboratory work and post-laboratory activities appeared to affect participants' views of scientific knowledge and their approach in justifying scientific beliefs. What one cannot infer at this point in time is whether these belief changes are enduring or whether some students are simply more adaptable than others are. More research studies are needed to investigate the effects of instruction on epistemological growth or changes.

Sub-Question-2b

RQ2b. What laboratory pedagogical practices (e.g., pre- and post- laboratory activities, laboratory work) do students believe influenced their images of the nature of chemistry (NOS) during the semester general chemistry laboratory course?

The findings discussed in chapters 6 and 7 addressed this research question concerning what laboratory pedagogical practices if any, did students believe influenced their NOS beliefs about science during the general semester chemistry laboratory course. The results are discussed and related back to the key laboratory education as well as NOS beliefs literature.

Strong support was shown by the participants (N=20) indicating that they found the laboratory work to be the most effective in influencing their NOS beliefs. Minimal participant support was shown for the pre-laboratory with it being ranked second in influencing overall NOS beliefs. Overall the post-laboratory was ranked third suggesting that it had a minimal influence on participants' NOS beliefs.

The participants provided unprompted belief comments about their views about the nature of scientific knowledge throughout their reflective and interview comments discussed in chapters 6 and 7. The data suggests that reflection is necessary to achieve an understanding of NOS, as the interview subjects did increase and improve their understanding if only slightly (Johnston & Southerland, 2002; Lederman, et al., 2003; Southerland, et al., 2003). Due to the difficulty and abstractness of the issues of the

NOS, the students must be made to reflect on these issues, typically in reaction to laboratory activities in order for understanding to take place (Akerson & Abd-El-Khalik, 2002). Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) suggest that many college students have difficulty synthesizing their laboratory experiences into a coherent picture of NOS. The use of explicit NOS laboratory instruction may improve the participants' views of NOS. However according to Lederman (2004), a one-size-fits-all approach to laboratory scientific inquiry is not typical of real scientific practice and not likely suitable for advancing consistent and desired NOS views of science, even through explicit or reflective means.

What one cannot infer at this point in time is whether these laboratory instructional views and NOS belief changes are enduring or whether some participants are simply more adaptable than others are. More research studies are needed to investigate the effects of instruction on NOS beliefs.

Limitations

This study has several limitations. One limitation of this study is that the results cannot be generalized. The sample size was small (N=56) and the chemistry students are generally not representative of the general student population. In addition, the study was not designed with a control group. The low sample size and lack of a control group may raise questions about power and type II error.

This study was of an exploratory nature to lay a foundation for focusing on more specific features of epistemological and NOS reasoning in light of specific instructional features (pre-lab, laboratory work, or post-lab) for future research. Therefore the use of the word “growth” in the title of the dissertation may be a misnomer. It is a bit too presumptuous to infer growth patterns from two data points. The design of the study makes it difficult to explain the observed changes either as indicators of the general effects of instruction or of a particular form of instruction. In any event there is not sufficient data to make definitive claims about “growth”. The word change may be a more suitable term.

In studies of this nature (involving repeated measures), completing the initial responses to an instrument could impact responses on the repeated measure of the instrument. A testing effect can occur when the pre-assessment itself influences the post-assessment. The reliability of the assessment instruments may change in human ability to measure differences (due to experience, fatigue, etc). Therefore, initial and final interviews were implemented to assist in checking the validity of the participants’ scores on the EBAPS and NSKS. The initial scores of the interview participants were compared to their initial interview responses. This method was repeated with the final scores and interviews.

Another limitation is the influence that other learning experiences may have had on the participants’ beliefs. Participation in college supports students’ intellectual development. In addition to academic curriculum, there are co-curricular experiences that influence students’ development. These factors can be categorized as internal and external factors. The internal factors include students’ gender, age, personal experience, and domain competency.   External factors include curriculum, major fields of study, and social context in college. It is important that students’ development potential, including external factors that influence their developmental growth, be taken into consideration. Although this area is worth researching, it was not the focus of this study.

The issue of whether and how the twenty volunteer interviewees were similar to or different from the remaining thirty-six of the fifty-six participants needed to be considered. Further formal statistical comparisons of the two subgroups on the EBAPS and NSKS to determine if there are similarities in the patterns of responses would add to the studies assumptions. However, this will be attended to at a later date.

Lastly, all of the participants in the study were enrolled in different sections of the same chemistry laboratory course with the same instructor whom was also the researcher. Effects thought to be from the study could instead be a result of her influence on the participants. To control for this phenomenon, participants were interviewed by another researcher and all reflective responses were read after the conclusion of the study. Qualitative data were chosen based on responses to the quantitative parts of the study, and included data from many participants in the same class. Interview participants were self-selected and participated in the study because they wanted to or wanted extra credit. Some participants dropped out of the study after the pre-test; others dropped out after the second week of the course.

Further Research

Researchers of personal epistemology note the need for further work in the area of students' NOS and personal epistemological beliefs and instructional experiences (Hofer, 2002; Schommer-Aikins, 2004). For some instructors of chemistry, the development of appropriate epistemological beliefs in their students is an important goal of instruction. For others, epistemology may not be as important. These instructors, however, would still be wise to encourage appropriate and thorough epistemological self-reflection, because it may facilitate conceptual learning.

Considering the goals of laboratory instruction, one should consider to what extent laboratory courses: (1) help reinforce concepts from the lecture course; (2) improve laboratory skills; (3) convey scientific processes; (4) promote positive attitudes towards science; and (5) students learn some facts about the nature of chemistry and chemicals as a result of laboratory instruction.

Future research should aim to extract and explain differences in terms of the sample characteristics, the laboratory methodological differences, and possible variance in the EBAPS and NSKS themselves. The exploration of students' epistemological or NOS beliefs as related to science is rarely, if ever, a part of a student's classroom experience. None of the participants in the study reported having discussed their beliefs in any college class or reported having their beliefs inventoried prior to this study.

References

Abd-El-Khalick, F., & Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, *22*, 665-701.

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education*, 88(5), 785-810.

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education*, 76, 477-491.

Aschbacher, P. R. & Alonzo, A.C. (2004). Using Science Notebooks to Assess Students' Conceptual Understanding. Paper presented at the Annual Meeting of the AERA.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice Hall.

Barnes, R. & Thornton, B. (1998). Preparing for laboratory work. In Black, B. and Stanley, N. (Eds), *Teaching and Learning in Changing Times*, 28-32. Proceedings of the 7th Annual Teaching Learning Forum, The University of Western Australia, February 1998. Perth: UWA. http://lsn.curtin.edu.au/tlf/tlf1998/barnes.html (April 10, 2005).

Barton, R. (1997). Computer-aided graphing: a comparative study. *Journal of Information Technology for Teacher Education, 6*(1), 59 – 72.

Barton, R. (2005). Supporting teachers in making innovative changes in the use of computer aided practical work to support concept development in physics education. *International Journal of Science Education, 27*(3), 345 – 365.

Bass, K.M., Baxter, G.P., & Glaser, R. (2001). *Using reflective writing exercises to promote writing-to-learn in science.* Paper presented at the Annual Meeting of the AERA, Seattle.

Baxter Magolda, M. B. (1987). The affective dimension of learning: Faculty-student relationships that enhance intellectual development. College Student Journal, 21, 46-58.

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development.* San Francisco: Jossey-Bass.

Baxter Magolda, M. B. (2002). Epistemological reflection: The evolution of Epistemological assumptions from age 18 to 30. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Baxter, Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist*, 39, 31-42.

Belenky, M.F., Clinchy, B. M., Goldberger, N. R., and Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind*. New York: Basic Books.

Bell, P. (2004). The school science laboratory: Considerations of learning, technology, and scientific practice. Paper presented at the "High School Science Laboratories: Role and Vision" meeting, Board on Science Education, National Academy of Sciences. Washington D. C.

Bell, P,. & Linn, M. (2002) Beliefs About Science: How Does Science Instruction Contribute? In Hofer, B & Pintrich, P (Eds) *Personal Epistemology*, Chapter 16, pp.321-346, Lawrence Earlbaum Assoc. Mahwah, New Jersey.

Bell, R. L., Blair, L. M., Crawford, B. A. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching*, 40, 487-509.

Bendixen, L. D. (2002). A process model of epistemic belief change. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Bendixen, L. D. and Rule, D. C. (2004) An integrative approach to personal epistemology: A guiding model. *Educational Psychologist*, 39, 69-80.

Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B. K. S., & Tibell, L. A. E. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education,* 25, 351-372.

Berg, A. (2005). Factors related to observed attitude change toward learning chemistry among university students. *Chemistry Education: Research and Practice*. 6, 1-18.

Bianchini, J., Whitney, D., et al. (2001). "Toward Inclusive Science Education: University Scientists' Views of Students, Instructional Practices, and the Nature of Science." *Science Education,* 86, 42-78.

Biggs, J. B., Kember, D., and Leung, D. Y. P. (2001). The revised two-factor Study Process Questionnaire: R-SPQ-2F. *British Journal of Educational Psychology*, 71, 133-149.

Bloom, B. S. (Ed.) (1956). *Taxonomy of Educational Objectives.* New York: David McKay Co.

Bock, M. (1999). Baxter Magolda's epistemological reflection model. *New Directions for Student Services.* 88, 29-40.

Bodner, G. M. (1986). Contstructivism: A theory of knowledge. *Journal of Chemical Education*, 63, 873-878

Boekaerts, M. (1997). Self-Regulated learning: A new concept embraced by researchers, policy makers, educators, teachers, and students. *Learning and Instruction*, 7, 161-186.

Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds.). (2000). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

Brickhouse, N. W., Dagher, Z. R., Letts, W. J., & Shipman, H. L. (2000). Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course. *Journal of Research in Science Teaching,* 37, 340-362.

Brownlee, J. (2002). Students learning to teach: Conversing with students about their epistemological beliefs. *HERSDA Conference Proceedings.*

Bruning, R. H., Schraw, G. J., Morby, M. M., and Ronning, R. R. (Eds.) (2004). *Cognitive Psychology and Instruction.* New Jersey: Pearson Prentice Hall.

Buehl, M.M. & Alexander, P.A. (2004) Motivation and performance differences among domain specific epistemological belief profiles. Paper presented at the Annual Meeting of the American Psychological Association, Honolulu: HI

Bunce, D. M. (2001). Does Piaget still have anything to say to chemists? *Journal of Chemical Education*. 78, 1107.

Burnstein, R. & Lederman, L. M. (2001). Using wireless keypads in lecture classes. *The Physics Teacher*, *39*, 8-11.

Byers, W. (2002). Promoting active learning through small group laboratory classes. *University Chemistry Education,* 6, 28-34.

Carey, S., Evans, R., Honda, M., & Unger, C. (1989). "An experiment is when you try it and see if it works": A study of grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education*, 11, 514–529.

Carey, S., & Smith, *C.* (1993). On understanding the nature of scientific knowledge. *Educational Psychologist.* 28, 235-25.

Chin, C., & Brown, D. (2000). Learning in Science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching*, 37 (2), 109-138.

Clough, M. P. (1997). Strategies and activities for initiating and maintaining pressure of students' naïve views concerning the nature of science. *International Journal of Science Education,* 28, 191-204.

Clow, D. (1998). Teaching, learning, and computing. *University Chemistry Education*, 2, 21-28.

Cooley, W. W., & Klopfer, L. E. (1961). Test on understanding science. Princeton, NJ: Educational Testing Service.

Cooper, M. M. (1995). "Cooperative learning: An approach for large enrollment courses," *Journal of Chemical Education*, 72, 162-4.

Coppola, B. P., and Jacobs, D. C. (2001). Is the scholarship of teaching and learning new to chemistry? *Disciplinary Styles in the Scholarship of Teaching and Learning,* Carnegie Foundation for the Advancement of Teaching.

Coxhead, P., & Whitefield, R. (1975). Science understanding measure test manual, University of Aston, Birmingham.

Dagher, Z., Brickhouse, N., Shipman, H., & Letts, W. (2004). How some college students represent their understanding of scientific theories. *International Journal of Science Education*, 26, 735-755.

Dawe, S. (2003). Practical Work: The Universal Panacea? Available at: http://www.bishops.ntc.nf.ca/rriche/ed6620/practical.html (Accessed: 2006).

DeMeo, S. (2001). Teaching chemical technique: A review of the literature. *Journal of Chemical Education*, 78, 373- 79.

Denzin, N.K. & Lincoln, Y.S. (1994). *Handbook of qualitative research.* Thousand Oaks, CA: Sage Publications.

DiPasquale, D. M., Mason, C. L., and Kolkhorst, F. W. (2003). Exercise in inquiry: Critical thinking in an inquiry-based exercise physiology laboratory course. *Journal of College Science Teaching,* 32, 388-393.

Domin, D. (1999). A content analysis of general chemistry laboratory manuals for evidence of higher-order cognitive tasks. Journal of Chemical Education. 75, 109-111.

Drayton, B. & Falk, J. (2002). Inquiry-oriented science as a feature of your school system: What does it take? *Science Educator,* 11(1), 9 – 17.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23, 5-12.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). Young people's images of science. Buckingham: Open University Press.

Duell, O. K., and Schommer-Aikins, M., (2001). Measures of people's beliefs about knowledge and learning. *Educational Psychology Review*, 13, 419-446.

Duschl, R. A., Hamilton, R. J., & Grandy, R. E. (1992). Psychology and epistemology: Match or mismatch when applied to science education? In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice.* Albany, NY: State University of New York Press.

Dweck, C. S., and Legget, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, 95, 256-273.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education, 85*(5), 554-567.

Elby, A., Frederiksen, J., Schwarz, C., & White, B. (1999). *Epistemological Beliefs Assessment For Physical Science*. Retrieved May 9, 2004 from http://www2.physics.umd.edu/~elby/EBAPS/home.htm.

Entwistle, N. J., and McCune, V. (2004). The conceptual bases of study strategy inventories. *Educational Psychology Review*, 16, 325-345.

Farmer, W. A., Farrell, M. A., and Lehman, J. R. (1991). Secondary science instruction: An integrated approach. Massachusetts: Addison-Wesley.

Felder, R. and Brent, R. (2004). The intellectual development of science and engineering students: Part 1. Models and Challenges. *Journal of Engineering Education.* 93, 269-277.

Felder, R. and Brent, R. (2004). The intellectual development of science and engineering students: Part 2. Teaching to promote growth. *Journal of Engineering Education.* 93, 279-291.

Felder, R. and Brent, R. (2005). Understanding student differences. *Journal of Engineering Education,* 94, 57-72.

Finster, D. C. (1989). Developmental instruction: Part I. Perry's model of intellectual development. *Journal of Chemical Education,* 66, 659-661.

Finster, D. C. (1991). Developmental instruction: Part II. Application of the Perry model to general chemistry. *Journal of Chemical Education,* 68, 752-756.

Fitch, J. (2004). Student feedback in the college classroom: a technology solution. *Educational Technology, Research and Development*, 52, 71-81.

Friedler, Y. & Tamir, P. (1984). Teaching and learning in high school laboratory classes In Israel. *Research in Science Education*, *14*, 89 – 96.

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer-based laboratories. *Journal of Research in Science Teaching*, 27, 173-191.

Gabel, D. L. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education, 76*, 548 – 554.

Gall, M. D., Borg, W. R., & Gall, J. P. (2007). Educational research: An introduction (8th ed.) White Plains, NY: Longman.

Garratt, J. (1998). Inducing people to think. *University Chemistry Education*, 2, 29-33.

Garrett-Ingram, C. (1997). Something to believe in: The relationship between epistemological beliefs and study strategies. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago.

Guba, E., & Lincoln, Y. (1989). *Fourth Generation Evaluation*. Beverly Hills, CA:Sage

Gunstone, R. & Champagne, A. (1990). Promoting conceptual change in the laboratory. In E. Hegarty-Hazel (Ed.), *The student laboratory and the science curriculum*. London: Routledge.

Halloun, I., & Hestenes, D. (1998). Interpreting VASS Dimensions and Profiles. *Science & Education,* 7, 553-577.

Hammer, D. M. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction,* 12, 151-183.

Hammer, D., & Elby, A. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal Epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah, NJ: Erlbaum.

Hammer, D. M. and Elby, A. (2003). Tapping epistemological resources for learning physics. *Journal of the Learning Sciences,* 12, 53-90.

Herrington, A. J. (1997). *Developing and responding to major writing projects*. In M. D. Sorcinelli, & P. Elbow, (Eds.), Writing to Learn: Strategies for Assigning and Responding to Writing Across the Disciplines, (Vol. 69, pp. 67-75). San Francisco:Jossey-Bass

Herron, J. D., and Nurrenbern, S. C. (1999). Chemical education research: Improving chemistry learning. *Journal of Chemical Education*, 76, 1353-1361.

Hodson, D. (1996). Laboratory work as scientific method: three decades of confusion and distortion. *Journal of Curriculum Studies, 28*, 115 – 135.

Hofer, B. K. and Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, 67, 88-140.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*, 378-405.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review, 13*, 353-383.

Hofer, B. K. and Pintrich, P. R. (2002). Personal epistemology as a psychological and educational construct: An introduction. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hofer, B. K. (2002a). Epistemological world views of teachers: From beliefs to practice. *Issues in Education,* 8, 167-173.

Hofer, B. K. (2004). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist*, 39, 43-55.

Hofstein, A. (2004). The laboratory in chemistry education: Thirty years of experience with developments, implementation, and research. *Chemistry Education: Research and Practice.* 5, 247-264.

Hofstein, A., and Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education.* 88, 28-54.

Hofstein, A., Navon, O., Kipnis, M., & Mamlock-Naaman, R. (2005). Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching*, 42, 791-806.

Hogan, K. (1999). Thinking aloud together: A test of an intervention to foster students' collaborative scientific reasoning. *Journal of Research in Science Teaching*, 36 (10), 1085-1109.

Hogan K. (2000) Exploring a process view of students' knowledge about the nature of science. *Science Education*, 84, 51-70.

Jehng, J., Johnson, S. D., and Anderson, R. (1993). Schooling and students' epistemological beliefs about learning. *Contemporary Educational Psychology*, 18, 23-25.

Johnstone, A.H. (1997). Chemistry Teaching- Science or Alchemy? *Journal of Chemical Education,* 74, 262-268.

Johnstone, A. H., and Al-Shuaili, A. (2001). Learning in the laboratory; some thoughts from the literature. *University Chemistry Education.* 5. 42-51.

Keys, W. C., Hand, B., Vaughn, P. and Collins, S. (1999). Using the science writing Heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching*, 36, 1065–1084.

Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching*, 37, 676-690.

Kimball, M. E. (1967-1968). Understanding the nature of science: A comparison of scientists and science teachers. *Journal of Research in Science Teaching*, 5, 110-120.

King, P. M. and Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco: Jossey-Bass.

King, P. M. and Kitchener, K. S. (2002). The reflective judgment model: Twenty years of epistemic cognition. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

King, P. M., and Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions through adulthood. *Educational Psychologist*, 39, 5-18.

Kirschner, P. A. (1992). Epistemology, Practical Work And Academic Skills In Science Education, *Science & Education* 1, 273–299.

Koprowski, J. L. (1997). Sharpening the craft of scientific writing. *Journal of College Science Teaching*, 27, 133-35.

Kuhn, D., Amsel, E., and O'Laughlin, M. (1988). The development of scientific thinking skills. Orlando, FL: Academic Press.

Kuhn, D. (1991). *The skills of argument*. Cambridge, England: Cambridge University Press.

Kuhn, D., Cheney, R., and Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development*, 15, 309-328.

Kuhn, D., and Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Layman, J. W. (1996). *Inquiry and Learning*. New York: The College Board.

Lazarowitz, R. & Tamir, P. (1994). Research on using laboratory instruction in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning: A project of the national science teachers association* (pp. 94 – 128). New York: MacMillan.

Leach J., Ryder J. and Driver R. (1996) *ULISP Working Paper 2: The Research Project Study: Design and Methodology.* Centre for Studies in Science and Mathematics Education, University of Leeds, UK.

Leach, J., Ryder J. & Driver R. (1997) *ULISP Working Paper 5: Undergraduate science research projects and students' images of the nature of science.* Centre for Studies in Science and Mathematics Education, University of Leeds, UK.

Leach, J., Millar, R., Ryder, J, Séré, M-G., Hammelev, D., Niedderer, H., & Tselfes, V. (1998) *Survey 2: Students' images of science as they relate to labwork learning*. Working Paper 4 of the European Commission Labwork in Science Education Project, PL 95-2005.

Lederman, N. G., & Zeidler, D. L. (1987). Science teachers' conceptions of the nature of science: Do they really influence teaching behavior? *Science Education*, 71, 721-734.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331-359.

Lederman, N. G., Bell, R. L. & Wade, P. D. (1997) *Assessing knowledge and teaching of the nature of science: problems, concerns, and suggestions*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Chicago, IL.

Lederman, N.G. (1998). The state of science education: Subject matter without context. *Electronic Journal of Science Education*, 3(2), December 1998.

Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing the nature of science: What is the nature of our assessments? *Science and Education*, 7, 595-615.

Lederman, N. G. (2004). Syntax of nature of science within inquiry and science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific Inquiry and Nature of Science*. Dordrecht/Boston/London: Kluwer Academic Publishers.

Leonard, W. H. (2000). How do college students best learn science? *Journal of College Science Teaching,* 29, 385-388.

Lincoln, Y., & Guba, E.G. (1985). *Naturalistic Inquiry*. Beverly Hills, CA: Sage.

Linn, M. C. (1995). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework. *Journal of Science Education and Technology,* 4, 103 – 126.

Linn, M. C. & Hsi, S. (2000). *Computer, Teachers, Peers: Science Learning Partners*. Mahwah, NJ: Erlbaum.

Lord, T. (1994). Using constructivism to enhance student learning in college biology. *Journal of College Science Teaching*, 23, 346-348.

Louca, L., Elby, A., Hammer, D., and Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist,* 39, 57-68.

Lunetta, V. N. (1998). The School Science Laboratory. In B. Frazer & K. Tobin (1998), *International Handbook of Science Education.* (pp. 249 – 262). Dordrecht: Kluwer.

MacGregor, J., Cooper, J. L., Smith, K. A., and Robinson, P. (2000). Strategies for energizing large classes. *New Directions for Teaching and Learning*, 81, 1-4.

Malina, E. G. & Nakhleh, M. B. (2003). How students use scientific instruments to create understanding: CCD spectrophotometers. *Journal of Chemical Education,* 80, 691 – 698.

Markow, P. G. & Lonning, R. A. (1998). Usefulness of concept maps in college chemistry laboratories: Students' perceptions and effects on achievement. *Journal of Research in Science Teaching*, *35*(9), 1015 – 1029.

McComas, W. F., Almazroa, H. & Clough, M. P. (1998). The nature of science in science education: An introduction. *Science & Education*, 7, 511-532

McComas, W. F. (2004). *Seeking NOS Standards: What Content Consensus Exists in Popular Books on the Nature of Science.* Paper presented at the meeting of National Association for Research in Science Teaching.

Meichtry, Y. J. (1993). The Impact of Science Curricula on Student Views About the Nature of Science. *Journal of Research in Science Teaching, 30*, 429-443.

Millar, R., Le Marechal, J-F., Tiberghien, A. (1998). *A map of the variety of labwork.* Working Paper 1 of the European Commission Labwork in Science Education Project, PL 95-2005.

Millar, R. (2002). Thinking About Practical Work, in S. Amos and R. Boohan (eds). *Aspects of Teaching Secondary Science: Perspectives on Practice*, London: *RoutledgeFalmer*, pp 53-59.

Millar, R. (2004). *The role of practical work in the teaching and learning science*. Paper presented at meeting: High school science laboratories: Role and vision. National Academy of Sciences, Washington, DC.

Milwood, K. A. & Sandoval, W. A. (2004). *A comparison of students' beliefs about school science and professional science*. Paper presented at the Annual Meeting of the American Educational Research Assn. San Diego, CA.

Moss, D. M., Abrams, E. D., & Robb, J. (2001). Examining student conceptions of the nature of science. *International Journal of Science Education*, vol.23, no.8, 771-790.

Nachmias, R. & Linn, M. C. (1987) Evaluations of science laboratory data: The role of computer. *Journal of Research in Science Teaching, 24*, 491-506

Nakhleh, M. B. (1994). A review of microcomputer-based labs: How have they affected science learning? *Journal of Computers in Mathematics and Science Teaching*, 13, 368 – 381.

National Research Council (1997). *Science teaching reconsidered: A handbook*. Washington, D.C.: National Academy Press.

National Research Council (1999). *How people learn: Brain, mind experience, and school*. Washington, D.C.: National Academy Press.

National Survey of Student Engagement (2004). *Student engagement: Pathways to collegiate success*. Bloomington, IN: Indiana University Center for Postsecondary Research.

Newton, L. (1997). Graph talk: some observations and reflections on students' data-logging. *School Science Review*, *79*, 49 – 53.

Newton, L. (2000). Data-logging in practical science: research and reality. *International Journal of Science Education*, 22, 1247 –1259.

Nolen, S. B. (2003). Learning environment, motivation, and achievement in high school science. *Journal of Research in Science Teaching*, 4, 347-368.

Odom, A. L., & Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching*, 32, 45-61.

Olmstead, J. A. (1999). The mid-lecture break: When less is more. *Journal of Chemical Education*, 76, 525-527.

O'Sullivan, D. W., and Copper, C. L. (2003). Evaluating active learning: A new initiative for a general chemistry curriculum. *Journal of College Science Teaching*, 32, 448-452.

Padgett, D. (1998). *Qualitative Methods in Social Work Research*. Thousand Oaks, CA: Sage Publications.

Palmer, B., and Marra, R. M. (2004). College student epistemological perspectives across knowledge domains: A proposed grounded theory. *Higher Education*, 47, 311-335.

Paulsen, M. B., and Wells, C. T. (1998). Domain differences in the epistemological beliefs of college students. *Research in Higher Education*, 39, 365-384.

Pavelich, M. J. and Moore, W. S. (1996). Measuring the effect of experiental education Using the Perry model. *Journal of Engineering Education*, 85, 287-292.

Pavelich, M., Jenkins, B., Birk, J., Bauer, R., & Krause, S. (2004). *Development of a Chemistry Concept Inventory for Use in Chemistry, Materials and other Engineering Courses.* Paper Presented at the Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, Savannah, GA.

Perry, W. G. (1970). *Forms of intellectual development and ethical development in the college years: A scheme*. New York: Holt, Rinehart & Winston.

Pienta, N. J.; Amend, J. R. (2004). Electronic Data Collection to Promote Effective Learning During Laboratory Activities. In *The Chemists' Guide to Effective Teaching;* Pienta, N. J., Cooper, M. M., Greenbowe, T., Eds.; Prentice-Hall Publishing Co.

Pintrich, P. R. (2002). Future challenges and directions for theory and research on personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of scientific conception: Toward a theory of conceptual change. *Science Education,* 66: 211-227.

Prain, V., & Hand, B. (1996). Writing for learning in secondary science: Rethinking practices. *Teaching & Teacher Education*, 12, 609-612.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 95, 223-231.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in Introductory physics. *American Journal of Physics, 66*, 212-224.

Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. *Chemistry Education Research and Practice*, 8, 172-185.

Rivard, L. P. (1994). A review of writing to learn in science: Implications for practice and research. *Journal of Research in Science Teaching*, 31, 969-983.

Rivard, L.P. & Straw, S.B. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education*, 84, 566-593.

Rogers, L. T. (1997). New data-logging tools-new investigations. *School Science Review,* 79, 61- 68.

Roth, W. M., & Roychoudhury, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, 31, 5-30.

Rubba, P. A. (1977). *Nature of scientific knowledge scale: Test and user's manual.* East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service No. ED 146 225).

Rubba, P. A., & Anderson, O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education*, 62, 449-458.

Russell, A. A., & Hill, J. C. (1989). California Chemistry Diagnostic Test (E*xaminations Institute of the American Chemical Society Division of Chemical Education No. CD89*). USA: American Chemical Society Division of Educational Examination.

Ryder, J., Leach, J. & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching*, 36(2), 201-219.

Sadler, T. D., Chambers, F. W., and Zeidler, D. L. (2002). Investigating the crossroads of the nature of science, socioscientific issues, and critical thinking. *Paper presented at the annual meeting of the National Association for Research in Science Teaching.* New Orleans, LA.

Sandavol, W. A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching*, 40, 369-392.

Schmid, S. & Yeung, A. (2005) The influence of a pre-laboratory work module on student performance in the first year chemistry laboratory. *Research and Development in Higher Education*, **28**, 471–479.

Schoenfeld, A., (1983). Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance. *Cognitive Science*, 7, 329-363.

Schoenfeld, A., (1988). When good teaching leads to bad results: The disasters of "well taught" mathematics classes. *Educational Psychologist*, 23, 145-166.

Schommer, M. (1990). Effects of the beliefs about the nature of knowledge on comprehension. J*ournal of Educational Psychology*, 82, 498-504.

Schommer, M., Crouse, A., and Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, 84, 435-443.

Schommer, M. (1993). Epistemological development and academic performance among secondary students. *Journal of Educational Psychology*, 85, 406-411.

Schommer, M. (1994). Synthesizing epistemological belief research: Tentative Understandings and provocative confusions. *Educational Psychology Review*, 6, 293-319.

Schommer, M., and Walker, K. (1997). Epistemological beliefs and valuing school: Considerations for college admissions and retention. *Research in Higher Education*, 38, 173-186.

Schommer-Aikins, M. (2002). An evolving theoretical framework for an epistemological belief system. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Schraw, G. (2001). Current themes and future directions in epistemological research: A commentary. *Educational Psychology Review*, 13, 451-464.

Schraw, G., Bendixen, L. D. and Dunkle, M. E. (2002). Development and evaluation of the Epistemic Belief Inventory (EBI). In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Sere, M.G., Leach, J., Niedderer, H. *et al.* (1998). *Labwork in science education: Executive Summary*. European Commission Targeted Socio-Economic Research Programme.

Settlage, J. (1995). Children's conceptions of light in the context of a technology-based curriculum. *Science Education*, 7, 535 – 553.

Shepardson, D.P. & Britsch, S.J. (2000). Analyzing children's science journals. *Science and Children*, November/December, 13-17.

Shiland, T. W. (1999). Constructivism: The implication for laboratory work. *Journal of Chemical Education*, 76, 107 – 109.

Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of schools science experiences on epistemological development. *Cognition and Instruction*, 18, 349-422.

Smith, K. A., Sheppard, S. D., Johnson, D. W., and Johnson, R. T. (2005). Pedagogical engagement: Classroom-based practices. *Journal of Engineering Education*, 95, 87-101.

Songer, N., & Linn, M. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, 28, 761-784.

Steiner R, Sullivan J (1984). Variables correlating with student success in organic chemistry. *J. Chem. Educ.*, 61:1072 – 1074.

Strike, K. A. & Posner, G. J. (1992). A revisionist theory of conceptual change. In Duschl, R. A. & Hamilton, R. J. (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147 – 176). New York: State University of New York Press.

Taber, K. S. (2000). Chemistry lessons for universities: A review of constructivist ideas. University Chemistry Education, 4, 63-72.

Tapper, J. (1999). Topics and manner of talk in undergraduate practical laboratories. *International Journal of Science Education*, *21*(4): 447 – 464.

Thoermer, C., & Sodian, B. (2002). Science Undergraduates' and graduates' epistemologies of science: the notion of interpretive frameworks. New Ideas in Psychology, 20, 263-283.

Tiberghien A., Veillard L., Le Marechal J. F., Buty, C. & Millar, M. (2001). An analysis of labwork tasks used in science teaching at upper secondary school and university levels in several European countries. *Science Education*, *85*, 483 – 508.

Tobin, K. (1990). Research on science laboratory activities: In pursuit of better questions and answers to improving learning. *School Science and Mathematics* 90, 403-418.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, 10, 159-169.

Valanides, N. & Angeli, C. (2005). Effects of instruction on changes in epistemological beliefs. Contemporary Educational Psychology, 30, 314-330.

Valentine, J. C., DuBois, D. L., and Copper, H. (2004). The relation between self-beliefs and academic achievement: A meta-analytic review. *Educational Psychologist*, 39, 111-133.

Vhurumuku, E., Holtman, L., Stein, D. K., & Mikalsen, O. (2004). An investigation of Zimbabwean A-level chemistry students: Laboratory work based images of the nature of science. Paper p*resented at the Proceedings of the 12th Annual Conference of the Southern African Association for Research in Mathematics, Science, and Technology Education,* Cape Town, Africa.

Weinburgh, M. (1998). *Gender, Ethnicity, and Grade Level as Predictors of Middle School Students' Attitudes Toward Science.* Georgia State University. (*www.ed.psu.edu/CI/Journals/1998AETS/s5_1_weinburgh.rtf*)

Wimpfheimer, T. (2004). Peer-evaluated poster sessions: An alternative to grading general chemistry laboratory work. Journal of Chemical Education, 81, 1775-1776.

Wise, J., Lee, S. H., Litzinger, T. A., Marra, R. M., and Palmer, B. (2004). A report on a four–year longitudinal study of intellectual development of engineering undergraduates. *Journal of Adult Development*, 11, 103-110.

Wolters, C. A. and Pintrich, P. R. (1998) Contextual Differences in Student Motivation and Self-Regulated Learning in Mathematics, English, and Social Studies Classrooms. *Instructional Science* 26, 27-47.

Wyatt, R. (2003). *Campus Technology: Online Biology Pre-Labs*. http://www.campus-technology.com/article.asp?id=7770 (April 14, 2005).

Zachos, P., Hick, T. L., Doane, W. E. & Sargent, C. (2000). Setting theoretical and empirical foundations for assessing scientific inquiry and discovery in educational programs. *Journal for research in science teaching*, 37, 938-962.

Zeegers, P. (2001). Approaches to learning in science: A longitudinal study. *British Journal of Educational Psychology*, 71, 115-132.

Zeidler, D. L. (1984). Moral issues and social policy in science education: Closing the literacy gap. *Science Education*, 68, 411-419.

Zeidler, D. L., Walker, K. A., Ackett, W. A. & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86, 343-367

Ziman, J. (1995). *Reliable knowledge: An exploration of the grounds for belief in science.* New York: Cambridge University Press.

Zimmerman, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational Psychologist, 23*, 3-17.

Zimmerman, B. J., Bandura, A., and Martinez-Pons, M. (1992). Self-motivation for academic attainment: The role of self-efficacy beliefs and personal goal setting. *American Educational Research Journal*, 29, 663-676.

Zusho, A., Pintrich, P. R., and Coppola, B. (2003). Skill and Will: The role of motivation and cognition in the learning of college chemistry. *International Journal of Science Education*, 25, 1081-1094.

Appendices

Appendix A: Chemical Concepts Inventory

We are asking you to complete this inventory to determine the prior conceptual knowledge and misconceptions in general chemistry that students bring to the classroom. THIS INVENTORY CANNOT AFFECT YOUR GRADE IN ANY WAY

Instructions:

1. Please write and bubble in your student identification number (U Number) on the scantron with pencil

2. On the signature line write CCI and the date

3. This inventory consists of 22 multiple choice questions.

4. Several of the questions are paired. In these cases, the first question asks you about a chemical or physical effect. The second question then asks for the reason for the observed effect.

5. Please do not write on this inventory, bubble your answers on the scantron.

6. Turn in both the inventory and the scantron.

7. You may not remember some of the material from your high school chemistry course. Please take the time to think about the questions and answer to the best of your ability.

We appreciate your help with this project.

Chemistry Concepts Inventory

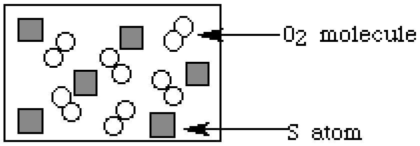
1. Which of the following must be the same before and after a chemical reaction?
(a) The sum of the masses of all substances involved.
(b) The number of molecules of all substances involved.
(c) The number of atoms of each type involved.
(d) Both (a) and (c) must be the same.
(e) Each of the answers (a), (b), and (c) must be the same.

2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?
(a) Air.
(b) Oxygen gas and hydrogen gas.
(c) Oxygen.
(d) Water vapor.
(e) Heat.

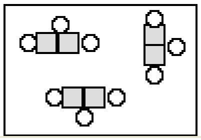
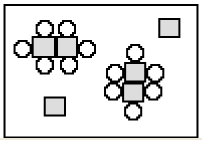
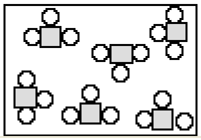
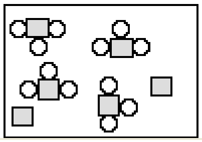
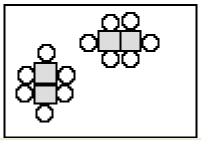
3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?
(a) Water evaporates from the milk and condenses on the outside of the glass.
(b) The glass acts like a semi-permeable membrane & allows the water to pass, but not the milk.
(c) Water vapor condenses from the air.
(d) The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?
(a) 19 Pounds.
(b) 20 Pounds.
(c) Between 20 and 21 pounds.
(d) 21 pounds.
(e) More than 21 pounds.

5. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.

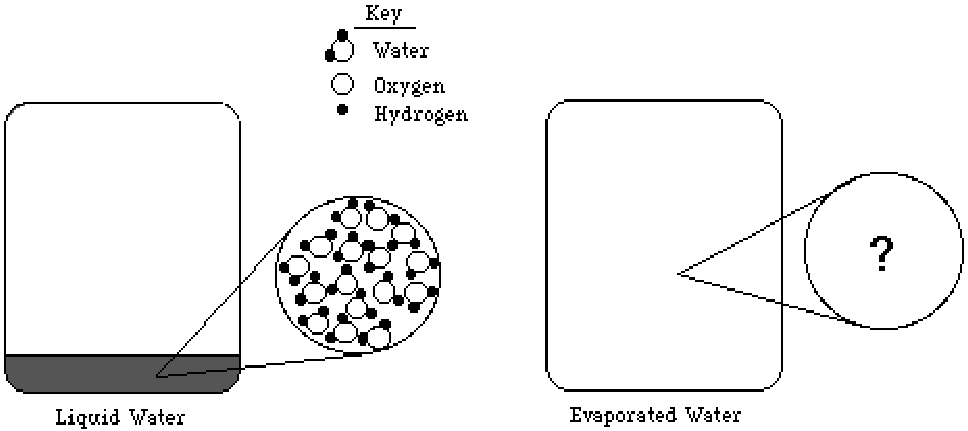


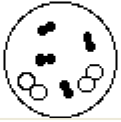
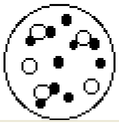
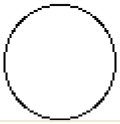
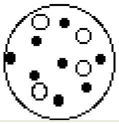
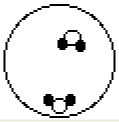
Which diagram shows the results after the mixture reacts as completely as possible according to the equation: $2S + 3O_2 \rightarrow 2SO_3$

..........A...........	..........B............	..........C............	..........D.............	..........E...........

6. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after the water evaporates?



.....A......	.....B......	.....C......	.....D.......	.....E......

7. True or False? When a match burns, some matter is destroyed.
(a) True (b) False

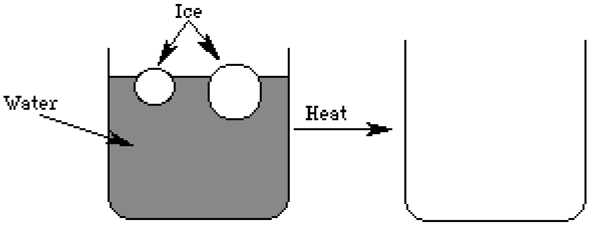
8. What is the reason for your answer in question 7?
(a) This chemical reaction destroys matter.
(b) Matter is consumed by the flame.
(c) The mass of ash is less than the match it came from.
(d) The atoms are not destroyed, they are only rearranged.
(e) The match weighs less after burning.

9. Heat is given off when hydrogen burns in air according to the equation

$$2H_2 + O_2 \rightarrow 2H_2O$$

Which of the following is responsible for the heat?
(a) Breaking hydrogen bonds gives off energy.
(b) Breaking oxygen bonds gives off energy.
(c) Forming hydrogen-oxygen bonds gives off energy.
(d) Both (a) and (b) are responsible.
(e) (a), (b), and (c) are responsible.

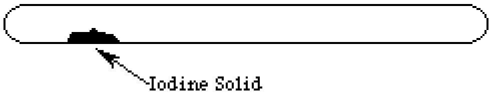
10. Two ice cubes are floating in water:



After the ice melts, will the water level be:
(a) higher?
(b) lower?
(c) the same?

11. What is the reason for your answer?
(a) The weight of water displaced is equal to the weight of the ice.
(b) Water is more dense in its solid form (ice).
(c) Water molecules displace more volume than ice molecules.
(d) The water from the ice melting changes the water level.
(e) When ice melts, its molecules expand.

12. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



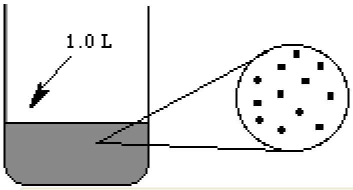
The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:
(a) less than 26.0 grams.
(b) 26.0 grams.
(c) 27.0 grams.
(d) 28.0 grams.
(e) more than 28.0 grams.

Appendix A (Continued)

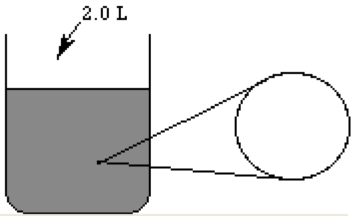
13. What is the reason for your answer?
(a) A gas weighs less than a solid.
(b) Mass is conserved.
(c) Iodine gas is less dense than solid iodine.
(d) Gasses rise.
(e) Iodine gas is lighter than air.

14. What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: ©
(a) 4
(b) 200
(c) 30,000,000
(d) 6.02 x 1023

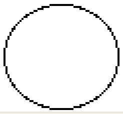
15. Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown. Which response represents the view after 1.0 L of water were added (Figure 2).



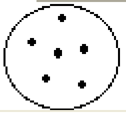
.....Figure 1........................



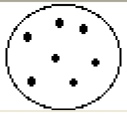
.....................Figure 2......



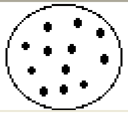
.......A.......



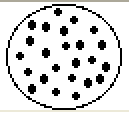
.......B........



.......C........



.......D........



.......E.......

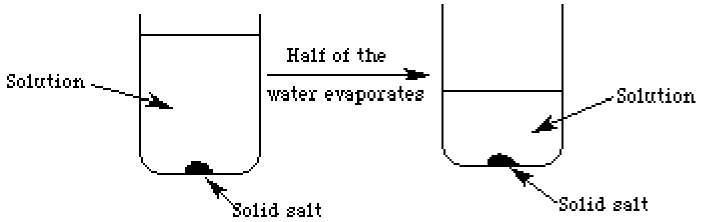
16. 100 mL of water at 25¡C and 100 mL of alcohol at 25¡C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50¡C. Two minutes later the temperature of the water is 50¡C.
Which liquid received more heat as it warmed to 50¡C?
(a) The water.
(b) The alcohol.
(c) Both received the same amount of heat.
(d) It is impossible to tell from the information given.

17. What is the reason for your answer?
(a) Water has a higher boiling point then the alcohol.
(b) Water takes longer to change its temperature than the alcohol.
(c) Both increased their temperatures 25¡C.
(d) Alcohol has a lower density and vapor pressure.
(e) Alcohol has a higher specific heat so it heats faster.

18. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:
(a) less than the nail it came from.
(b) the same as the nail it came from.
(c) more than the nail it came from.
(d) It is impossible to predict.

19. What is the reason for your answer?
(a) Rusting makes the nail lighter.
(b) Rust contains iron and oxygen.
(c) The nail flakes away.
(d) The iron from the nail is destroyed.
(e) The flaky rust weighs less than iron.

20. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume temperature remains constant.)



The concentration
(a) increases.
(b) decreases.
(c) stays the same.

21. What is the reason for your answer to question 20?
(a) There is the same amount of salt in less water.
(b) More solid salt forms.
(c) Salt does not evaporate and is left in solution.
(d) There is less water.

22. Following is a list of properties of a sample of solid sulfur:
i. Brittle, crystalline solid.
ii . Melting point of 113 ¡C.
iii . Density of 2.1 g/cm3.
iv . Combines with oxygen to form sulfur dioxide

Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample?

(a) i and ii only.
(b) iii and iv only.
(c) iv only.
(d) All of these properties would be the same.
(e) None of these properties would be the same.

Appendix B: Epistemological Beliefs Assessment for the Physical Sciences

Instructions:

- We are asking you to complete this inventory to assist us in probing the epistemological stances of students taking physics, chemistry, or physical science
- For each of the items, please read the statement, and indicate (on the scantron answer sheet) the answer that describes how strongly you agree or disagree, or fill in the answer that best fits your view, or whether you agree with one student or the other

- The data collected will be handled anonymously throughout.

- This inventory cannot affect your grade only help improve it.

- The inventory consists of 30 statements.

- Calculators are not needed for these questions

- Please do not write on this inventory.

- Bubble your choices on the scantron using pencil

- Write in and Bubble your study ID number (U #)

- Write EBAPS on the signature line with the date

- Turn in both the inventory and the scantron

EPISTEMOLOGICAL BELIEFS ASSESSMENT FOR THE PHYSICAL SCIENCES

Part 1 - <u>DIRECTIONS</u>*:* For each of the following items, please read the statement, and indicate (on the scantron answer sheet) the answer that describes how strongly you agree or disagree.

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

1. Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.

2. When it comes to understanding physics or chemistry, remembering facts isn't very important.

3. Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year.

4. When it comes to science, most students either learn things quickly, or not at all.

5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.

6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air!

7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much he or she already knows.

8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything.

9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class.

10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

11. When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.

12. When learning science, people can understand the material better if they relate it to their own ideas.

13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.

14. Understanding science is really important for people who design rockets, but not important for politicians.

15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems.

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.

17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

Part 2 DIRECTIONS*:* Multiple choice. On the answer sheet, fill in the answer that best fits your view.

18. If someone is trying to learn physics, is the following a good kind of question to think about?
Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?

(a) *Yes, definitely*. It's one of the best kinds of questions to study.
(b) *Yes, to some extent*. But other kinds of questions are equally good.
(c) *Yes, a little*. This kind of question is helpful, but other kinds of questions are more helpful.
(d) *Not really*. This kind of question isn't that great for learning the main ideas.
(e) *No, definitely not*. This kind of question isn't helpful at all.

19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is.

In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.

(a) Although things behave in accordance with rules, those rules are often complicated, hard to apply, or not fully known.
(b) Some things just don't behave according to a consistent set of rules.
(c) Usually it's because the rules are complicated, hard to apply, or unknown; but sometimes it's because the thing doesn't follow rules.
(d) About half the time, it's because the rules are complicated, hard to apply, or unknown; and half the time, it's because the thing doesn't follow rules.
(e) Usually it's because the thing doesn't follow rules; but sometimes it's because the rules are complicated, hard to apply, or unknown.

20. In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.

(a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.
(b) The major formulas are kind of "separate" from the main concepts, since concepts are *ideas*, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.
(c) Mostly (a), but a little (b).
(d) About half (a) and half (b).
(e) Mostly (b), but a little (a).

21. To be successful at *most things in life*...

(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

22. To be successful at *science*...

(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

23. Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one.

(a) A large collection of short-answer or multiple choice questions, each of which covers one specific fact or concept.
(b) A small number of longer questions and problems, each of which covers several facts and concepts.
(c) Compromise between (a) and (b), but leaning more towards (a).
(d) Compromise between (a) and (b), favoring both equally.
(e) Compromise between (a) and (b), but leaning more towards (b).

Part 3 DIRECTIONS*:* In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other

24.

Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate.

Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before circling one.
(a) I agree almost entirely with Brandon.
(b) Although I agree more with Brandon, I think Jamal makes some good points.
(c) I agree (or disagree) equally with Jamal and Brandon.
(d) Although I agree more with Jamal, I think Brandon makes some good points.
(e) I agree almost entirely with Jamal.

25.

Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.

Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.

Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

(a) I agree almost entirely with Anna.
(b) Although I agree more with Anna, I think Emily makes some good points.
(c) I agree (or disagree) equally with Anna and Emily.
(d) Although I agree more with Emily, I think Anna makes some good points.
(e) I agree almost entirely with Emily.

26.

Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.

Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.

(a) I agree almost entirely with Justin.
(b) Although I agree more with Justin, I think Dave makes some good points.
(c) I agree (or disagree) equally with Justin and Dave.
(d) Although I agree more with Dave, I think Justin makes some good points.
(e) I agree almost entirely with Dave.

27.

Julia: I like the way science explains how things I see in the real world.

Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.

Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.

(a) I agree almost entirely with Julia.
(b) I agree more with Julia, but I think Carla makes some good points.
(c) I agree (or disagree) equally with Carla and Julia.
(d) I agree more with Carla, but I think Julia makes some good points.
(e) I agree almost entirely with Carla.

28.

Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?

Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.

Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

(a) I agree almost entirely with Leticia.
(b) I agree more with Leticia, but I think Nisha makes some good points.
(c) I agree (or disagree) equally with Nisha and Leticia.
(d) I agree more with Nisha, but I think Leticia makes some good points.
(e) I agree almost entirely with Nisha.

29.

Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth.

Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

(a) I agree almost entirely with Jose.
(b) Although I agree more with Jose, I think Miguel makes some good points.
(c) I agree (or disagree) equally with Miguel and Jose.
(d) Although I agree more with Miguel, I think Jose makes some good points.
(e) I agree almost entirely with Miguel.

30.

Jessica and Mia are working on a homework assignment together...

Jessica: O.K., we just got problem #1. I think we should go on to problem #2.

Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.

Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer.

Mia: No, I think it's possible to get the right answer without really understanding what it means.

(a) I agree almost entirely with Jessica.
(b) I agree more with Jessica, but I think Mia makes some good points.
(c) I agree (or disagree) equally with Mia and Jessica.
(d) I agree more with Mia, but I think Jessica makes some good points.
(e) I agree almost entirely with Mia.

Appendix C: Nature of Scientific Knowledge Scale

Instructions:

- We are asking you to complete this inventory to assist us in assessing student conceptions relating to the Nature of Science (NOS)
- The data collected will be handled anonymously throughout.
- This inventory cannot affect your grade only help improve it.
- The inventory consists of 48 statements, with several paired statements.
- Calculators are not needed for these questions
- Please do not write on this inventory.
- Bubble your choices on the scantron using pencil
- Write in and Bubble your study ID number (U #)
- Write NSKS inventory on the signature line with the date
- Turn in both the inventory and the scantron

Appendix C (Continued)

Nature of Scientific Knowledge Scale (NSKS)
(Rubba, P. A., & Anderson, O.,1978).

1	2	3	4	5
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

1. Scientific laws, theories and concepts do not express creativity.

2. Scientific knowledge is stated as simply as possible.

3. The laws, theories and concepts of biology, chemistry and physics are related.

4. The applications of scientific knowledge can be judged good or bad, but the knowledge itself cannot.

5. It is incorrect to judge a place of scientific knowledge as being good or bad.

6. If two scientific theories explain a scientist’s observations equally well, the simpler theory is chosen.

7. Certain pieces of scientific knowledge are good and others are bad.

8. Even if the applications of a scientific theory are judged to be good, we should not judge the theory itself.

9. Scientific knowledge need not be capable of experimental test.

10. The laws, theories and concepts of biology, chemistry and physics are not linked.

11. Consistency among test results is not requirement for the acceptance of scientific knowledge.

12. A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.

13. The evidence for scientific knowledge need not be open to public examination.

14. Scientific laws, theories and concepts are not stated as simply as possible.

15. There is an effort in science to build as great a number of laws, theories and concepts as possible.

16. We accept scientific knowledge even through it may contain error.

17. Scientific knowledge expresses the creativity of scientists.

Appendix C (Continued)

1	2	3	4	5
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

18. Moral judgment can passed on scientific knowledge.

19. The laws, theories and concepts of biology, chemistry and physics are not related.

20. Scientific laws, theories and concepts express creativity.

21. It is meaningful to pass moral judgment on both the application of scientific knowledge and the knowledge itself.

22. The evidence for scientific knowledge must be repeatable.

23. Scientific knowledge is not a product of human imagination.

24. Relationships among the laws, theories and concepts of science do not contribute to the explanatory and predictive power of science.

25. The truth of scientific knowledge is beyond doubt.

26. Today’s scientific laws, theories and concepts may have to be changed in the face of new evidence.

27. We do not accept a piece of scientific knowledge unless it is free of error.

28. A scientific theory is similar to a work of art in that they both express creativity.

29. There is an effort in science to keep the number of laws, theories and concepts at a minimum.

30. The various sciences contribute to a single organized body of knowledge.

31. Scientific beliefs do not change over time.

32. Scientific knowledge is a product of human imagination.

33. The evidence for a piece of scientific knowledge does not have to be repeatable.

34. Scientific knowledge does not express the creativity of scientist.

35. Biology, chemistry and physics are similar kinds of knowledge.

36. If the applications of a piece of scientific knowledge are generally considered bad, then the piece of knowledge is also generally considered to be bad.

Appendix C (Continued)

1	2	3	4	5
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

37. Scientific knowledge is subject to review and change.

38. Scientific laws, theories and concepts are tested against reliable observations.

39. If two scientific theories explain a scientist's observations equally well, the more complex theory is chosen.

40. Scientific knowledge is specific as opposed to comprehensive.

41. Scientific theories are discovered, not created by man.

42. Those scientific beliefs which were accepted in the past, and since have been discarded, should be judged in their historical context.

43. Scientific knowledge is unchanging.

44. Biology, chemistry and physics are different kinds of knowledge.

45. Consistency among test results is a requirement for the acceptance of scientific knowledge.

46. Scientific knowledge is comprehensive as opposed to specific.

47. The laws, theories and concepts of biology, chemistry and physics are interwoven.

48. A piece of scientific knowledge should not be judged good or bad.

Appendix D: Initial Laboratory Work Questionnaire

Initial Questionnaire on Laboratory Work

Study ID #_________________________

Part 1-This section explores what you think about laboratory work. (Please check the box that best describes your level of agreement with each statement).

I think that laboratory work	**Agreement Level**					
	Strongly Agree	Agree	Neither	Disagree	Strongly disagree	
1. is overdone in my studies						
2. is an important part of my studies						
3. has helped me to understand scientific theories						
4. is more enjoyable if I work on an experiment in conjunction with others						
5. is preferable if I work on an experiment by myself						
6. is something I am confident about						
7. is something I find difficult						
8. should be included in program						
9. should be optional in program						

Appendix D (Continued)

Part 2- This section concerns how confident you feel about the skills and knowledge you may possess at the start of your laboratory course. ‘Very high’ means you think you could teach someone else the skill, ‘high’, you could certainly do it yourself, neither high nor low, you are unsure whether you could do it yourself, ‘low’, you probably couldn’t do it, and ‘very low’, you certainly couldn’t do it**.** (Please check the box that best describes your level of confidence about each statement)

I can	**Confidence Level**				
	Very High	High	Neither	Low	Very Low
10. Follow laboratory instructions					
11. Assemble apparatus-equipment					
12. Take numerical readings accurately					
13. Plan experiments					
14. Plot graphs of numerical results					
15. Analyze graphs of numerical results					
16. Process data reliably					
17. Estimate uncertainties in numerical results					
18. Report observations accurately					
19. Interpret observations reliably					
20. Assess health and safety risks					
21. Understand theories underlying experiments					
22. Write good scientific reports					

Part -3-Laboratory Skills

Of the skills below which three – five do you regard as most important? (Please check three-five below).

Skill	
1. Follow instructions	
2. Assemble apparatus	
3. Take numerical readings accurately	
4. Plan experiments	
5. Plot graphs of numerical results	
6. Analyze graphs of numerical results	
7. Process data reliably	
8. Estimate uncertainties in numerical results	
9. Report observations accurately	
10. Interpret observations reliably	
11. Assess health and safety risks	
12. Understand theories underlying experiments	
13. Write good scientific reports	

Appendix E: Student Evaluation of Laboratory Instruction

Student Reflective Evaluations on Laboratory Instruction - Section 1

Lab Title______________________________ Study ID #______________

For the three features and their sub-features please indicate by checking the appropriate box on how helpful you found each of the following pedagogical features with respect to understanding and necessity of the laboratory learning experience <u>if applicable.</u> Starting with **1 to indicate not essential**, to **5 where you considered the feature extremely essential** to your understanding and necessity of the laboratory learning experience **if applicable**

	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Feature	1	2	3	4	5
1. **Pre-lab**					
a. Lab Manual					
b. Quiz					
c. Questions-FC					
d. Discussion					
e. Technology (e.g. BB, PRS)					
2. **LabWork**					
a. Lab Manual					
b. Group Discussions					
c. Lab NB					
d. Technology (e.g. MBL)					
e. Bench Work					
3. Post-lab					
a. Lab Manual					
b. Lab NB					
c. Discussion					
d. Technical Writing-Analysis					
e. Technology (e.g. BB)					

Appendix E (Continued)

For questions 7-8 please respond in the space provided with respect to your understanding and necessity of the laboratory learning experience.

7. How do the instructional methods (e. g. pre-lab, post-lab, technology, and laboratory notebook) used in these chemistry laboratory activities compare with other science laboratory activities you have experienced? Explain.

8. What have you learned, if anything, concerning the nature of science (i.e. chemistry) with respect to the instructional methods? Concerning your epistemological beliefs with respect to the instructional methods? Explain

Student Reflections of Pre-Post Laboratory Experiences Questionnaire Section 2

Choose one statement for each topic that best describes your perceptions regarding the pre- and post laboratory methods. You may make comments on the back of the questionnaire.

Achievement

A. I feel that I achieve more in my learning if I do the experiment after participating in a pre-lab discussion.

B. I feel that I achieve more in my learning if I do the experiment then participate in a post-lab discussion.

C No clear difference

Difficulty

A. It is more difficult to perform an experiment before it is discussed.

B. It is more difficult to perform an experiment after it is discussed.

C. Initially, it was more difficult to perform an experiment before it was discussed, but now I prefer to discuss the experiment after I have performed it.

D. Doing the experiment before or after I participated in the discussion made no clear difference.

Enjoyment

A. Overall, I enjoy the laboratory more if I do the experiment before a discussion

B. Overall, I enjoy the laboratory more if I do the experiment after the discussion.

C. No clear difference

Understanding

A. I understand the connection between theory and practice well if I do the experiment first and then participate in a discussion

B. I understand the connection between theory and practice well if I do the experiment after I participate in the discussion.

C. No clear difference

Reflective Self-assessment of Laboratory Learning – Section 3

DIRECTIONS: *For each of the following items, please read the statement, and circle the answer that best describes the kind of learning you believe you gained by doing this laboratory activity. Then briefly reflect on your choices in the space provided below each statement by identifying situations in this particular activity that modeled each learning category*

1. Knowledge: (i.e., to recall, describes, identifies facts, terms, or phenomena)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

2. Comprehension: (i.e., to interpret, predict, explain so others understand)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

3. Application: (i.e., to solve, apply, use concepts or learning to other situations)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

Appendix E (Continued)

4. Analysis: (i.e., to analyze, troubleshoot, distinguish concepts through reasoning)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

5. Synthesis: (i.e., to create, integrate, design patterns, create new meaning of concepts)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

6. Evaluation: (i.e., to compare, contrast, justify solutions or value of concepts)

A: Nothing B: A Little C: Some D: A lot E: Very Much

Reflections

Appendix F: Interview Formats/Scripts

Initial Interview Questions

Potential Prompt/Probe questions:

- ✓ What do you mean by _______?
- ✓ Can you expand on your answer for me?
- ✓ Can you give me an example of what you mean?
- ✓ Can you give me a view that you think is wrong?

Now I would like your beliefs/views on the following statements and/or questions. This is not about right or wrong responses however you need to respond with more than just yes or no offering supporting statements and examples.

Personal Epistemological Beliefs in Science

Q-1- Structure of Scientific Knowledge

- ✓ Chemistry knowledge is a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas.

- ✓ Chemistry knowledge is coherent, conceptual, highly-structured and a unified whole knowledge.

Q-2- Nature of Knowing and Learning Science

- ✓ Learning science (chemistry) consist mainly of absorbing information.

- ✓ Learning science relies on constructing one's own understanding, working actively through the material, relating new material to prior experiences/intuitions/knowledge, and reflecting upon and monitoring one's understanding.

Q-3- Real-life Applicability

- ✓ Scientific knowledge and scientific ways of thinking apply only to the classroom and laboratory settings, not to real life.

Q-4- Evolving Knowledge

- ✓ All scientific knowledge is set in stone.

- ✓ There is no difference between scientific evidence-based reasoning and mere opinion.

- ✓ Sometimes different science instructors give different explanations for scientific events/concepts/phenomena. When 2 instructors explain the same thing differently, can one be more correct than the other? Explain

- ✓ When 2 explanations are given for the same situation, how would you go about deciding which explanation to believe? Please give details and examples

- ✓ Can one ever be sure of which explanation to believe? If so, how can you? If not, why not?

Q-5- Source of Ability to Learn

- ✓ Being good at learning and doing science is mostly a matter of fixed natural ability so most people cannot become better at learning and doing science.

Nature of Science

There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statements:

Q-6- Creative

- ✓ Scientific theories and models are products of the human mind and may or may not accurately represent reality.

Q-7- Developmental

- ✓ Scientific knowledge is a changing and evolving body of concepts and theories.

Q-8 - Parsimonious

- ✓ The ultimate goal of science is to gather all the complex facts about natural phenomena

Q-9 -Testable

- ✓ The scientific method will eventually let people learn the real truth about the natural world and how it works.

Final Interview Question Format- Instructional

I would like your beliefs/views on the following statements and/or questions. This is not about right or wrong responses however you need to respond with more than just yes or no offering supporting statements and examples.

Potential Prompt/Probe questions:

- ✓ What do you mean by _______?
- ✓ Can you expand on your answer for me?
- ✓ Can you give me an example of what you mean?
- ✓ Can you give me a view that you think is wrong?

1. What instructional feature (pre-lab, laboratory work, or post-lab) was the most effective in promoting your learning in this course?
2. What instructional feature (pre-lab, laboratory work, or post-lab) was the least effective in promoting your learning in this course?
3. What could you have done differently to promote your learning?
4. What are the most important skills you learned in chemistry laboratory?
5. Of the skills below rank in order which **five** you **now** regard as the most important?

Skill	
1. Follow instructions	
2. Assemble apparatus	
3. Take numerical readings accurately	
4. Plan experiments	
5. Plot graphs of numerical results	
6. Analyze graphs of numerical results	
7. Process data reliably	
8. Estimate uncertainties in numerical results	
9. Report observations accurately	
10. Interpret observations reliably	
11. Assess health and safety risks	
12. Understand theories underlying experiments	
13. Write good scientific reports	

6. How would you rank the following aspects of pre-laboratory? (Using each category level only once)

	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Feature	1	2	3	4	5
Pre-lab					
a. Lab Manual					
b. Quiz					
c. Questions					
d. Discussion					
e. Technology (e.g. BB, PRS)					

7. How would you rank the following aspects of laboratory work? (Using each category level only once)

	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Feature	1	2	3	4	5
Lab-Work					
a. Lab Manual					
b. Group Discussions					
c. Lab NB					
d. Technology (e.g. MBL)					
e. Bench Work					

8. How would you rank the following aspects of post laboratory analysis? (Using each category level only once)

	Least Essential	Somewhat Essential	Essential	Very Essential	Extremely Essential
Feature	1	2	3	4	5
Post-lab					
a. Lab Manual					
b. Lab NB					
c. Discussion					
d. Technical Writing-Analysis					
e. Technology (e.g. BB)					

9. Describe the role and significance of the laboratory notebook in any scientific workplace. (e. g. classroom, research laboratory, hospital, pharmacy)

10. Describe the role and significance of the scientific laboratory report/analysis in any scientific workplace. (e. g. classroom, research laboratory, hospital, pharmacy)

11. What three of the six learning skill levels in Bloom's Taxonomy did you utilize most often in this course?

Epistemological Beliefs Final Interview

Epistemological beliefs are individuals' beliefs about the nature and structure of knowledge. Personal beliefs about what knowledge is and how we understand, integrate and apply knowledge (known as personal epistemologies) are entrenched in the process of learning science. In this case specifically to

probe the epistemological stances of students taking physics, chemistry, or physical science.

I would like your beliefs/views on the following statements and/or questions. This is not about right or wrong responses however you need to respond with more than just yes or no offering supporting statements and examples.

1. Structure of Scientific Knowledge – weakly connected without much structure versus strongly connected and highly structured

What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **Structure of Scientific Knowledge** in this course?

2. Nature of Knowing and Learning in Science – consists mainly of absorbing/memorizing information and facts versus relies on constructing one's own understanding by relating new material to prior knowledge, prior experiences, and actively working through the material

What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **Nature of Knowing and Learning in Science** in this course?

3. Real Life Applicability of Science – scientific knowledge is restricted to the classroom and laboratory versus applies to everyday real life situations such as one's home, automobile, diet, and health.

What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **Real Life Applicability of Science** in this course?

4. Evolving Knowledge of Science – from the point of view that all scientific knowledge is set in stone to the belief that there is no distinction between evidence-based reasoning and mere opinion

What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **Evolving Knowledge of Science** in this course?

5. Source of Ability to Learn Science – that learning science is a matter of fixed natural ability versus that most individual's can learn science if they want to

What instructional feature (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **Source of Ability to Learn Science** in this course?

Nature of Science Final Interview

Typically, the Nature of Science (NOS) has been used to refer to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. The NOS refers to one's understanding about the social practices and organization of science and how scientists collect, interpret, and use data to guide further research (Ryder, Leach, & Driver, 1999).

I would like your beliefs/views on the following statements and/or questions. This is not about right or wrong responses however you need to respond with more than just yes or no offering supporting statements and examples.

1. Scenario Problem

Some scientists believe that explanations of chemical phenomena, such as atomic theory, are accurate and true descriptions of atomic structure. Other scientists say that we cannot know whether or not these theories are accurate and true, but that scientists can only use such theories as working models to explain what is observed.

What do you think about this statement? How did you come to hold that point of view or answer? On what do you base that point of view or answer?

Appendix F: (Continued)

2. <u>What instructional feature</u> (pre-lab, laboratory work, or post-lab), if at all do you believe influenced your beliefs about the **<u>Nature of Science</u>** in this course?

Example 1: Nature of Science Interview (Carey, et al., 1989; Sandoval & Morrison, 2003)

Goals of Science

1. What do you think science is all about?
2. What do you think the goal of science is?
3. What do you think scientists do?
   3a. How do they achieve their goals?

Types of Questions

4. Do you think scientists ask questions?
   4a. What sorts of questions do you think scientists ask?
   If No, go to question 6
5. How do scientists answer their questions?
   5a. Can you give an example of a scientist's question and what he or she would do to answer it?

Nature and Purpose of Experiments

6. What is an experiment?
7. Do scientists do experiments?
   7a. If No, skip to question 10.
8. Why do scientists do experiments?
   8a. If "to test ideas" Then: How does the test tell the scientist something about the idea?

Roles of Ideas: Conceptions of Hypotheses and Theories

9. How does a scientist decide what experiment to do?
10. Have you ever heard the word "hypothesis"?
    10a. If No, explain: A hypothesis is an idea scientists have, an idea about how an experiment would turn out.
    10b. If Yes, ask: What is a hypothesis?
    10c. If "educated guess" or "guess" Then ask: Do you think a hypothesis is the same as a guess or do you think there is a difference? What is the difference?
11. Do you think a scientist's ideas influence the experiments he or she does?
    11a. If Yes: How?
    11b. If No: Do scientists ever test their ideas?
12. How do you think scientists come up with their ideas?
13. Have you ever heard the word theory?
    13a. If Yes: What is a theory? Do you think scientists have theories?
    In all cases, explain: "A theory is a general idea about how and why things happen the way they do. For example, biology is a theory about living things."

14. Do you think a scientist's theory influences his or her ideas about specific experiments?
    14a. How?

Unexpected Results and Disproving Ideas

15. If a scientist does an experiment and the results are not as he or she expected, would the scientist consider this a bad result?
    15 a. Why or why not?
    15b. Can they learn anything from this?
    15c. What?

16. Say a scientist is going to do an experiment to test his or her idea. Would a scientist do an experiment that might prove this idea is wrong?
    16a. Why or why not?

Nature of Change Processes

17. What happens to a scientist's ideas once he has done a test?
18. Do scientists ever change their ideas?
    18a. If Yes: When would they do that and why?
19. Do scientists ever change their whole theories?
    19a. If Yes: When would they do that and why?

Achieving Goals and Making Mistakes

20. Do scientists always achieve their goals?
    20a. If not, why not?
21. Can scientists make mistakes or be wrong?
    21a. How?

Example 2: Potential Interview Script - NOS

There are many differing views or images of the nature of science and scientific knowledge. I would like your views on the following statements:

1. Scientific knowledge is a changing and evolving body of concepts and theories

Potential Prompts:
Can you expand on your answer for me?
Can you give me an example of what you mean?
Can you give me a view of scientific knowledge that you think is wrong?

2. Scientific method will eventually let people learn the real truth about the natural world and how it works.

Potential Prompts:
Can you expand on your answer for me?
Can you give me an example of what you mean?
Can you give me a view that you think is wrong?

3. Theories and models are products of the human mind and may or may not accurately represent reality.

Potential Prompts:
Can you expand on your answer for me?
Can you give me an example of what you mean?
Can you give me a view that you think is wrong?

4. The ultimate goal of Science is to gather all the facts about natural phenomena

Potential Prompts:
Can you expand on your answer for me?
Can you give me an example of what you mean?
Can you give me a view that you think is wrong?

Example 3: Potential Final Interview Question Format

To assess perceived changes in student views of the nature of science and their personal epistemology as related to laboratory instruction and corresponding attributes. Participants are asked to elaborate and explain responses from other measures (i.e. CCI, NSKS, EBAPS, and laboratory questionnaire) and the first interview.

Participants are asked:

1. Have your views or level of understanding of the nature of science changed in any way from your views at the start of the semester?
    - ♦ If so, how?

2. How, if at all, has the laboratory experience influenced your views on the nature of science?

3. If response to #2 is negative, yet views have changed:
    - ♦ To what do you attribute the change in your views or level of understanding?

4. If response to #1 and #2 are negative:
    - ♦ Why do you think your views or level of understanding of the nature of science has been stable?

5. Consider the laboratory instructional experience, the laboratory notebooks, and other instructional sessions.
    - ♦ Do you think any of these components of the laboratory influenced your views of the nature of science? personal epistemology?
    - ♦ If so, what components? How? And Why?

6. Can you recall examples or specific instances that you feel had an influence on your understanding? Explain.

Appendix G: Sample- Laboratory Work

Example 1

Data Analysis: Accuracy, Precision, Uncertainty, Significant Figures, Error, and Data Collection

General Procedure

The following activities will allow you to apply the principles of accuracy, precision, error, significant figures, and uncertainty to a practical situation that will familiarize you with linear, volume, and mass measurements. The exercises will help you develop the dexterity required to accurately use measurement tools.

Methods

A. Visit the applicable web sites for this topic located on Blackboard under "Web Resources", read over each and download as needed. Record all observations, measurements, calculations, etc. in lab notebook.

B. **Mass Measurements** – Record letter of bars. Use an electronic balance to weigh three bars. Refer to electronic balance web site. Weigh the three bars and record the mass of each to the nearest ± 0.01 g. .

C. **Length Measurements** – Use a metric ruler to measure the length, width, and height of the three bars. Measure and record the value of each to the nearest ± 0.1 cm. Convert all values to inches.

D. **Liquid Volume Measurements-1 –** Fill a 10.0 mL graduated cylinder ~ ¾ full with water. Record the volume. Pour the water into a pre-weighed small beaker (± 0.01 g). Mass the beaker and water and record. Repeat 3 more times with fresh water, record the volume and re-mass the beaker each trial.

E. **Liquid Volume Measurements-2 –** Fill a 50.00 ml ¾ full (~12.50 mL). Deliver the water12.50 mL of water. Deliver the water into a pre-weighed small beaker (± 0.01 g). Mass the beaker and water and record. Repeat 3 more times with fresh water and re-mass the beaker each trial.

F. **Density of a Solid -** Using your results from B and C determine the density of each bar with metric units and English units. Collect the class density data for those lab groups that used the same metal as you. The accepted density will be posted on BB after all lab sections have performed the lab.

G. **Predicting unit divisions of metric rulers and determine instrument precision**

H. **Graphing Analysis - Find the Relationship: An Exercise in Graphing Analysis -** In several laboratory investigations you do this year, a primary purpose will be to find the mathematical relationship between two variables. For example, you might want to know the relationship between the pressure exerted by a gas and its temperature. In one experiment you do, you will be asked to determine the relationship between the volume of a confined gas and the pressure it exerts. A very important method for determining mathematical relationships in laboratory science makes use of graphical methods.

I. **Physical Properties of Matter with *Vernier* – MBL**

Example 2

Starting Vernier - Logger *Pro* and Preparing to Collect Data

- Locate the Logger *Pro* icon on your computer and double-click on it, or use the Start menu (Windows 95/98/2000/NT).
- An important feature of LabPro is its ability to detect auto-ID sensors, and automatically set up an experiment. The computer will attempt to communicate with LabPro.
- Select the correct port and click Scan.
- If you have connected a Stainless-Steel Temperature Probe and the computer has detected the LabPro interface, you will see the following screen, which shows a graph of Temperature *vs*. Time.
- Notice how the program automatically identified the temperature probe (an auto-ID sensor).
- The current temperature reading is displayed in the status bar at the bottom of the screen.
- The default data collection mode is time graph. In this example, you have a Temperature Probe, reading in Celsius, and collecting data as a function of time for 120 seconds.
- If you now disconnect the Temperature Probe, connect a different auto-ID sensor, and choose New from the File menu, Logger *Pro* will set up a new experiment for the new sensor.

Auto-ID Sensor Activity

- Plug the Stainless-Steel Temperature Probe into channel CH 1 on LabPro, and lay the temperature probe on the tabletop.
- Start the Logger *Pro* software. Logger *Pro* will detect the auto-ID sensor, set the data collection parameters, and computer display.
- In this case, collection parameters are 1.0 sample per second and 120 samples.
- The program displays a graph and data table on the computer.
- The vertical axis of the graph will have temperature scaled from 0 to 100°C.
- The horizontal axis will have time scaled from 0 to 120 seconds change to the appropriate scale as needed.
- You are ready to collect data; Click Collect to begin data collection.
- Wait about 10 seconds and place the Temperature Probe into the solution.
- Allow Logger *Pro* to complete data collection.
- Notice that the sensor does not read the new temperature instantly; it takes a moment to respond.
- Now that the run is complete, pull down the Analyze menu and choose Examine.
- The cursor will become a vertical line. As you move the cursor across the screen, temperature and time values corresponding to the cursor position will be displayed. Move the cursor to the point when the probe was first placed in the solution.
- Record that time.
- Move the cursor to find the highest temperature, and record that time**.**

Classification of Chemicals Reactions& Mass-to-Mole Calculations

(Adapted from USF Tampa Campus Lab Manual – Lab Trek (1997))

Example 3

Part A. The Classification of Chemical Reactions

- Write and balance the chemical reaction for each performed
- Note any temperature changes (exothermic versus endothermic)
- Record all observations in your lab notebook

1. **Synthesis or Combination reaction**:

Obtain a short length (~1.5cm) of magnesium metal ribbon. Note & record its physical properties. Holding the ribbon with tongs over a watch glass, bring it into contact with a lighted match or portable burner flame. Hold the end of the Mg ribbon in the flame until it ignites. What do you observe? *Do not stare directly at the flame*. Has a chemical reaction occurred? How do you know? What is the name of the product?

2. **Decomposition reaction:**

2a. Demonstrated by instructor- Volcano

Obtain a small vial of ammonium dichromate from your instructor. Place the compound on a watch glass or in a beaker so that it forms a small, cone-shaped pile. Ignite the apex of the cone using the Bunsen burner flame. Withdraw the flame as soon as the material begins to burn. What do you observe? How do the physical properties of the reactants and products compare? What was the hissing sound? *CAUTION*: *do not touch the hot watch glass or beaker with your hands.* Where did all this heat come from?

2b. Elephant's Toothpaste

Perform in the sink with the graduated cylinder sitting in the center. Add a few drops of food coloring and ~ 2.0 mL of dish soap to the graduated cylinder. Carefully add ~15 mL of 30% Hydrogen Peroxide to the graduated cylinder. Carefully and slowly avoiding the sides of the graduated cylinder add ~2.4 g of the catalyst (KI or NaI, or MnO_2). What do you observe? How do the physical properties of the reactants and products compare? *CAUTION: very carefully touch the graduated cylinder with your hands.* Where did all this heat come from? Has a chemical reaction occurred? How do you know? What is the name of the product(s)?

Appendix H: Sample- Pre-Laboratory Activities

Example 1

The research and development section of a liquid refreshment factory on the planet of Molborg received an unlabeled box with unlabeled containers of one of their new potential products. In order to determine the identity of the substances in the unlabeled box the laboratory ran tests to determine the percent sugar concentration and density of the unlabeled unknown and compared the results to their known values of the new products.

a. Given the data below determine identify the unlabeled potential product of the unknown substances by comparing and contrasting the experimental data with the known data. Justify your choice mathematically by answering the questions and performing the necessary calculation on the following pages.

b. Consider the following: Calculate the means for the experimental values for each variable; Use the estimated uncertainty method to determine the range in the experimental values for both variables; carefully consider the entire data set and report the "best value" for the density and % sugar of the unknown substance. Identify the unknown substance from the list of known substances in the table. Comment on how/why you arrived at this choice.

Experimental Data			**Known Data**		
Unknown Samples	% Sugar	Density (g/mL)	Known Product	% Sugar	Density (g/mL)
1	12.23	1.038	Tropical OJ	12.18	1.044
2	12.13	1.040	Duck OJ	12.28	1.046
3	12.26	1.046	Hour OJ	12.21	1.042
4	12.18	1.044	Fresh OJ	12.03	1.038
AVG			XXXXXXXX	XXXXX	XXXXXXXX

Example 2

Differences in Values from Measurement - 1

(Adapted from Leach et al., 1998)

Two groups of chemical nutritionists have been asked to measure the mass of 100.0 cm^3 of nut oil. Each group takes nine samples of 100.0 cm^3 of the oil from a large container and weighs each sample. These are their results, after having sorted them into ascending order:

Mass of 100.0 cm^3 Peanut Oil (g)		
Trial	**Group A**	**Group B**
1	81.9	84.9
2	83.5	85.7
3	86.5	86.6
4	87.1	86.9
5	87.3	87.0
6	87.5	87.3
7	87.5	88.2
8	90.5	88.5
9	92.1	88.8
Average	87.1	87.1

1. What should Group A state as their result for the mass of 100.0 cm^3 of nut oil?
   Please write your answer in the box below

2. In the box below briefly explain your reasoning

Example 3-Pre-Laboratory –Questions – Quiz Questions

1) Using the scientific literature sources-handbooks listed in the background reading in the lab handout (located in the library) answer the following using the sources listed in the reading. **Do not use the Internet and properly cite all sources**
a. What is the melting point of naphthalene?
Source:
b. Identify synonym(s) for naphthalene
Source:
c. Describe the hazards-precautions (MSDS) of using naphthalene.
Source:

2) Based on the Law of Conservation of Mass; calculate how many grams of oxygen are needed in the following reaction, if 12.43 g of Magnesium was consumed & 34.54 g of MgO is produced: $Mg + O_2 \rightarrow MgO$ Explain your results

3) ___$AlCl_3(aq)$ + ___$NH_4OH(aq) \rightarrow$ ___$Al(OH)_3(s)$ + ___$NH_4Cl(aq)$

If 24.5 g of $AlCl_3$ are treated with excess NH_4OH, how many grams of NH_4Cl are produced? Assume 100% of the reactant is converted to product. **Show work, etc.**

4) The density of olive oil is 0.79 g/mL. What is the volume of 300.0 g? (D= M/V)
Show work and report this value to the correct number of significant figures with units

5) Complete the following conversion: **520 kg of chocolate into lb if 1 kg = 2.20 lb**.
Show all work and report this value to the correct number of significant figures with units

6) Identify the reactants to be used in the elements, compounds and mixture lab

7) Predict the products for the following double replacement reaction
$K_3PO_4 + BaCl_2 \rightarrow ? + ?$

8) Tin (II) Fluoride (SnF2), also known as stannous fluoride, is added to some dental products to help prevent cavities. How many grams of tin (II) fluoride can be made from 55.0 g of hydrogen fluoride, HF, if there is an excess of tin (Sn).
Sn(s) + 2HF(aq) → SnF2 (aq) + H2

9) ·A blacksmith dropped a 2.00 kg piece of steel (iron, sFe = 0.449 J/g water, which was initially at 25.0°C, and waited until the steel temperature was the same as the final temperature of water (88.6°C). Determine the mass of water if the initial temperature of was 800.0 K. (heat capacity of water is 4.1814 J/g metal)

10) Given the following incomplete redox reaction, balance this equation in ACID solution with the set of smallest whole number coefficients:
MnO_4^{-1} + Br^{-1} (aq) ----> Mn^{2+} (aq) + Br_2 (g)

11) Two clear solutions are poured together. A pale blue, chalky material is formed which sinks to the bottom of the test tube. The test tube becomes cold. The substances in the blue material cannot be separated from each other by physical means. What type of change is described in the paragraph? Explain

12) A blue crystalline material is heated strongly in a test tube. A clear liquid condenses around the mouth of the tube and the crystals gradually lose their blue color and become white powder. Every gram of blue crystal produces 0.36 g of clear liquid and 0.64 g of colorless powder. The same weight-mass relationships are observed for samples of the crystals taken from many different sources. These observations would be consistent with a hypothesis that the blue crystals are? Explain

Appendix I: Keeping a Laboratory Notebook

General Information:

Why use a laboratory notebook? "A laboratory notebook is one of a scientist's most valuable tools. It contains the permanent written record of the researcher's mental and physical activities for experiment and observation, to the ultimate understanding of physical phenomena. The act of writing in the notebook causes the scientist to stop and think about what is being done in the laboratory. It is in this way an essential part of doing good science." *from Writing the Laboratory Notebook by Howard M. Kanare; American Chemical Society 1985*

- ***Always write in the lab notebook in PEN with permanent blue or black ink.***
- Do not write in pencil or erasable ink. Do not write with felt tip or colorful gel pens.
- ***Use a single line or X to cross out a mistake, and write the correct word or number next to it. Initial the cross-out.*** Example: **~~misttake (~~mistake)** ***FB***
- Do not use white out or scribble out mistakes.
- ***You must practice*** **real-time** ***entry of data, observations, and steps in the lab. In other words, record data directly into your notebook.***
- ***Ask the instructor to review and sign your data pages BEFORE you leave lab each day that you collect data.***
- Do not write on scratch paper, and copy into the notebook later. This could result in the loss or confusion of data and makes the validity of your data suspect. Lab reports will NOT be accepted and you will receive no credit for an experiment if you do not practice real-time entry.
- Organize data tables before you begin collecting data.
- Clearly label and organize each section of your report.
- Clearly label all data tables, calculations, and graphs.
- Keep the *Table of Contents* up-to-date.
- ***Remove*** **only** ***pages marked*** **COPY** ***from your notebook.***
- Do not remove the original pages, even if you mess them up. Removing pages makes your data suspect.
- Write lab reports for an upper level college science major audience that has education with chemistry in it.
- Write for an audience that you assume has not read the lab handout but has a solid knowledge base in science
- ***Neatness and legibility are important. We must be able to easily read what you write. Therefore, leave space between the components.***

❖ **Subject to change(s) at the discretion of the instructor.**

Keeping a Laboratory Notebook

The laboratory notebook is the "ticket" to lab along with proper dress and out of lab. Without the laboratory notebook you will not be admitted to lab and a grade of zero for that lab will be recorded. Have laboratory notebook pages signed prior to leaving lab.

Your carbon-copy notebook should include the following sections:

- **Table of Contents** – Using the inside front cover of the lab notebook fill out after every lab activity.
- **Lab Title** - ***Heading:*** Fill in all the heading boxes on the first page of the Lab Report Section. Subsequent pages should include your name and title of activity
- **Purpose with Predictions** - Brief description of experimental goal(s) and any necessary predictions (hypothesis). Some predictions will be made prior and some after collection of data
- **Procedure -** do not copy the procedure instead properly cite the lab manual, create a modified flow-chart of the procedure (unless told otherwise) and list any modifications-changes, waste disposal and suggestions made to the procedure identified in class (on board/discussion).
- **Notes** taken in pre-lab discussion
- **Raw Data** / **Observations -** This section is a record of what you do and observe, *as you perform the experiment.*
    1. Quantitative data (numerical measurements) must be recorded with *units* in appropriate tables.
    2. Qualitative data (observations) – colors, textures, evolution of gases, precipitations, etc. – should be recorded here as well.
    3. ***All data taken in lab must be recorded in pen directly in the lab notebook.*** Include titles, heading, units *etc*., on your original tables and any reorganized tables.
- **Data Analysis - Calculations/ Results**
    1. Calculations, tables, graphs, and qualitative verbal descriptions of outcomes.
    2. All calculations must be shown with original formulas and full solutions. Keep track of units at all steps. Label all calculations, tables and graphs. Calculate % error where appropriate
    3. Summarize results in a table(s).
- **Conclusion:** Include your overall scientific interpretations of the lab results and incorporate in paragraph format any analysis or integrated questions.

Notes:

If you will be preparing a Basic Laboratory Report (BLR) or Formal Lab Report (FLR) for a particular lab then students need to show only sample calculations of each type of calculation and eliminate the conclusion.

Appendix J: Sample Pre-laboratory Discussion Activities

Tube Activity

Example1 : Tube Activity

Possible scenario

1. Present the tube in front of students
2. Ask students to carefully observe and record all patterns of the ropes on the tube
3. Pulls on the end of the rope and wait for a while
4. Pull on rope ends clockwise at one time
5. Pull on rope ends across the tube at another
6. Repeat pulling the ropes until students say they understand or get enough data of the patterns of the rope.
7. Tell students they have to answer the question “What does inside of the tube look like?” “What makes the ropes move like that?”
8. Ask students to make their tubes based on observations that they made, which behave as the same way as yours.
9. Ask students to present their tubes
10. Conduct a debriefing for NOS.

- ♦ After presentations, ask students if they can see the inside of the tube that you showed students to address the distinction between observation and inference.
- ♦ You can explicitly explain how observation is different from inference. As examples of inferential entities, you can provide students with the structure of the earth, gravity, and the structure of the atom.
- ♦ To address the importance of observations, you can ask students “Is any inference OK in science?”, “How can we know which inference is better?”, “To make a better inference, what would you do?”
- ♦ When students had different models of the tube, you can discuss the notion that scientists can interpret the same data in different ways (associating with human subjectivity).
- ♦ In addition, when students’ different tubes behaved in the same way as yours, it should be addressed that it is very difficult to determine which tube is better. In other words, we hardly say one is right and the other is wrong. Make explicit to students that what they have done is very similar to what scientists do by providing students with real examples in science such as the structure of the atom.

Example 2: Fruit (Density) Activity

Possible Scenario

1. Place an aquarium or large clear container filled with water.

2. Ask students to predict what will happen when a banana (fruit) is put into the aquarium. “Is it going to sink or float?”

3. Have students make their prediction and explain why.

4. Place the banana into the aquarium and ask students to make a careful observation.

5. Show students different banana and ask them to make a prediction what will happen if when you try different bananas in size and in freshness.

6. Place the different bananas into the aquarium and ask students to make a careful observation.

7. Ask students “What’s going to happen if I peel off this banana? Is it going to sink or float?” “Do you think this banana will behave in the same way as before?”

8. Place the banana into the aquarium and ask students to make a careful observation.

9. Ask students why or why not bananas behave differently.

10. Ask students to come up with a question to investigate and how they can test their explanation for bananas’ different behaviors.

11. When sharing students’ work, ask students “What data do you have to support your conclusion?” to discuss the consistency between data and a conclusion. It is also important to address the difference between data and evidence. Explain that data are the same as observations, but scientists can take observations as evidence in favor of their explanations. As a result, the same data can be taken as evidence for two incomparable explanations.

Example 3: Activity Series of Metals PowerPoint

Slide 1
Another qualitative investigation

Slide 2
Qualitative – What
Quantitative – How much

Slide 3
Experimental Objective

- Determine the relative reactivity of

Copper, Cu	Tin, Sn	Calcium, Ca	Magnesium, Mg
Zinc, Zn	Silver, Ag	Hydrogen gas, H_2	

Slide 4
Reactivity

- Metals and hydrogen gas can be ***oxidized*** (lose electrons)
- Something must be ***reduced*** (gain electrons)

○ Water
○ Acid
○ Metal cation

Slide 5
Reactivity

- Metals and hydrogen gas can be ***oxidized*** (lose electrons)

$Ca \rightarrow Ca^{2+} + 2e^-$
$H_2 \rightarrow 2H^+ + 2e^-$

- Oxidizing agents are ***reduced*** (gain electrons)

○ Water $2H_2O + 2e^- \dashrightarrow H_{2(g)} + 2OH^-$
○ Acid $2H^+ + 2e^- \dashrightarrow H_{2(g)}$
○ Metal cation $Cu^{2+} + 2e^- \rightarrow Cu$

Slide 6
Relative Reactivity
Cu, Sn, Ca, Mg, Zn, Ag, H_2

- What metals are oxidized by water?

These are the most reactive

- What metals are oxidized by acid?

These are more reactive than H_2.

- What metals are oxidized by what cations?

A metal can be oxidized by the cation of a less reactive metal.

Slide 7
Oxidation by water

- Metals in large test tubes
- Deionized water
- Observe
- Record
- Conclude *The most reactive metals are oxidized by water.*
  $2Na + 2H_2O \rightarrow 2NaOH + H_2$

Slide 8
Oxidation by acids

- Metals in small test tubes
- 6 M HCl
- Observe - Record
- Conclude *Metals oxidized by an acid are more reactive than* H_2*.*

$Ni + 2H^+ \rightarrow Ni^{2+} + H_{2(g)}$

Slide 9
Oxidation by metal cations

- Metal cation solutions in small test tubes

○Stock bottle back of lab
○Silver Nitrate - dropper bottle (Avoid staining skin)

- 6 x 4 wellpate for reactions
- Observe - Record
- Conclude *A metal is oxidized by the cation of a less reactive metal.*

$Ni + Cu^{2+} \rightarrow Ni^{2+} + Cu$

Slide 10
Data Analysis

- Rank in order of reactivity (least to most)

Ca, Cu, Mg, Sn, Zn, Ag, H_2

- Write net ionic equations to represent all reactions

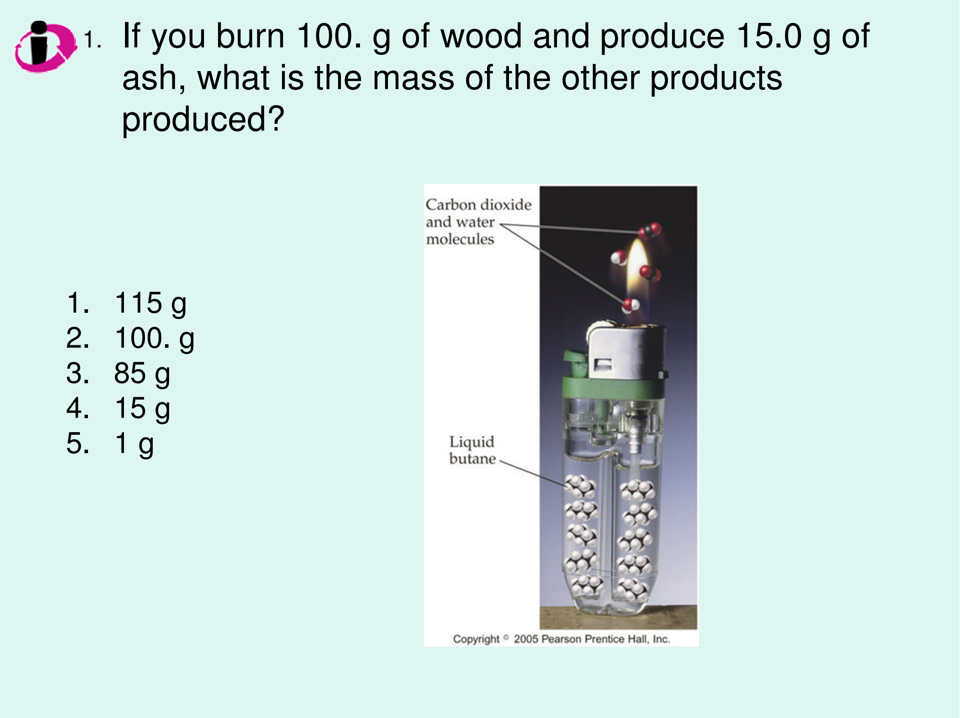
Patterns in chemistry

Slide 11
Waste Handling

- Transfer all reaction liquid into large individual waste beaker using wash bottle
- Transfer waste to designated liquid waste container
- Wash reaction vessels with soap and water – rinse with deionized water

Appendix J (Continued)

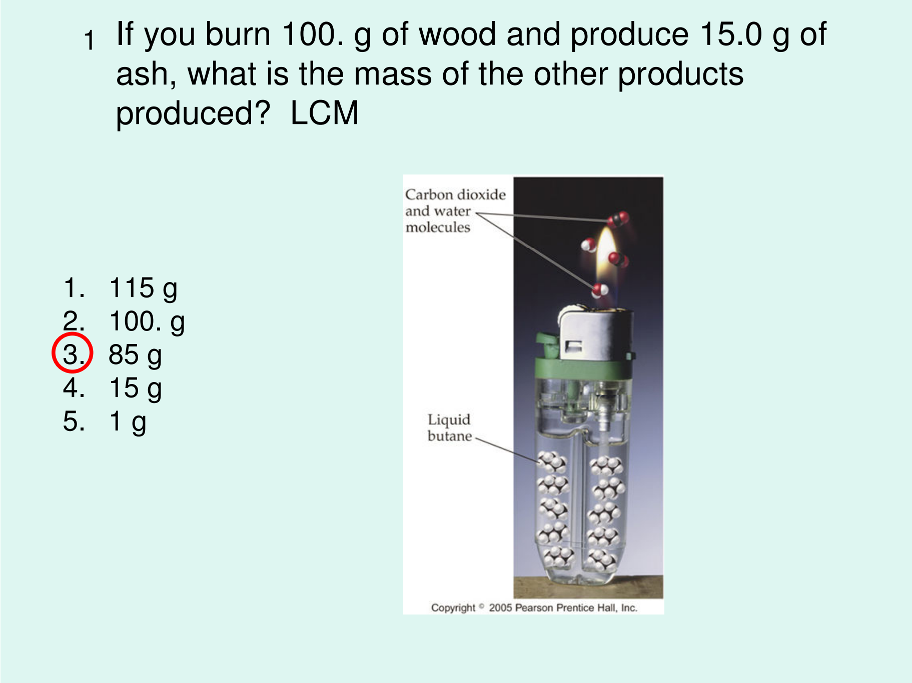
Example 4: PRS PowerPoint Slides-Questions



1. If you burn 100. g of wood and produce 15.0 g of ash, what is the mass of the other products produced?

1. 115 g
2. 100. g
3. 85 g
4. 15 g
5. 1 g

Copyright © 2005 Pearson Prentice Hall, Inc.



1 If you burn 100. g of wood and produce 15.0 g of ash, what is the mass of the other products produced? LCM

1. 115 g
2. 100. g
[✓ 3.] 85 g
4. 15 g
5. 1 g

Copyright © 2005 Pearson Prentice Hall, Inc.

Appendix K: General Overview of Laboratory Reports

Important Reminders:

- Due no later than posted date on the lab schedule or will be considered late
- title page: related title, date, student(s) name, class
- typed, 12 point font, Arial, Times New Roman, Times, Tahoma or Courier,
- 1 inch margins, 1.5 - double spaced within paragraphs, prefer blocked margins
- 3 prong paper folder

Presentation - Report:

- Includes criteria expected to be reported in a technical paper or scientific journal
- Assume that the reader of your report knows a little something about chemistry and your topic or wants to know for their research. You are the expert.
- Correct format for graphs, tables, drawings and discussion of qualitative data
- Report is written in scientific style: clear, to the point, past tense, and **not written** in first person
- Report is grammatically correct: spelling, subject-verb agreement, complete sentences & in past tense. Avoid first person (I, we…..)
- Avoid discussing how to do the calculation, just show the calculation and discuss its significance.
- Use metric units

Guidelines for a Basic Lab Report (*BLR)

General Information:

- Typed Report with separate title page
- Body of report ranges from 3-7 pages
- 1.5 spacing and 1 inch margins

Components:

- Title page
- Brief **introduction** of the theory/concepts/basic equations behind experiment (~ 1pg)
- **Purpose – Predictions** - Brief description of experimental goal(s) and any necessary predictions (hypothesis) that you had to make in lab with any class data
- **Data Analysis / Observations**
  1. Quantitative data (numerical measurements) must be recorded with *units* in appropriate tables.
  2. Qualitative data (observations) – colors, textures, evolution of gases, precipitations, etc. – should be recorded here as well. Chemical Reactions must be shown if applicable
  3. Create/Copy needed graphs (properly labeled) or other visual representations of data using Microsoft Excel (graphs, diagrams, pictures…) or other software program. Include class data (as needed)
- **Calculations/ Results**
  1. Sample(s) of all calculations must be shown with original formulas and full solutions. Keep track of units at all steps. Label all calculations, tables and graphs. Calculate % error where appropriate
  2. Summarize all results in a table.
- **Conclusion:** Include your overall scientific interpretations of the lab results and incorporate answers to analysis questions within body of writing (paragraph)
- **References – Properly cited**
- **Lab Notebook pages attached with original graphs(as required)**

FORMAL LAB REPORTS-OVERVIEW

- **A scientific paper-report at a minimum includes the following parts:**

  - **Title Page –** should tell the reader what kind of work is being reported; title should be creative. Describes lab content concisely, adequately and appropriately

  - **Abstract –** summarizes 4 essential aspects of the report: the purpose of the experiment-research, key findings, significance and major conclusion. T**he reader should be able to determine the major conceptual-theoretical focus of the research/experiment. Should be one single spaced paragraph of 150-200 word. Composed after paper is written, but placed at beginning**

  - **Introduction -** introductory/thesis paragraph – functions:
    1. place it in the context of what is already known about the topic, in other words discuss the concepts
    2. Explain the theory, reactions, etc. behind the experiment
    3. Presents the question(s) being asked or studied; state the purpose, variables, etc.

  - **Procedure – Briefly summarize the procedure in your own words. If the lab procedure was qualitative in nature then include typed flow charts summarizing the procedure. Reference and list any changes made to procedure. Cite the lab manual Usually no more than one-two pages**

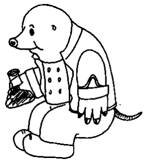
  - **Results – Data Analysis–** Components:
    1. Presents original experimental data in an accurate and organized fashion.
    2. Several well organized **paragraphs describing qualitative observations-data**. Presented clearly, without comment, bias or interpretation
    3. Generate new graphs (properly labeled) or other visual representations (flow charts) of data using Microsoft Excel (graphs, diagrams, pictures…). **Do not post raw data** here place in appendix
    4. Create easy to read **data tables** including all of your **qualitative and quantitative data.**
    5. Includes labels and/or units for all data
    6. Show important sample math calculations
    7. Always calculate % error if dealing with qualitative data and accepted values
    8. Usually dominated by calculations, tables, figures, graphs, and observations
    9. Graphics need to clear, easily read and properly labeled

- **Discussion-Conclusion** – this is where you will analyze and interpret the results of your experiment and point out their chemical significance. Consider the following:

  1. What do the results indicate clearly?
  2. What have you determined?
  3. Explain what you know with certainty based on your results and theory; draw conclusions
  4. What is the significance of the results?
  5. What ambiguities exist?
  6. What questions might one raise?
  7. Find logical explanations for problems in the experimental data.
  8. Open with effective comparison of results and hypothesis
  9. Restate your question, purpose, variables, etc….
  10. Discuss the specific data, chemical reactions, including math results with theory values. Incorporate answers to any discussion questions if applicable.
  11. State whether your results did or did not confirm your hypothesis and support or negate your hypothesis from your results.
  12. Remember to number figures, tables, and calculations throughout the paper. Refer to figures, tables, and calculations as you discuss your results.
  13. Provides sufficient and logical explanation to support results and conclusion.
  14. Directly addresses what has been learned in the lab
  15. Considers the chemistry (concepts) involved. How do your results fit in with what you know?
  16. Sufficiently addresses other issues pertinent to the lab including sources of error. Identify weaknesses in your experimental design. Describe how these imperfections may have affected your results.
  17. List any problems that arose during the experiment itself (Unforeseen difficulties with the procedure may affect the data and need to be described)
  18. Demonstrate clear and thoughtful scientific inquiry
  19. Draw a Conclusion

- **Appendix**

1. Lab Notebook pages: Original raw data graphs, tables, etc. should be included in this section. **Generate new flow charts, graphs – tables for results section of paper.**



Appendix L: Consent Form

UNIVERSITY OF SOUTH FLORIDA

INFORMED CONSENT FORM

The following information is being presented to help you decide whether or not you want to be a part of a minimal risk research study. Please read carefully. If you do not understand anything, please contact the principal researcher, Linda S. Keen-Rocha, who can be contacted at lrocha@mail.usf.edu or 727-USF-4785.

Title of Study:
Personal Epistemological Growth in a College Chemistry Laboratory Environment

Principal Investigator:
Linda S. Keen-Rocha

Study Location(s):
USF College of Arts and Sciences- St Petersburg and College of Education – Tampa

Purpose of the Study:

It remains to be determined whether certain effective instructional practices are linked to the development of specific epistemological and NOS (nature of science) beliefs. The major intent of this study is to develop an understanding of the relation between students' images of science, personal epistemological beliefs and laboratory classroom instructional practices.

Plan of Study-Procedures:

Participation in this semester study will require approximately 90-360 minutes of your time over the semester. Your involvement in the process will require you to do the following:

- Participate in answering conceptual chemistry questions with a chemistry concept knowledge assessment instrument – Chemical Concepts Inventory - CCI (15-20 minutes)
- Participate in assessing your images of science with the Nature of Science Knowledge Scale (NSKS) assessment instrument (15-20 minutes)
- Participate in the Epistemological Beliefs Assessment for Physical Sciences (EBAPS) Instrument that requires you to reflect on your views about the nature of knowledge and learning in the physical sciences (e.g., chemistry, physics) (20-30 minutes)

- Participate in an initial or final interview or both which will be audio taped (30-90 minutes)
- Participate in evaluating laboratory instructional techniques with an assessment instrument (15 minutes per laboratory activity)

Benefits of Being a Part of this Research Study

- The direct benefits of your participation in this study will help us better understand the effectiveness of specific pedagogical laboratory techniques, improve student learning opportunities and help us to better understand how students' images of science and personal epistemological beliefs influence their learning science. These learning experiences may help the student assess their own perceptions of themselves as learners. Students will receive extra credit points on their midterm and final exam for their level of participation. Students not participating may choose to write a scientific paper(s) to receive the extra credit.

Risks of Being a Part of this Research Study

- No significant risks or discomforts are associated with your participation in this study. If you agree to participate in the assessments, survey-questionnaires, and possible interview(s) you will be asked to reflect on if/how what you learned.
- If you agree to the reflection/responses review, a researcher will comb through your writings to look for themes.

Confidentiality of Your Records

- ♦ Any information obtained during this study which could identify you will be kept strictly confidential. Your privacy and research records will be kept confidential to the extent of the law.
- ♦ However, certain people may need to see your study records. By law anyone who looks at your records must be keep them confidential. The only people who will be allowed to see these records are the study staff and people who make sure that we are doing the study in the right way. They also make sure that we protect your rights and safety:
  - o The USF Institutional Review Board (IRB) and staff
  - o The United States Department of Health and Human Services (DHHS)
- ♦ The data will be stored in a locked cabinet in the investigator's office and will only be seen by the investigator during the study and for three years after the study is complete. The information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported as aggregated data. The audiotapes will be erased after transcription. Faculty from the College of Arts and Science and College of Education who are involved in this research will compile these anonymous data.

Volunteering to Be Part of this Research Study

- Participation in the evaluation study of the program is completely voluntary. You are free to participate in this research study or to withdraw at any time.
- If you choose not to participate, or if you withdraw, there will be no penalty or loss of benefits that you are entitled to through the date you exit the study nor will your academic status be affected in any way.

Questions and Contacts

- If you have any questions about this research study, contact Linda Keen-Rocha at lrocha@mail.usf.edu or 727-553-4785.
- If you have questions about your rights as a person who is taking part in a study, call USF Research Compliance at (813) 974-5638.

Investigator Statement

I have carefully explained to the subject the nature of the above protocol. I hereby certify that to the best of my knowledge the subject signing this consent form understands the nature, demands, risks and benefits involved in participating in this study.

Name and Phone number of investigator:

Linda S. Keen-Rocha, MA, Doctoral Candidate, Principal Investigator
Office: (727) USF-4785

Consent, Right to Receive a Copy:

I agree that:

- I have fully read this informed consent form describing a research project.
- I have had the opportunity to question one of the persons in charge of this research and have received satisfactory answers.
- I understand that I am being asked to participate in research. I understand the risks and benefits, and I freely give my consent to participate in the research project outlined in this form, under the conditions indicated in it.

You are voluntarily making a decision whether or not to participate in this research study. Your signature certifies that you have decided to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

___________ **Check and initial if you agree to be audio taped during the interview(s).**

Signature of Participant: ____
Signature of Research Participant Month and Year

____
Print Name

Demographics:

1) Course Section-Study ID # __________________________________

2) Student U#:___________________________

3) sex: __________

4) college rank: no college rank freshman sophomore junior senior

5) semesters of high school chemistry: 0 1 2 3 over 3

6) semesters of college level chemistry completed: 0 1 2 3 4 5 6 7 8

7) College Major: ____

Name and Phone number of investigator:
Linda S. Keen-Rocha, MA, Doctoral Candidate, Principal Investigator
Office: (727) USF-4785

Appendix M: Chemical Concepts Inventory Key
(American Chemical Society Division of Chemical Education, 2001)

1. d
   (Note: Some instructors who teach that a change in internal energy reflects a change in mass prefer c)
2. d
3. c
4. d
5. d
6. e
7. b
8. d
9. c
10. c
11. a
12. c
13. b
14. c
15. b
16. a
17. b
18. c
19. b
20. c
21. b
22. c

Appendix N: EBAPS Scoring Scheme

EBAPS Scoring with Excel Template

1) In the scoring template the q01, q02, q03...q30 columns are for students' raw answers to each of the 30 questions, with A = 1, B = 2, C = 3, D = 4, E = 5.

2) Get your data into a spreadsheet in that form, with each row corresponding to a different student, and the template will do the rest.

3) The q_01, q_02,...,q_30 columns are the scaled scores, on a sale of 0 to 4, with 4 = most sophisticated.

4) The axis_1, axis_2, etc. columns are students' subscale scores (again on a scale of 0 to 4) for each of the 5 subscales, with

Axis 1 = Structure of knowledge

Axis 2 = Nature of learning

Axis 3 = Real-life applicability

Axis 4 = Evolving knowledge

Axis 5 = Source of ability to learn

Appendix N (Continued)

EBAPS Logistics and Scoring

Color Coding	Subscales
Red	Structure of knowledge
Orange	Nature of learning
Green	Real-life applicability
Blue	Evolving knowledge
Purple	Source of ability to learn
Note: Black indicates the item doesn't belong to a subscale.	
Items 19 and 28 belong to two subscales.	

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

Part 1

1. Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.
A = 4, B = 3, C = 1, D = 0.5, E = 0

2. When it comes to understanding physics or chemistry, remembering facts isn't very important.
A = 0, B = 1.5, C = 2.5, D = 3.5, E = 4

3. Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year.
A = 0, B = 1, C = 2, D = 3.5, E = 4

4. When it comes to science, most students either learn things quickly, or not at all.
A = 4, B = 3, C = 2, D = 1, E = 0

5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.
A = 0, B = 1, C = 2, D = 3, E = 4

6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are likely to be valid. Everything's up in the air!
A = 4, B = 4, C = 2, D = 1, E = 0

7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much she already knows.
A = 4, B = 4, C = 2, D = 1, E = 0

8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything.
A = 4, B = 2.5, C = 1.5, D = 0.5, E = 0

9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class.
A = 0, B = 1, C = 2, D = 3, E = 4

10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.
A = 4, B = 3, C = 2, D = 1, E = 0

11. When handing in a physics or chemistry test, you can generally have a sense of how well you did even before talking about it with other students.
A = 0, B = 1, C = 2, D = 3, E = 4

12. When learning science, people can understand the material better if they relate it to their own ideas.
A = 0, B = 0.5, C = 1, D = 3, E = 4

13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.
A = 4, B = 3, C = 1, D = 0.5, E = 0

14. Understanding science is really important for people who design rockets, but not important for politicians.
A = 4, B = 3, C = 2, D = 1, E = 0

15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems.
A = 4, B = 3, C = 2, D = 1, E = 0

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.
A = 0, B = 1, C = 2, D = 3, E = 4

17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.
A = 4, B = 3, C = 1.5, D = 0.5, E = 0

Part 2

DIRECTIONS: Multiple choice. On the answer sheet, fill in the answer that best fits your view.

18. If someone is trying to learn physics, is the following a good kind of question to think about?
"Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?"
(a) Yes, definitely. It's one of the best kinds of questions to study.
(b) Yes, to some extent. But other kinds of questions are equally good.
(c) Yes, a little. This kind of question is helpful, but other kinds of questions are more helpful.
(d) Not really. This kind of question isn't that great for learning the main ideas.
(e) No, definitely not. This kind of question isn't helpful at all.
A = 4, B = 3.5, C = 1.5, D = 0.5, E = 0

19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to any set of rules, no matter how complicated and complete that set of rules is.
In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.
(a) Although things behave in accordance with rules, those rules are often complicated, hard to apply, or not fully known.
(b) Some things just don't behave according to a consistent set of rules.
(c) Usually it's because the rules are complicated, hard to apply, or unknown; but sometimes it's because the thing doesn't follow rules.
(d) About half the time, it's because the rules are complicated, hard to apply, or unknown; and half the time, it's because the thing doesn't follow rules.
(e) Usually it's because the thing doesn't follow rules; but sometimes it's because the rules are complicated, hard to apply, or unknown.
A = 4, B = 0, C = 3, D = 2, E = 1

20. In physics and chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.
A = 4, B = 0, C = 3, D = 2, E = 1
(a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.
(b) The major formulas are kind of "separate" from the main concepts, since concepts are ideas, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.
(c) Mostly (a), but a little (b).
(d) About half (a) and half (b).
(e) Mostly (b), but a little (a).

21. To be successful at most things in life... A = 4, B = 3, C = 2, D = 1, E = 0

(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

22. To be successful at science... A = 4, B = 4, C = 2, D = 1, E = 0

(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

23. Of the following test formats, which is best for measuring how well students understand the material in physics and chemistry? Please read each choice before picking one. A = 0, B = 4, C = 1, D = 2, E = 3

(a) A large collection of short-answer or multiple choice questions, each of which covers one specific fact or concept.
(b) A small number of longer questions and problems, each of which covers several facts and concepts.
(c) Compromise between (a) and (b), but leaning more towards (a).
(d) Compromise between (a) and (b), favoring both equally.
(e) Compromise between (a) and (b), but leaning more towards (b).

Part 3

DIRECTIONS: In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other

24.
Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate. A = 4, B = 4, C = 2, D = 1, E = 0
Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.
With whom do you agree? Read all the choices before circling one.
(a) I agree almost entirely with Brandon.
(b) Although I agree more with Brandon, I think Jamal makes some good points.
(c) I agree (or disagree) equally with Jamal and Brandon.
(d) Although I agree more with Jamal, I think Brandon makes some good points.
(e) I agree almost entirely with Jamal.

25.

Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.
Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.
Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

(a) I agree almost entirely with Anna.
(b) Although I agree more with Anna, I think Emily makes some good points.
(c) I agree (or disagree) equally with Anna and Emily.
(d) Although I agree more with Emily, I think Anna makes some good points.
(e) I agree almost entirely with Emily.
A = 0, B = 1, C = 2, D = 4, E = 4

26.

Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.
Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.

(a) I agree almost entirely with Justin.
(b) Although I agree more with Justin, I think Dave makes some good points.
(c) I agree (or disagree) equally with Justin and Dave.
(d) Although I agree more with Dave, I think Justin makes some good points.
(e) I agree almost entirely with Dave.
A = 4, B = 4, C = 2, D = 1, E = 0

27.

Julia: I like the way science explains how things I see in the real world.
Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.
Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.

(a) I agree almost entirely with Julia.
(b) I agree more with Julia, but I think Carla makes some good points.
(c) I agree (or disagree) equally with Carla and Julia.
(d) I agree more with Carla, but I think Julia makes some good points.
(e) I agree almost entirely with Carla.
A = 4, B = 4, C = 2, D = 1, E = 0

28.
Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?
Maria: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.
Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

(a) I agree almost entirely with Leticia.
(b) I agree more with Leticia, but I think Maria makes some good points.
(c) I agree (or disagree) equally with Maria and Leticia.
(d) I agree more with Maria, but I think Leticia makes some good points.
(e) I agree almost entirely with Maria.
A = 0, B = 1, C = 2, D = 3, E = 4

29.
Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth.
Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

(a) I agree almost entirely with Jose.
(b) Although I agree more with Jose, I think Miguel makes some good points.
(c) I agree (or disagree) equally with Miguel and Jose.
(d) Although I agree more with Miguel, I think Jose makes some good points.
(e) I agree almost entirely with Miguel.
A = 0, B = 2, C = 4, D = 2, E = 0

30.
Jessica and Mia are working on a homework assignment together...
Jessica: O.K., we just got problem #1. I think we should go on to problem #2.
Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.
Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer.
Mia: No, I think it's possible to get the right answer without really understanding what it means.

(a) I agree almost entirely with Jessica.
(b) I agree more with Jessica, but I think Mia makes some good points.
(c) I agree (or disagree) equally with Mia and Jessica.
(d) I agree more with Mia, but I think Jessica makes some good points.
(e) I agree almost entirely with Mia.
A = 0, B = 1, C = 2, D = 4, E = 4

Appendix O: NSKS Scoring Procedures

Scale	Points	Positive Items
(1) Strongly Agree	5	2, 3, 4, 5, 6, 8
(2) Agree	4	12, 16, 17, 20, 22, 26
(3) Neutral	3	28, 29, 30, 32, 35, 37
(4) Disagree	2	38, 42, 45, 46, 47, 48
(5) Strongly Disagree	1	

Scale	Points	Negative Items
(1) Strongly Agree	1	1, 7, 9, 10, 11,13, 14
(2) Agree	2	15, 18, 19, 21, 23, 24
(3) Neutral	3	25, 27, 31, 33, 34, 36
(4) Disagree	4	39, 40, 41, 43, 44
(5) Strongly Disagree	5	

NSKS Subscales	**Items**
Amoral	4, 5, 7, 8, 18, 21, 36, 48
Creative	1, 17, 20, 23, 28, 32, 34, 41
Development	16, 25, 26, 27, 31, 37, 42, 43
Parsimonious	2, 6, 14, 15, 29, 39, 40, 46
Testable	9, 11, 12, 13, 22, 33, 38, 45
Unified	3, 10, 19, 24, 30, 35, 44, 47
Subscale(s) Score	8 – 40 points
Overall Score	48 -240 points

NSKS Representative Placement Scale

Realist----------------------------------neutral---------------------------------Instrumentalist
(48) (unaccepted NOS view) (144) (accepted NOS view) (240)

Realist – absolute; theories are either true or false
Instrumentalist – subjective; theories are tools

Appendix P: CCI-EBAPS-NSKS Interview Participant - Scores

Descriptive Statistics of Interviewed Participants (N=20)

ID	CCI	EBAPS Pre	EBAPS Post	NSKS Pre	NSKS Post
1	72	2.70	3.13	143	155
2	76	2.35	2.55	144	153
3	81	2.38	2.97	138	148
4	67	2.70	2.62	138	149
5	86	1.88	2.08	144	151
6	63	2.37	3.12	149	151
7	63	2.32	2.77	143	152
8	72	2.83	3.22	147	145
9	45	2.53	2.60	147	155
10	72	2.05	3.45	141	153
11	58	2.80	2.98	143	149
12	63	2.63	2.78	138	150
13	49	2.63	2.48	146	144
14	65	2.48	3.02	132	142
15	76	2.98	3.12	140	145
16	77	2.85	3.55	143	148
17	65	2.50	2.45	136	142
18	76	2.63	2.77	143	148
19	67	2.52	2.87	140	152
20	58	2.65	2.80	138	146

About the Author

Linda S. Keen-Rocha received a bachelor's degree in Biological Science from the University of Maryland in 1985. She received a Master of Education degree in Biological Sciences from the University of South Florida in 1997. She has conducted research in optic nerve regeneration, population ecology, bridge corrosion, and other areas of science the past 20 years. She is entering her twenty-fifth year of teaching with 12 of those years in the high school setting teaching anatomy and physiology, chemistry, and other related courses. She has taught biology, anatomy, and chemistry courses at the college level for 13 years in Maryland and Florida. She has made presentations at regional and national meetings and has authored several publications related to science education laboratory instructional issues. Her primary research interests include: personal epistemological beliefs in science, nature of science, science pedagogy, self-regulated learning, learning styles, and technology in science education.