IDENTIFYING VARIATIONS IN THINKING ABOUT THE NATURE OF SCIENCE: A PHENOMENOGRAPHIC STUDY

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This work is dedicated to my amazing parents - John and Nora Keiser. All of my professional and personal successes can easily be traced back to their unconditional love and support.

ABSTRACT

It is hard to imagine how one can be scientifically literate without understanding what science is about. One of the central elements of science education reform efforts over the last twenty years has been ensuring that students have a deep understanding of the nature of science (Abd-El-Khalick et al., 2008). However, research suggests these efforts have done little to improve students' understanding of the nature of science (Sutherland et al., 2007). Much of the current research is aimed at evaluating the correctness of students' conceptions or classifying conceptions according to philosophical positions (Bell et al, 2003; Khishfe 2008). This study attempts to build off that work by using an emergent phenomenographic research approach to identify variations in high school chemistry students' thinking about the nature of science, using open-ended written response data from a six-item questionnaire that probes the following aspects of the nature of science:

- Purpose of science
- Tentativeness of scientific knowledge and the nature of theories
- Creativity & imagination
- Aim & structure of experiments

This analysis yielded 39 primary level codes, which were then collapsed based on similarity into 14 categories of description. These categories reflect a wide range of understanding about science. Further analysis highlighted relationships between the categories and suggests two different orientations toward the nature of science. Some high school students orient their thinking about science in terms of an activity driven to prove or make certain, characterized by a collection of facts, whereas other students orient their thinking about science in terms of a finding out activity that results in discovering new information. The results of this study reveal more nuanced conceptions within these four aspects of the nature of science. Implications for science education and future research are discussed.

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CHAPTER 1

INTRODUCTION TO THE STUDY

Background and Purpose

There is a great deal of research that suggests the views held by students of the nature of science are not consistent with the contemporary conception of the scientific endeavor (Duschl, 1990; Lederman, 1992; Driver, Squires, Rushworth, & Wood-Robinson; 1994, Lederman, Abd-El-Khalick, Bell, Schwartz, 2002). There is a growing concern among scientists and educators that students fail to understand conceptions of what constitutes an accurate view of scientific endeavors, and that this failure undermines efforts to develop a scientifically literate public. This concern is grounded, at least in part, in scientists' and teachers' frustration at what they see, during national, state, and local debates over controversial issues such as evolution, climate change, and stem cell research, as a lack of public understanding about the nature and purpose of science (Cavanagh, 2008). Without possessing an accurate and up-to-date conception of scientific endeavors, students cannot fully understand the role of science in society and will be left with simplistic or naïve views about science (Driver et al, 1996, Osborn et al., 2003). These students will likely grow into citizens who are not equipped to make informed decisions that are based on scientific evidence and knowledge.

The need for improving science literacy has been an explicit goal of national policy efforts since the Soviet Union launched its earth-orbiting satellite Sputnik in 1957, an event which precipitated decades of science education reform (DeBoer, 1991 pp. 146-147). However, the failure to improve science knowledge and skills among students despite multiple reform efforts, and the difficulty of translating reform goals into classroom practices, are well documented (Yager, 1992; Southerland et al, 2007). Our ineffective efforts to produce scientifically literate students who possess adequate science knowledge and skills continue to be evidenced in multiple ways and reports (Cavanagh, 2008; Cech, 20008; Shapiro-NSTA Reports, 2008).

The Science Generation: A National Imperative, hosted at the American Museum of Natural History in 2008, was a high-profile conference attended by many national and worldwide leaders in science, education, and politics. This conference was devoted entirely to improving the production of scientifically literate students within our education systems and improving science literacy among the general public (Cech, 2008). There have been a series of recent national and international reports that confirm the ineffectiveness of science education reform efforts. The 2006 Program for International Student Assessment (PISA) ranked U.S. students, on average, lower than those from 16 other industrialized nations on a science literacy measure (Cavanagh, 2008). According to another international report, The Condition of Education 2008, U.S. students score below the average rating on science literacy comparisons (Shapiro-NSTA Reports, 2008). This continued failure to significantly improve science literacy underscores the importance of research in understanding students' conceptions of science.

It is hard to imagine how one can be scientifically literate without understanding what science is about. Understanding the underlying epistemic values, methods, and practices of science is essential if citizens are going to engage with the issues that confront society (Osborne, et al., 2003). Ensuring that students have an adequate conception of the nature of science has been a goal of science education for almost a century (Lederman, 2002). One of the most consistent and central elements of science education reform over the last twenty years has been ensuring that students have a deep understanding of the nature of science (Abd-El-Khalick et al., 2008; Duschl, 1990; Millar and Osborne, 1998; National Science Teacher Association 2000; Sutherland et al., 2007). This attention has generated extensive research assessing students' and teachers' views of the nature of science and fueled the design, development, and implementation of curricula aimed at improving those views (Abd-El-Khalick et al., 2008; Akerson and Hanuscin, 2007; Bell et al, 2003; Chen, 2006; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Khishfe and Lederman, 2006; Lederman et al., 2002). However, this same body of research suggests these efforts have met with limited success (Sutherland et al., 2007). These marginal improvements suggest that continued and varied research is needed to better understand how students conceptualize the nature of science.

Rationale

Instruments that have been used to assess students' conceptions of the nature of science have erroneously assumed that students perceive and interpret the test statements the same way that researchers do (Aikenhead & Ryan, 1992). Even qualitative research done in this area often approaches data interpretation via a deductive framework by evaluating students' conceptions with what the researchers call a *worldly perspective* (Aikenhead & Ryan, 1992), a *more informed view*, (Akerson and Hanuscin, 2007; Bell et al, 2003; Khishfe 2008; Khishfe and Lederman, 2006), or *the 'new' philosophy of science* (Murcia and Schibeci, 1999). Evaluating the "correctness" of students' conceptions in this way could be problematic, because the philosophical positions of the researchers are likely to color their interpretations. Rather than evaluate student claims on a continuum of "informed" to "uninformed," or to dichotomously divide students' claims into existing philosophical positions, the aim of this research is to robustly describe the key aspects of the various ways students conceptualize science. That is, the aim is to describe all the qualitatively different ways high school students think about the nature of science. Identifying these key aspects of the various ways students conceptualize science complements the growing body of research (Abd-El-Khalick & Lederman, 2000; Khisfe & Abd-El-Khalick, 2002; Schwartz & Lederman, 2002; Bartholomew, Osborne, and Ratcliffe, 2004) that suggests teachers need to explicitly teach the nature of science. The more nuanced findings that may come from this work might assist science educators in designing curricula and assessments with more precise conceptual hooks that are able to engage students based on their preexisting conceptions, Curricula based on variations in student thinking can be used to construct a more effective nature of science curriculum and may inform future science education research.

Purpose of the Study and Research Question

The objective of this study is to use an emergent phenomenographic research approach to identify the qualitatively different ways high school chemistry students think about the nature of science. The focus of this work will be on identifying the variation in their thinking. The primary research question driving this study is: What are the variations in the qualitatively different ways students think about the following aspects of the nature of science?

- Purpose of science
- Tentativeness of scientific knowledge
- Creativity and imagination
- Aim and structure of experiments

These aspects warrant study because most of the previous research simply classified student views of these as *naïve* or *informed* (Akerson and Hanuscin, 2007; Bell et al, 2003; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Khishfe and Lederman, 2006). Research that did attempt to explicate student thinking about these aspects has reported differences in their findings regarding the most common student conceptions (Driver et al., 1996; Ryan and Aikenhead, 1992; Stein and McRobbie, 1997).

Definition of Key Terms

Nature of Science—The epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development. Although there is not widespread agreement regarding the nature of science among philosophers, historians, social scientists, and science educators, this study is based on four aspects of the nature of science that are not controversial and have been found accessible to K-12 students (Lederman et al., 2002). These four aspects of the nature of science identified and explicated by Lederman and his colleagues are described below.

- *Purpose of science*—This aspect addresses if and to what extent a person considers science to be based on observations of the natural world. The VNOS line of research often refers to this aspect as the *Empirical Nature* *of Scientific Knowledge*. This study adopted the more vernacular label used by Driver et al. (1996).

- *Tentativeness of scientific knowledge*—This aspect addresses the position that scientific knowledge is not absolute or certain. Scientific knowledge (e.g., theories and law) is subject to change as new advances in thinking or technology are made possible or existing evidence is reinterpreted under different theoretical, methodological, or cultural frames.
- *Creativity and imagination*—This aspect addresses the position that the generation of scientific knowledge, such as the invention of explanations (e.g., Bohr's model of an atom) and theoretical entities (e.g., species concept), involves human imagination and creativity.
- *Aim and structure of experiments*—This aspect addresses a person's conception of a scientific experiment and if and to what extent one considers an experiment to be required for the development of scientific knowledge.

Phenomenography—A qualitative research tradition that focuses on mapping the different ways in which people experience, conceptualize, perceive, and understand various aspects of phenomena in the world around them (Marton, 1986). The variation in thinking is captured and described at the group level using emergent themes called *Categories of Description*. Taken together, the categories of description are considered to occupy the phenomenographic *Outcome Space* that represents the qualitatively different ways a given phenomenon could be experienced or thought about.

Summary and Overview of Study

There is a great deal of literature that suggests students do not possess an adequate view of the nature of science. This is troublesome, because one of the key elements of national reform efforts over the last twenty years has been ensuring that students have a deep understanding of the nature of science. Much of the previous research in the nature of science realm is designed to assess the correctness of students' conceptions or categorize their thinking based on historical or philosophical positions. The goal of this research differs in that its aim is to identify more nuanced variation in student thinking within four particular aspects of the nature of science that have been identified by previous research. Specifically, the objective of this study is to use an emergent phenomenographic research approach to identify the qualitatively different ways high school chemistry students think about the nature of science. Categories of description will be developed to capture variations in student thinking about these four particular aspects of the nature of science (i.e., Purpose of Science, Tentativeness of Scientific Theories, Creativity and Imagination, Aim and Structure of Experiments).

Chapter 2 provides a brief overview of the science education research literature related to objectives of this work. Chapter 3 describes the research design and methodology, including the sample of students and the instrument used to collect data. Chapter 4 walks the reader through the analysis of the data and subsequent results. Chapter 5 provides an overview, relates the findings to prior research and discusses the implications for science education and future research efforts.

CHAPTER 2

LITERATURE REVIEW

Science Literacy and the Connection to the Nature of Science

Science Literacy

The need for improving science literacy has been an explicit goal of national policy efforts since the Soviet Union launched its earth-orbiting satellite Sputnik in 1957, an event which precipitated decades of science education reform (DeBoer, 1991). However, the failure to improve science knowledge and skills among students despite multiple reform efforts, and the difficulty of translating reform goals into classroom practices, are well documented (Yager, 1992; Southerland et al, 2007). Our ineffective efforts to produce scientifically literate students who possess adequate science knowledge and skills continue to be evidenced in multiple ways and reports. The Science Generation: A National Imperative, held at the American Museum of Natural History in 2008, was a high-profile conference attended by many national and world-wide leaders in science, education, and politics. This conference was devoted entirely to improving the production of scientifically literate students within our education systems and improving science literacy among the general public (Cech, 20008).

There have been a series of recent national and international reports confirming the ineffectiveness of science education reform efforts to improve science literacy. The 2006 Program for International Student Assessment (PISA) ranked U.S. students, on average, lower than those from 16 other industrialized nations on a science literacy measure (Cavanagh, 2008). According to another international report, The Condition of

Education 2008, U.S. students score below the average rating on science literacy comparisons (Shapiro-NSTA Reports, 2008).

This continued failure to significantly improve science literacy underscores the importance of research in understanding students' conceptions of science, because an understanding of the fundamental aspects of the nature of science is viewed as a critical component to achieving a scientifically literate society. Driver et al. (1996) argue that an understanding of the nature of science is necessary if school science is to effectively improve the public's understanding of science. Driver and her colleagues make the following arguments for promoting a better public understanding of science:

- *Utilitarian argument*—an understanding of the nature of science is necessary for people to make sense of science and manage technology in their everyday life.
- *Democratic argument*—an understanding of the nature of science is necessary for people to fully understand and make informed decisions regarding socio-scientific issues.
- *Cultural argument*—an understanding of the nature of science is necessary for people to appreciate the key role science plays in contemporary culture.
- *Moral argument*—an understanding of the nature of science is necessary for people to develop an awareness of the moral commitments embodied by the scientific community, for example, simultaneously encouraging the criticism of ideas and the freedom of thought.

- *Science Learning argument*—an understanding of the nature of science is necessary for people to develop a deep understanding of science content knowledge.

In addition, there is growing concern and frustration among scientists and educators that the general public lacks an adequate understanding of the nature and purpose of science, a lack that is most evident during national, state, and local debates over controversial issues such as evolution, climate change, and stem cell research (Cavanagh, 2008). Without possessing an accurate and contemporary conception of scientific endeavors, students cannot fully understand the role of science in society and will be left with simplistic or naïve views about science (Driver et al., 1996, Osborn et al., 2003). These students will likely grow into citizens who are not equipped to make informed decisions that are based on scientific evidence and knowledge.

The National Science Education Standards (National Research Council, 1996) describe scientific literacy as the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity. This implies that a person can identify scientific issues, evaluate the quality of scientific information, and formulate arguments that are scientifically and technologically informed. Understanding the enterprise of science is essential for students to develop an appreciation of the power and limitations of science and its vital role in contemporary society. Knowing the underlying epistemic values, methods, and practices of science is essential if citizens are going to engage with the issues that confront society (Osborne et al., 2003).

Continued Efforts to Develop an Understanding of the Nature of Science

Helping students develop an informed conception of the nature of science has been an agreed-upon goal of almost all science educators for nearly 85 years (Lederman et al., 2002). However, a great deal of contemporary research suggests students are not acquiring views of the nature of science that are consistent with the contemporary conception of the scientific endeavor (Duschl, 1990; Lederman, 1992; Driver, Squires, Rushworth, & Wood-Robinson; 1994, Lederman, Abd-El-Khalick, Bell, Schwartz, 2002). This research consistently indicates that students do not develop an adequate understanding of the nature of science through their participation in school science (Bell, Blair, Crawford, & Lederman, 2003). This lack of understanding exists in spite of the explicit inclusion of the nature of science in the National Science Education Standards (National Research Council, 1996), Project 2061 Benchmarks (American Association for the Advancement of Science, 1993), and College Pathways to the Science Education Standards (Seibert & McIntosh, 2001). One of the most consistent and central elements of science education reform of the last twenty years is ensuring students have a deep understanding of nature of science (Abd-El-Khalick et al., 2008; Duschl, 1990; Millar and Osborne, 1998; National Science Teacher Association 2000; Sutherland et al., 2007).

Attention from these national reform efforts has generated extensive research to assess students' and teachers' views of the nature of science and has fueled the design, development, and implementation of curricula aimed at improving those views (Abd-El-Khalick et al., 2008; Akerson and Hanuscin, 2007; Bell et al, 2003; Chen, 2006; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Khishfe and Lederman, 2006; Lederman et al., 2002). However, this same body of research suggests these efforts have met with limited success at improving student and teacher views of the nature of science (Sutherland et al., 2007).

Ironically, although there is a general consensus regarding the importance of including the nature of science in high school curricula, there is no general consensus on how to define or what is meant by the phrase *nature of science*. There is no clear agreement among historians, philosophers, educators, and practicing scientists about what constitutes an accurate definition of the nature of science. In fact, DeBoer (1991) recounts how the development of science education goals to teach the epistemological underpinnings of and the methods of practicing science has changed and has been challenged over time.

Disputes over what constitutes the nature of science can largely be categorized as epistemologically or ontologically-based disagreements. Epistemological disagreements are concerned with how science is actually practiced and what and how knowledge is constructed and valued. Ontological disagreements concern the nature of truth and the objectivity of science (Brickhouse, Dagher, Letts, & Shipman, 2000; Osborne et al 2003). Perhaps this lack of consensus should not be a concern, because as Herron (1965) stated, anything as complex as the nature of scientific knowledge or scientific inquiry is capable of being seen from a variety of viewpoints. He also warned that one should be wary of a specific label for the nature of science, because it may suggest our need for consensus has surpassed our need for precision of language. Despite these disagreements, Lederman's (1992) description of the nature of science tends to be widely cited in the literature and will be used for the purposes of this work. He describes the nature of science as typically referring to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. Although there is no clear consensus on a specific definition for the phrase *nature of science*, there is general agreement among scholars on several fundamental aspects, particularly in terms of a level considered appropriate for secondary school science instruction (Lederman et al., 2002; Smith & Scharmann, 1999).

Research on the Nature of Science

Nature of Science Instruments

Osborne et al. (2003) write that one can argue that science education is science's worst enemy, leaving students ambivalent, confused and frustrated about the subject largely because of insufficient tools used to evaluate critically the claims of science and scientists. Despite the research activity within this domain and the prominence of the nature of science in national reform efforts, researchers continue to struggle with how to validly assess nature of science knowledge (Sutherland et al., 2008). Instruments that have been used to assess students' conceptions of the nature of science have erroneously assumed that students perceive and interpret the test statements the same way that researchers do (Aikenhead & Ryan, 1992). Even qualitatively based research done in this area often approaches data interpretation via a deductive framework by evaluating students' conceptions with what the researchers call a *worldly perspective* (Aikenhead & Ryan, 1992), a *more informed view*, (Lederman et al., 2002; Bell et al., 2003), or *the 'new' philosophy of science* (Murcia and Schibeci, 1999). Evaluating the "correctness" of students' conceptions in this way could be problematic because the philosophical positions of the researchers are likely to color their interpretation (Sutherland, 2008). Chen (2006) noted that previous nature of science instruments and related research seem to try to indoctrinate students to certain concepts, rather than assist them in developing a greater understanding of the nature of science which would better assist them with justifying their own beliefs. For instance, he suggested some instruments (e.g., the VNOS research stand) might reinforce a fallacy that tenets of post-positivism are superior to positivism or that anti-realism trounces realism. Matthews (1997) makes a similar observation when he criticizes Robinson (1968) for only considering (and advocating for) logical positivism as an accurate view of the nature of science.

In Blalock et al.'s (2008) comprehensive review of instruments that measure science attitudes, there is a category specifically devoted to nature of science instruments. Although the reasoning for including the nature of science category is not obvious, their analysis is legitimate and reveals several weaknesses among common nature of science instruments. This category was composed of five instruments designed to measure students' understanding of the nature of science. Overall, Blalock et al. note that nature of science instruments were psychometrically very weak relative to other categories in their study. The VNOS instrument (Lederman, 2002), which was adapted for this study, tied with another instrument (Ruba et al., 1981) as the highest-ranked nature of science instrument. However, even these two highest-ranking instruments only scored 7 out of a possible score of 28. The VNOS rubric breakdown was theory = 3, reliability = 0, validity = 0, dimensionality = 3, and development/usage = 1.

Liang et al. (2008) developed the Student Understanding of Science and Scientific Inquiry (SUSSI) instrument in an effort to address concerns of validity and reliability, and to be sensitive about not imposing the philosophical positions of the researcher onto the scoring criteria of the instrument. Their instrument has a dual response format that integrates a forced response Likert scale type of question with open-ended written responses. Although the SUSSI makes progress to address the aforementioned concerns, it still simply results in an evaluative judgment of “naïve” or “informed” similar to the VNOS approach. None of the instruments and related lines of research described above attempt to explicate student thinking, nor do they identify common variations in the way students conceive the nature of science.

Related Studies on the Nature of Science

The following is a review of the nature of science research studies that are commonly cited in the literature and/or are particularly similar to this work.

A research study that investigated aspects or elements of the nature of science that are relevant and accessible to K-12 students was the work of Osborne et al. (2003). This project, based in the United Kingdom, used a Delphi technique drawn from groups of scientists, philosophers, sociologists of science, science educators, and science teachers to identify ideas that should be taught about science. They identified the following nine themes:

- Scientific methods and critical testing
- Science and certainty
- Diversity of scientific thinking

- Hypothesis and prediction
- Historical development of scientific knowledge
- Creativity
- Science and questioning
- Analysis and interpretation of data
- Cooperation and collaboration in the development of scientific knowledge

These nine themes represent consensus regarding key components of a science curriculum and underscore the importance of teaching about science as part of teaching discipline-specific content (e.g., physics, biology, chemistry). Although this study did not investigate students' thinking about science, it is presented here because it is frequently cited in the nature of science research domain. It also represents a stepping off point, because this current study investigates student conceptions both directly (e.g., *Science and certainty* and *Creativity*) and indirectly (e.g., *Cooperation and collaboration in the development of scientific knowledge*) aligned with these nine themes.

Stein & McRobbie (1997) conducted a very similar research project in Queensland, Australia. They also used a phenomenographic approach based on the analysis of open-ended response data to investigate students' conceptions of the nature of science. High school and middle school students were asked to provide written responses to the following questions:

- What is science?
- What activities do scientists engage in? How do you think they go about those activities?

- What do you think scientific knowledge is?

Their analysis yielded six categories of description that illustrate how these students thought about science:

- Science is Done or Learnt at School
- Science is a Consumable Product
- Science is a Study of the World
- Science is a Process
- Science is Dynamic Knowledge
- Science is Influenced by the Social Context

Stein and McRobbie organized these categories from the most unsophisticated and egocentric (*Science is Done or Learnt at School*) to the most worldly and sophisticated one (*Science is Influenced by the Social Context*). They describe this variation in thinking as representing an evolution in understanding about science that gradually occurs as students acquire more experiences and exposure to science. They concluded that educators should address these categories from a constructivist perspective, using these existing notions to create learning experiences that enable students to construct new and more sophisticated levels of meaning.

As previously mentioned, the research instrument used in this study is adapted from Lederman et al. (2002), Views of Nature of Science (*VNOS*-*C*). This is the culmination of 15 years of research aimed at developing an instrument to evaluate the correctness of pre-service teachers' views of the nature of science (*VNOS*). The original VNOS instrument(s) were designed to identify aspects of the nature of science that are grounded in historical and philosophical notions of science (e.g., deterministic/absolutist or empiricist) and then evaluate the correctness of pre-service science teachers' views within these identified aspects. Lederman et al. (2002) identified the following as relevant and distinct aspects of the nature of science:

- Empirical nature of science
- The scientific method
- General structure and aim of experiments
- The role of prior expectations in experiments
- Validity of observationally based theories and disciplines
- Tentative nature of science
- Difference and relationship between theories and laws
- The nature of scientific theories
- The function of scientific theories
- Logic and testing of scientific theories
- Creative and imaginative nature of science

Lederman and his colleagues clarified the difference between these aspects of the nature of science and processes that characterize science. They described scientific processes as activities related to the collection and interpretation of data and the derivation of conclusions, whereas aspects of the nature of science are distinctly separate because they are concerned with the values and assumptions underlying these activities. They illustrate this point by noting that observing and hypothesizing are scientific processes and separate from aspects of the nature of science that suggest observations are constrained by a perceptual apparatus or that the generation of hypotheses involves imagination and creativity. With regard to their analysis and findings, Lederman et al. (2002) wrote that in many cases respondents' views were fluid, fragmented, and compartmentalized. They concluded that these types of views are internally inconsistent and labeled these ideas about science as naïve (or uninformed) because they lack an overarching, consistent framework.

The VNOS instrument has been adapted for use with high school (Bell et al., 2003; Khishfe and Lederman, 2006), middle school (Khishfe 2008), and elementary school students (Akerson and Hanuscin, 2007). These studies are described in greater detail below.

Bell et al. (2003) used the VNOS framework to determine if an 8-week apprenticeship program improved the nature of science views of high-achieving high school students. Most students started the apprenticeship with an understanding that scientific knowledge is derived from empirical evidence and is subject to change; however, their understanding of the tentativeness of scientific knowledge was described as naïve, because it was attributed to a lack of information and a lack of understanding that existing data could be reinterpreted. Students held misconceptions regarding the capacity for theories to be proven with more knowledge, the absoluteness of laws, the limited role of creativity, and the conception of a single scientific method. Despite the beliefs of the scientists who served as mentors for this program that student participants improved their knowledge of the scientific enterprise, these students' conceptions of the nature of science changed very little.

Khishfe and Lederman (2006) investigated the influence of two different explicit instructional approaches on improving high school students' understanding of the nature of science. In one group (integrated), the nature of science was explicitly taught as an integrated component of a unit on global climate change. In the other group (non-integrated), the nature of science was taught as a group of explicit activities about global warming, dispersed across the content. Based on the VNOS framework, they investigated five aspects of the nature of science:

- Tentativeness of scientific knowledge
- Empirical nature of science
- Role of creativity and imagination in science
- Distinction between observation and inference
- Subjective nature of scientific knowledge

The results showed improvements in students' views of the nature of science regardless of which instructional treatment they received. Comparing the groups did not provide conclusive evidence in favor of a specific instructional method. The researchers provide some quotes from each instructional treatment to support their categorization of naïve, intermediary or informed views. However, the authors did not report if or how students' views qualitatively varied within each aspect of the nature of science, or between treatment groups.

Khishfe (2008) investigated whether an explicit inquiry-oriented instructional approach improved the development of seventh grade students' view of the nature of science. The instructional approach engaged students in three inquiry-based activities paired with reflective discussions about the nature of science. Based on the VNOS framework, four aspects of the nature of science were investigated:

- Tentativeness of scientific knowledge
- Empirical nature of science
- Role of creativity and imagination in science
- Distinction between observation and inference

Before the intervention the majority of students held naïve views of the four aspects of the nature of science. During the study, many students developed an "intermediary" view of these aspects. By the end of the study, most students had developed an informed view of the tentative, empirical, and creative aspects of the nature of science; student views regarding the distinction between observation and inference remained unchanged. The findings suggest that explicit inquiry-based instruction promotes an understanding of the nature of science and that students pass through intermediary views as they move from a naïve to an informed understanding of the nature of science. The author provided some quotes and some dialogue excerpts from student interviews to support the categorization of naïve, intermediary or informed views for each aspect; however, there is little to no explication of the qualitatively different types of responses students provided on the questionnaire, nor did the researcher report variations in thinking beyond naïve, intermediary or informed views during the semi-structured follow-up interviews.

Akerson and Hanuscin (2007) performed a study that investigated the influence of a 3-year professional development program on elementary teachers' views of the nature of science and their instructional practices, and the subsequent impact of their instruction on elementary students' views of the nature of science. Three teachers (kindergarten, first grade, and fifth/sixth grade) were profiled as they participated in a professional development program that explicitly addressed nature of science aspects and emphasized inquiry-based instructional practices. Reflection activities were paired with the explicit nature of science activities. Students' ideas about the nature of science were captured at the beginning and end of the school year using semi-structured VNOS-based interviews and then captured throughout the year based on classroom observations. Students in each grade developed more informed views of the aspects of the nature of science that were emphasized by their teacher. Fifth and sixth grade students showed a more substantial improvement than their kindergarten and first grade counterparts. The results suggest that explicit reflective professional development strategies can positively impact students' views of the nature of science. The authors did not report if or how students' conceptions of the nature of science qualitatively differed within or between grades.

In general, these VNOS-based studies do not identify common variations in thinking beyond or within the aspects of the nature of science they investigate, nor does this strand of research attempt to report conceptions of the nature of science that reflect the actual thinking of the students (or student teachers) participating in their studies.

Aspects of the Nature of Science Investigated in this Study

This study will focus on the following aspects: the purpose of science, the tentativeness of scientific knowledge, the role of creativity and imagination in science, and the aim and structure of experiments. These are fundamental aspects of the nature of science that are apparent in the National Science Teachers Association's (NSTA) position statement on the nature of science (Appendix A). These aspects represent interesting avenues for research because most of the previous research has investigated these through a normative lens that simply classified views as *naïve* or *informed* (Akerson and Hanuscin, 2007; Bell et al, 2003; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Khishfe and Lederman, 2006) and/or have reported differing findings regarding the most common student views (Driver et al., 1996; Ryan and Aikenhead, 1992; Stein and McRobbie, 1997). Further, these aspects are linked to science literacy because they are essential for developing a deep understanding of science and influence thinking on socio-scientific issues (Driver et al., 1996, Osborn et al., 2003). The researcher believes these aspects align with typical curricular topics (e.g., instruction on the structure of an atom using Bohr's model, verification and/or inquiry based laboratory experiments) that are likely part of the target population's (i.e., high school chemistry students) school science experiences. Previous research related to these four aspects of the nature of science is presented below.

The purpose of science

NSTA's position statement on the nature of science (Appendix A) characterizes science as the systematic gathering of information through various forms of direct and indirect observations and the testing of this information by methods including, but not limited to, experimentation. It also states that the principal product of science is knowledge in the form of naturalistic concepts and the laws and theories related to those concepts.

One of the most widely cited studies investigating how students characterize the purpose of science was a large ideographic investigation that was conducted with 9- to 16-year old students (Driver et al., 1996). These researchers reported the following as the three most common features that characterize young people's images of science:

- Scientists ask questions that can be investigated empirically
- Scientists ask questions related to a prototypical domain of science (e.g., biology)
- Activities perceived as stereotypical of scientific work, such as using microscopes, working with chemicals, and performing experiments

This study was intended to document students' ideas about the nature of science through several different probes (e.g., written scenarios, activities) and interviews. These probes were very specific and highly contextualized. The specificity of the probes might be considered a limitation of the study because the details of the probes can inform or influence the student's thinking. There is a possibility that the findings of the study are more a reflection of the researchers' ideas about how science supposedly operates than of actual student images of science. As Lederman and O'Malley (1990) discuss, if students have never been asked to think about science as a "way of knowing," assessment procedures may actually be creating—instead of merely measuring, as intended—the students' views.

The sample size for this study was relatively large for a qualitatively oriented investigation, consisting of 30 pairs of students at age points 9, 12, and 16 years old, and appears to have resulted in robust findings. However, all students were from one local education authority in the north of England. Despite that large sample of students, this study reflects a relatively narrow population of students' thinking and may not be reflective of other populations. There may be cultural differences between English and American student views of the nature of science, because as Wimsatt (1981) suggests, no two people will have the same cognitive resources, even within the same culture and with the same training. Therefore, one would expect differences between American and English worldviews. These differences in worldview influence students' perceptions of science.

Another widely cited study that probes students' conceptions of the purpose of science was based on a large survey of Canadian high school students' views of science, technology, and society issues. In this study, Aikenhead and Ryan (1992) reported that students' views varied widely. Two of the most common views were that scientific knowledge is produced to satisfy the curiosity of scientists and that the purpose of science is to make the world a better place. These ideas are distinct from Stein and McRobbie's (1997) study which suggested students relate the purpose of science to something that is *Done or Learnt at School*, is connected to a *Consumable Product*, or is related to broad, indefinable fields of inquiry such as *The Study of the World*. However, other research (Bell et al., 2003; Dogan and Abd-El-Khalick, 2008; Khishfe 2008) reported that students view science as based solely on evidence and perceive science as being completely objective. This type of thinking does not appear to support the epistemological underpinnings of Aikenhead and Ryan (1992) and Stein and McRobbie (1997). The discrepancy in findings regarding students' views of the purpose of science warrants additional research in this area.

Tentativeness of scientific knowledge

Lederman et al. (2002) described scientific knowledge as reliable and durable, but never as absolute and certain. They state, "Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on these claims, and as extant evidence is reinterpreted in the light of new theoretical advances, changes in the cultural and social spheres, or shifts in the directions of established research programs." When designing curricula, science education researchers and curriculum developers have focused on trying to teach the tentative and revisionary aspects of science, because these are believed to be a primary attribute of scientific knowledge and could be understood at an early age (Lederman and O'Mally, 1990). For instance, laboratory procedures are often naively promoted as the vehicle to teach an understanding of the nature of science simply because they involve hands-on activities. However, Lederman (1992) suggested laboratories do not teach the tentativeness of scientific knowledge. In his study, students complained that "labs always come out the same" and therefore were not very effective at communicating the nature of science. Similarly, Hofstein & Lunetta (1982) claim traditional (e.g., verification "experiments") laboratory activities do not enhance learning or an understanding of the scientific enterprise. As previously mentioned, Lederman et al (2002) categorized thinking as expert (informed) or novice (naïve). In their study 100% of the teacher candidates who were categorized as expert thinkers indicated theories can change. They typically attributed change in scientific knowledge to new technology, new data, and sometimes to new insights. The following quote was provided to typify this more informed view: "Everything in science is subject to change with new evidence and interpretation of that evidence." Within the group categorized as naïve thinking, 78% stated theories do not change. The following quote was provided to typify this more naive view: "If you get the same result over and over and over, then you become sure that your theory is a proven law, a fact."

Bell et al. (2003) reported that all of the 10th and 11th grade students who participated in the scientific apprenticeship initially expressed a view that scientific theories can change; however, all attributed such change to new empirical evidence, rather than a reinterpretation of existing data. The following quote was provided to reflect this type of limited view of student thinking: "A scientific law is definite, and nothing is named a law unless scientists agree that there is no question to its being true. For example, scientists are open to finding new information about atomic theory, but Newton's law of motion has been tested enough times that scientists are certain that it is true." Upon completion of the apprenticeship only 1 of the 10 students expressed a more sophisticated view of the tentativeness of scientific theories.

More recent studies suggest explicit instruction in the nature of science can promote a more sophisticated understanding among students of the tentative nature of scientific knowledge. Using the VNOS framework, Khishfe (2008) reported that 7th grade students' thinking regarding the tentativeness of scientific theories moved from 17% having an informed view (i.e., theories can change) before explicit nature of science instruction to 44% after the instruction. Some quotes were provided to help the reader compare and contrast how student thinking changed as a result of the explicit nature of science instruction. The following quotes capture the concrete way students perceived scientific knowledge before the explicit instruction: “They [scientists] haven’t actually seen it [the atom] with their eyes…then they are not certain until after they actually see it, maybe in 100 years or less”; “There’s got to be a dinosaur preserved frozen…should explore Antarctica.” The quotes that were provided to reflect the more informed student views after explicit instruction suggest that students had a better grasp of the revisionary aspects of scientific knowledge, despite simultaneously holding narrowly empirical notions of science, such as “seeing” leads to the certainty of scientific knowledge. Khishfe (2008) used the following quote to emphasize this point: “People used to think the Earth was flat but we know it’s not flat, we’ve seen pictures of the earth.” Khishfe and Lederman (2006) reported similar findings. In this study, students’ thinking regarding the tentativeness of scientific theories moved from 0% having an informed view before explicit nature of science instruction to 42% after instruction in one treatment group, and similarly from 0% to 24% after instruction in another treatment group. They provided similar quotes to typify naïve and more informed student thinking. For instance, naïve thinking is illustrated by the following: “No, they [scientists] are not certain [about atomic structure] unless they were able to see it front of them.” This is contrasted with the following quote used to characterize a more informed notion of science after explicit nature of science instruction: “Yes, some scientific knowledge may change. In the future a new discovery might be found and change some of the information they've found." However, in both studies little effort is made to report what changed in students' thinking, nor to identify the common reasons they attribute as to why scientific knowledge has the capacity to change or even categorize the range of ideas students tend to have regarding the tentativeness of scientific knowledge.

The role of creativity and imagination in science

Based on the literature reviewed to prepare for this study, students' views on the role of creativity and imagination in science represent one of the least investigated aspects of the nature of science. However, it is widely seen to be important and appears in reform documents such the National Science Education Standards (National Research Council, 1996), Project 2061 Benchmarks (American Association for the Advancement of Science, 1993), and the NSTA position statement on the nature of science. Creativity and imagination are fundamental to the scientific process because science involves designing experiments and constructing viable theories which explain natural phenomena. Hu and Adey (2002) argued that scientific research requires creativity almost by definition, because a scientist must go beyond existing knowledge and techniques in order create new understandings. Abd-El-Khalick et al. (2001) contend that creativity and imagination are important to science because, contrary to popular belief, science is not a lifeless, completely rational, and orderly activity. They report that novice views seldom incorporate creativity and restrict it to conjecture that happens before the "single" scientific method, whereas expert views of the nature of science describe creativity as permeating the scientific process. Similarly, Murcia and Schibeci (1999) reported that some student teachers in their sample believed that creativity has no role in the scientific process because science is about truth and fact, and only a small number of student teachers connected creativity with the development of theories.

Bell et al. (2003) note that even after participating in the science apprenticeship program, apprentices tended to limit the role of creativity in their understanding of science by restricting it to the initial stages of experimental design. They used the following quote to typify this type of limited thinking among the students:

> "I think that scientists should not use their imagination in some circumstances. In interpreting that data, they should go strictly with what's in the data. If they sort of try to make it slant one way or the other, or you get two people doing the same experiments, and they have the same data and they get different conclusions, I think that that is because they sort of have creative answers to what their data is showing …No, [it's not okay to use creativity] if you have the data, you should go with what the data says"

Khishfe (2008) reported improvements in the percentage of 7^{th} grade students having an informed view (i.e., scientists use creativity) after explicit nature of science instruction. Regarding the role of creativity and imagination in science, students with an informed view increased from 22% before explicit instruction to 50% after instruction. Likewise, it was reported that the percentage of students having a naïve view (i.e., scientists do not use creativity) decreased from 50% before explicit nature of science instruction to 28% after instruction. This study reported that many students seemed to hold on to their naïve views because their thinking is grounded in empirical notions of science (e.g., scientists must "see" something) or because creativity would "distort the perfection of science." The following quote is used to illustrate the durability of these naïve notions of science:

"[Scientists] use them [imagination and creativity] to create unique ways of doing things and looking at things. And it depends on the scientist, like putting jellyfish and monkey is pretty creative but they, if there was more than one person in that experiment and there probably was, it could be different." Further explicating these student conceptions might better inform why they tend to hold on to these more naïve notions and why creativity and imagination are limited to certain aspects of science. Understanding these conceptions might inform the development of instructional strategies used in these types of explicit instruction models.

The aim and structure of experiments

Similar to the role of creativity and imagination in science, there is little research that specifically addresses the purpose and structure of experiments in the production of scientific knowledge. Based on findings from *VNOS-B*, Lederman et al. (2002) added two items to the *VNOS-C* questionnaire that specifically assess a student's understanding of the role of experiments in the production of scientific knowledge. They found that students typically define scientific experiments as "procedures used to answer scientific questions." The following quotes were used to typify naïve student thinking regarding the role of experiments: "An experiment is a sequence of steps performed to prove a proposed theory"; "You usually have some sort of idea about the outcome. But I think that to have a scientific and valid experiment you should not have any bias or ideas in advance." Lederman et al. (2002) suggested that more informed views did not see experiments as proving a theory; rather, experiments add validity to a theory. They used the following quotes to typify this more informed notion: "An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same"; "To organize an experiment you need to know what is going to come out of it or it wouldn't really be a test method. I don't know how to organize a test without have a general idea about what you're looking for." Although there is a striking difference between the naïve and more informed views of science in their study, little to no effort is made to describe or understand this variation in thinking.

Carey and Evans (1989) found similar results when they investigated 7th graders' epistemological views of science. They report three general levels of understanding. At level 1, students do not make clear distinctions between ideas and activities, especially with regard to experiments. At this level, scientists are seen as trying to figure out something, but the motivation for this activity is confused with its achievement. Students do not think in terms of the construction of knowledge. This is congruent with Kuhn and Phelps (1982), who reported that 10- and 11-year old students could not distinguish between understanding a phenomenon (e.g., the *cause* of a color change) and producing it (e.g., *producing* a color change). This differs from level 2 students, who can make a distinction between ideas and experiments. Level 2 students understand that experiments can lead to the rejection and/or revision of ideas. However, these students lack a deeper understanding that this revision should explain more about the natural world. At level 3, students have a clearer understanding of the motivation for experiments and a deeper appreciation of the distinction between the results of an experiment and the ideas being tested. Level 3 students grasp the cumulative nature of science and the ultimate goal of science as a more complete explanation of the natural world. Although these studies are informative, the intent was a ranking of student ideas based on the researchers' notions of an "informed" or "deep" understanding, rather than identifying the key aspects in the various ways students think about science.

The VNOS research strands that were adapted for use with high school (Bell et al, 2003; Khishfe and Lederman, 2006), middle school (Khishfe 2008), and elementary school students (Akerson and Hanuscin, 2007) did not specifically report on the aim and structure aspect of the nature of science. However, many of these studies report that students think scientific theories can become laws through the accumulation of empirically derived evidence (e.g., performing experiments). Bell et al. (2003) describe this type of "absolute" and "proof" oriented thinking as persistent among high school students even after completing a science apprenticeship. This is consistent with Driver et al. (1996), who note that laboratory experiences where scientific knowledge flows directly and logically from a contrived observation (e.g., verification laboratory activities) lead students to simple epistemological understandings. The paucity of research literature that specifically addresses students' understanding of the aim and structure of experiments suggests further research is warranted.

Summary

This chapter provided an overview of the science education research literature related to the nature of science. It explained that a central and reoccurring element of science education reform efforts posits the nature of science as an essential component for developing a scientifically literate public. A review of research that focuses on assessments and curricular efforts aimed at improving student and teacher views of the nature of science suggests these efforts have met with limited success. The findings of specific research related to this study, including the particular aspects of the nature of science this work will address, were reviewed in detail.

The following chapter describes the research design and methodology, including the sample of students and the instrument used to collect data. Chapter 4 details the analysis of the data and the subsequent results. Chapter 5 provides an overview, relates the findings to prior research and discusses the implications for science education and future research efforts.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

This chapter contains descriptions of the methodological framework for this study as well as the data collected, the survey instrument used in that collection, the research subjects, and the analysis used to derive meaning from the data.

Methodology

Phenomenography will be the primary methodological perspective underlying this study. A thorough description of the methodological perspective is important because it is grounded in certain requirements and assumptions that guide how the research is conducted and how the data are analyzed. The focus of the phenomenographic research perspective is the variation in the key aspects of students' conceptions of phenomena at the group level. Marton's (1986) description of phenomenography seems to be the most frequently cited description of this research methodology. He describes phenomenography as being a research methodology for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of phenomena in the world around them.

Phenomenographic investigations are about developing an understanding of the qualitatively different ways in which people think about various phenomena. Therefore, phenomenography is not solely about the phenomena being experienced, nor about the human beings who are doing the thinking. Rather, phenomenography is concerned with the way people think about the relations between human beings and the world around them (Marton, 1986). Phenomenography is often described as a constitutional or relational perspective of learning because it assumes that knowledge is constituted between the phenomenon in question and the learner experiencing or thinking about the phenomenon. This relational methodological perspective fits particularly well with the research questions of this study.

The objective of this phenomenographic research is to describe the qualitatively different ways students think about particular aspects of the nature of science. This will be accomplished by developing structured sets of “categories of description.” Previous phenomenographic research in a variety of disciplines suggests there are usually 4–6 categories of description associated with a given phenomenon (Marton, 1986; Ebenezer and Erickson, 1996). A category of description becomes a piece of the researcher’s model of how a phenomenon is experienced (Bowden, 1995). Taken together, the categories of description are described by Marton (1986) as occupying an “outcome space” that represents the qualitatively different ways a given phenomenon could be experienced or thought about.

There are two important assumptions made when conducting phenomenographic research. First, there are a limited number of ways that the key aspects of a phenomenon are experienced or thought about. This assumption is supported by previous phenomenographic research (Marton, 1986) and research investigating variations in students’ prior knowledge (Finley, 1985; Heller & Finley, 1992; Driver et al., 1994; Wandersee et al., 1994). The second assumption underlying phenomenographic research is that a single person is not likely to express all the varying aspects or conceptions that surround a given phenomenon. Sandberg (1996) writes that the data obtained from a single individual may be insufficient to distinguish a conception. Therefore, data from multiple individuals must be combined to understand the different ways people think about the phenomenon in question. The large dataset utilized in this research should allow for a complete and thorough saturation of all the potential ways students may think about the nature of science.

Based on these assumptions, Marton (1986) describes how given individuals can “move about” within the outcome space because they can employ a variety of conceptions depending on their perception of the context and setting. Ebenezer and Erickson (1996) make this clearer when they explain that it is inappropriate to classify a student as holding a particular conception or occupying a given category of description because there is always potential for variability within that student. Thus, the phenomenographic perspective provides insight into thinking at the group level. These methodological and conceptual assumptions place phenomenography closer to the more contemporary fields of “social cognition” and “situated cognition” than the more traditional models of cognition that explain student conceptions at the personal level (Ebenezer and Erickson, 1996).

Other Methodological Perspectives Considered

Many previous studies have investigated students’ prior knowledge (e.g., misconceptions/alternative conception research) about natural phenomena (Posner, Strike, Hewson and Gertzog, 1982; Strike & Posner, 1985; Driver et al., 1994; Wandersee, Mintzes, & Novak, 1994). These studies are based on the assumption that people (e.g., students) construct meaning about a new experience or concept based on their prior experiences and knowledge. These studies are conducted from a Constructivist perspective, meaning knowledge is constructed by students and exists in their minds. This research is conducted from the researcher's perspective, with the researcher trying to describe what is in the student's minds; this analysis is at the individual or personal level. Further, these studies often attempt to evaluate the correctness of students' conceptions.

Phenomenography is a more appropriate methodology for this study than the previously described Constructivist perspective because Phenomenography focuses on human experience or human thinking. Phenomenographic research is conducted from the students' perspective, with the researcher trying to describe their thinking from their perspective and without any evaluation of correctness. Additionally, the focus of the phenomenographic perspective is the variation in the key aspects of students' conceptions of phenomena at the group level.

Phenomenology was also considered as a possible methodological frame for this study. The aim of most phenomenology-based research is "to describe the phenomenon as openly and faithfully as possible" (Karlsson, 1988, p.9). The researcher attempts to describe the "lived experience" of the subject within the context of the phenomenon in question. A phenomenological study should result in "the reader understanding better the essential, invariant structure (or essence) of the experience, recognizing that a single unifying meaning of the experience exists" (Creswell, 1998. p. 54). Phenomenography is a more appropriate methodological frame for this research study than phenomenology because the intent of the research is to reveal the qualitatively different ways students think about a phenomenon, rather than what constitutes the essence of the phenomenon.

Research Instrument

The research instrument used in this study is a six-item open-ended nature of science questionnaire (see Appendix B) administered as part of a larger evaluation study of the *Active Chemistry* curriculum. The six open-ended questions were adapted from Lederman et al.'s (2002) Views of Nature of Science (*VNOS-C*) 10-item structured interview protocol (see Appendix B for items *not* used). These items represent the aspects of the nature of science the research team intended to investigate. These six items were selected as a subset because they more explicitly connect to the science concepts, principles, and classroom practices experienced by high school chemistry students. Additionally, the research team believed that the open-ended response data would be richer if fewer questions were asked.

Nature of Science Questions

Adapted from *VNOS-C*, Lederman et al., 2002

1. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atoms looks like?
2. What is an experiment?
3. Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change? Explain why or why not. Defend your answer with examples.
5. Scientists perform experiments/investigations when trying to find answers to questions they put forth. Do scientists use their creativity and imagination during their investigations? Explain why or why not. Illustrate your answer with an example.
6. What in your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?

The *VNOS* questions are designed to elicit student teachers' understanding about the nature of scientific knowledge and the scientific enterprise at a level appropriate for secondary science instruction (Lederman et al., 2002). The research which produced the *VNOS* questionnaire has stretched over 15 years and resulted in a refined form of the instrument that appears to possess face and content validity (Abd-El-Khalick et al., 2001). The *VNOS* studies (Lederman & O'Malley, 1990; Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick et al, 2001) typically compare students' naïve views of the nature of science with more expert or more widely accepted views. Because the emphasis of these works was on producing an instrument that would reveal a student's misconceptions, there was not an extensive effort to document the qualitatively different conceptions that students hold around these aspects of the nature of science. *VNOS* represents an ideal instrument for this study because key questions have been identified and issues of phrasing and intelligibility have already been resolved.

It is important to note that the open-ended questions are not existing categories of description or even distinct aspects of the nature of science. Rather, they are probes that prior research has identified as useful for eliciting responses that reveal how students think about the nature of science. Each question is likely to elicit a response that can reveal a student's conceptions about any aspect of the nature of science. However, the *VNOS* questions were intended to primarily focus on one or two aspects of the nature of science:

a. Responses to Questions 1 and 4 should provide more focused insight into how students think about the tentativeness of scientific knowledge and theories.

b. Responses to Questions 2 and 3 should provide more focused insight into how students think about the aim and structure of experiments.

c. Responses to Question 5 should provide more focused insight into how students think about the role of creativity and imagination in science.

d. Responses to Question 6 should provide more focused insight into how students think about the purpose of science.

Taken as a whole, students' responses to the modified *VNOS* questionnaire should help illuminate their overall epistemology towards scientific knowledge. That is, their answers should provide insight into their thinking about how scientific knowledge is developed, specifically how the scientific enterprise produces explanations about the natural world and why they believe these explanations to be true or false. Their explanations may not be expressed in the same language as a philosopher of science, but it is assumed that they can entertain such questions and express their reasoning in a way that reveals their thinking.

Zollman (unpublished article) supports the advantage of using a large number of less in-depth data. The data typically used in phenomenography-based research are usually collected through extended interviews to gain deep insight into students' conceptualizations. However, the data used in this study are students' free writing responses to six open-ended questions. This method of using a large number of free writing responses is not uncommon in phenomenographic research because the essence of phenomenography is to identify variation in thinking at the group level. Therefore, data richness is a balance between breadth and depth. This is supported by the findings of Butcher and Prosser (1993). They performed a methodologically based study comparing an *intensive* phenomenographic investigation (based on interview data) with an *extensive* one (based on open-ended responses to a questionnaire). They found the phenomenographic research methodology is well suited for open-ended questionnaire data from a large group of subjects. They write,

> . . . the methodology of treating the trial set of data as a whole, without focusing on the variation between individuals, but focusing on the variation in the set of data as a whole, allows the researcher to see more in the data than does a content analysis of individual responses.

More specific to the domain of this proposed research, Stein & McRobbie (1997) performed a phenomenography in Queensland, Australia investigating middle school and early high school students' conceptions of the nature of science. They collected free writing response data using questionnaire items similar to the *VNOS-C* items. Bruce (1994) also recommends using written responses in phenomenographic research despite sacrificing more probing interview data.

Dataset—Population & Sample

The dataset utilized in this study is composed of 298 responses from a six-item open-ended nature of science questionnaire. All responses are from students currently enrolled in a high school chemistry course whose chemistry teacher participated in a pilot evaluation of the *Active Chemistry* curriculum. Students had approximately 50 minutes to answer the questionnaire and answer a separate question regarding a simple experimental design. Anecdotal evidence suggests that students spent the majority of the 50 minutes responding to the six-item questionnaire. The handwritten responses were professionally transcribed into 125 typed pages. The responses are organized by student using an anonymous, unique identification number that could be linked to demographic and other descriptive variables. The 298 nature of science responses represent a random sample from a large and diverse population, comprised of classrooms from 127 cities in 38 states and Puerto Rico representing a mix of urban, rural, and suburban settings. The following characterize the population dataset based on self-reported responses from teachers and students:

Table 1.

Population Dataset

% of Students	Student Characteristic
	Student Gender
52.7	Female
47.3	Male
	Student Race/ethnicity
67.4	White
16.3	Hispanic/Latino
8.2	African American
4.3	Asian/Pacific Islander
.6	Native American/ Alaskan Native
3.1	Other
	Student's Home Language Usage
75.6	English is the predominate language used at home
24.4	English is *not* the predominate language used at home
	Student Grade
8.4	9th Grade
27.4	10th Grade
56.8	11th Grade
7.4	12th Grade
	Previous Science Courses
51.3	Biology

% of Students	Student Characteristic
28.7	Chemistry
28.2	Earth Science
26.8	Physical Science
6.9	Physics
6.3	Environmental Science
7.7	Other than above

Data Analysis

In the spring of 2005, the researcher began to experiment with different approaches to analyzing the free writing response data. The process was non-linear, iterative and recursive. This time of experimentation allowed the researcher to become familiar with the data and to explore different ways to break up and analyze the student responses. These different readings and analyses provide alternative perspectives and ultimately converge on a stronger interpretation of the data that assists in answering the research questions.

Assumptions

1) It is assumed based on previous VNOS literature (Akerson and Hanuscin, 2007; Bell et al, 2003; Khishfe 2008) that students could understand the questionnaire items and successfully articulate their thoughts in ways that reveal their thinking.
2) It is assumed that students will hold a range of images or conceptions regarding the nature of science (Driver et al., 1996). It is also assumed that

> these conceptions will be at times inconsistent and internally conflicting; however, based on previous research it is likely these epistemologies can simultaneously co-exist (Khishfe, 2008; Ebenezer and Erickson, 1996).

First Iteration of Analysis—Interpreting Data Across Questionnaire Items

The original approach to analyzing the data was to organize the students' free writing responses by question. A sample of 100 student responses was randomly selected from the 298 responses that comprised this dataset. The data were organized by question, meaning there were 100 responses to Item 1, 100 responses to Item 2, 100 responses to Item 3, etc. In some instances, a student did not answer the question, so there were less than 100 student responses for each survey item. The following table captures this detail:

Table 2.

Student Responses Per Questionnaire Item

Questionnaire Item	# of Student Responses
Question 1	96
Question 2	91
Question 3	88
Question 4	87
Question 5	88
Question 6	94

All of the open-ended written responses were read for a particular question. The analysis began with Question 6—"What in your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)"—because the researcher thought the responses to that question would provide the greatest insight into the students' thinking about science in broad foundational terms, whereas the other questionnaire items would focus on more specific aspects of their thinking about the nature of science.

The researcher carefully read the student responses and started to code the text into units of meaning using Nvivo qualitative analysis software. The awkwardness of learning the software package, becoming familiar with data, keeping track of an emerging list of primary codes, and looking for similarities and differences across the responses became frustrating and eventually led the researcher to a more rudimentary method of analysis. All of the responses to a particular survey item were printed out and then cut so that each response was represented by a single slip of paper. Each response was carefully read and reread and separated into piles of emerging themes that captured the meaning of the text. In many instances, a single response contained more than one theme and therefore could be broken into smaller pieces of text that fit multiple categories. In these instances, slips of paper were cut in to smaller pieces or duplicated and categorized appropriately. Periodically, typically after carefully reading and categorizing ten responses, the researcher would revisit each of the emerging categories by rereading all the responses within the category. This process usually resulted in modifying category names, creating new categories and subcategories, moving student responses to different categories, and sometimes collapsing multiple categories into a single one. This iterative process of rereading to ensure that student response data and categories corresponded appropriately occurred approximately 10–11 times. The result of this work was a set of categories reflecting the qualitatively different ways students think about what constitutes science and what makes it different from other disciplines of inquiry. These results are detailed in Chapter 4.

This process of carefully reading each response and separating pieces of text into piles of emerging themes was repeated for questionnaire Items 2 (“What is an experiment?”) and 3 (“Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position”). These questionnaire items are intended to reveal students’ thinking about the aim and structure of experiments. As with the responses to Question 6, a single response sometimes contained more than one theme and therefore had to be divided into smaller pieces of text or duplicated to fit multiple categories. The researcher repeated the process described above of periodically rereading and revisiting emerging categories of description. This process again resulted in refining category names, creating new categories and subcategories, moving responses to different categories and collapsing categories. This iterative process resulted in a set of categories reflecting the qualitatively different ways students think about the aim and structure of experiments. These results are also detailed in Chapter 4.

Through the process of interpreting students’ written responses described above, the researcher began to realize that organizing the data by question and analyzing the responses for a single questionnaire item at a time emphasized that questionnaire item, rather than the students’ thinking. Although this “silo” approach to analyzing the data seemed to reveal accurate conceptions of how students think about specific aspects of the nature of science, it did not readily allow the researcher to make holistic interpretations about how a student or groups of students think about the nature of science in a more generalized way. To remedy this limitation, the written responses were reorganized by student, which allowed the researcher to read and interpret a student's entire written response. This change in the approach to the data places the student and his or her thinking in the center of the analysis rather than the questionnaire item.

Second Iteration of Analysis—Interpreting Data Across Students

The secondary approach to analyzing the data organized the students' free writing responses by student. Another sample of 100 student responses was randomly selected from the 298 responses that comprised the dataset. Using Nvivo qualitative analysis software, the researcher carefully read, analyzed, and coded each student's written response to all six questionnaire items. In most cases all six questions were answered. The length and detail of responses tended to vary; however, most students responded to the questions in sufficient detail to reveal their thinking about the nature of science. A close reading of how a student answered each item allowed the researcher to inductively build an interpretation of the student's conceptions of science from multiple items. Typically, written responses were read and coded in sets of 5 or 10 students. New codes were read and examined against the running list of primary codes. Codes were regularly reviewed, modified, added or collapsed as needed to reflect the emerging themes in the data. The initial reading and analysis typically would take approximately 1 to 2 hours for sets of 5 or 10 student responses, respectively. This analysis resulted in 41 primary level codes.

After an extended period of time away from the data, the researcher started to interpret the data and draw conclusions from the 41 original primary codes. The primary codes and the passages that comprise them were read and reread in order to distill the data into broader level themes. This was an iterative process of moving back and forth between emerging themes constituting the categories of description and primary level codes and student passages. This back and forth eventually resulted in collapsing the 41 original primary codes into 39 primary codes and a rethinking of the way the researcher was distilling the information into broad level themes. This reanalysis stretched over several months and eventually resulted in a revised Nvivo Nodes report (Appendix C), the list of 39 primary level codes (Table 5), 14 categories of description (Table 6), and the identification of two broad ways that students orient their thinking about the nature of science (Figure 3 and Table 7).

The list of primary codes in Table 5 represents a "saturation point" for the coding scheme. This is the point at which selecting new student responses does not require the generation of new codes because the student response can be adequately reflected in one of the existing codes. These responses were sorted according to these codes in an Nvivo Nodes report (Appendix C). This report reflects primary level themes emerging from the data. As described above, this was an iterative process of carefully reading and re-reading responses to ensure correspondence of the responses and themes. These codes were created and/or modified to allow for discrepancies. This collection of 39 primary level codes represents many nuances in how students think about science and in some instances reflects only slight variations in thinking about a specific aspect of the nature of science.

The primary level codes serve as the conceptual building blocks for further analysis intended to distill broader categories of description that reflect the qualitatively different ways that students think about science. This was accomplished through an analysis of the 39 codes that included multiple re-readings of the passages that comprise the codes. The analysis revealed 14 categories of description. These 14 categories represent a range of conceptions, from broader, more complete, more pervasive data that reflect responses from all six of the questionnaire items to more limited conceptions aligned with or conceptually related to a single aspect of the nature of science. Some categories are comprised of responses to a single questionnaire item while others are comprised of responses to multiple questionnaire items.

The researcher adhered to the following criteria for constructing categories of description to ensure the effort was methodologically sound and aligned with the phenomenographic tradition (Marton, 1986):

a) Individually, each category of description should stand in a way that tells something distinct about the way students are thinking about that aspect of the nature of science.

b) Categories should stand with a logical relationship to one another. Previous phenomenographic investigations suggest this is often hierarchical in nature

c) Categories should be explicated in a way that captures the key aspects of variation within the data.

Because phenomenography focuses on variation at the group level, the categories of description are considered in concert to make sense of the variation in thinking beyond a single individual. Taken together, the categories of description and their relationships reflect the "outcome space" that represents all of the qualitatively different ways students think about the nature of science (Marton, 1986). The outcome space represents the variation in the key aspects of students' conceptions of the phenomena at the group level. Within the outcome space, categories are arranged logically and hierarchically to reflect their internal relationship to the given aspect of the nature of science and to each other. The outcome space is a diagrammatic representation of the logical relationship between categories of description. In this work, the researcher decided to label and refer to this organizing concept as "completeness."

Completeness of the categories within the outcome space increases from the bottom to the top of the diagram. Completeness refers to the stability of the category; the more complete categories reflect themes that are characterized by a greater number of student responses and/or responses that tend to be more cohesive in the way students describe the phenomenon in question.

Categories can be organized vertically or horizontally within the outcome space to reflect relationships between categories and emphasize themes within the data. In the study, the researcher attempted to display the relationships between categories of description and emerging themes within the context of each outcome space. Sometimes categories at the top of the outcome space also reflect broader or more encompassing ways of thinking about the phenomena. For instance, a category toward the top of the outcome space may be best structured as inclusive of other, more specific categories toward the bottom of the outcome space. Figure 1 and Figure 2 are the outcomes spaces associated with the first analysis. They both reflect an organizing scheme that attempts to place more encompassing categories at the top of the outcome space. However, Figure 3 is the outcome space associated with the second analysis and does not reflect an organizing scheme that attempts to place more encompassing categories at the top of the outcome space. Sometimes categories of descriptions can be arranged within an outcome space to reflect a range of thinking along a conceptual continuum. Figure 2 and 3 represent outcome spaces in which the researcher arranged the categories along a horizontal continuum to better depict an underlying theme within the data.

Mapping Categories to Aspects of the Nature of Science

As discussed earlier in this chapter, the questionnaire items were designed to primarily focus on one of the four aspects of the nature of science investigated in this study. As part of the second analysis, the researcher mapped the 14 resulting categories of description back to these four aspects (Table 7). This activity was intended to illuminate possible relationships between an aspect of the nature of science and the related categories of description. For instance, some aspects might inherently have more variation in the way students conceive of or think about them relative to other aspects. This effort might also highlight themes that appear across the four different aspects.

Internal Confirmation

In order to help confirm the findings of this study, the researcher compared the results of the first and second iterations of analysis. As discussed earlier, the organizational scheme differed between these two sets of analyses. The first iteration arranged the raw data according to the questionnaire items. Two aspects of the nature of science (i.e., the aim and structure of experiments and the purpose of science) were examined in this manner. The second iteration arranged the raw data by the students responding to the questionnaire items to help emphasize the different ways that individual students or a group of students think about science. Responses to all six of the questionnaire items were included in the second iteration of analysis.

Tables 8 and 9 in Chapter 4 compare analogous categories between the first and second analyses. Table 8 depicts categories associated with the aim and structure of experiments, and Table 9 depicts categories associated with the purpose of science aspect of the nature of science. Analogous categories were identified based on the similarity of the conceptions; this was accomplished through a close reading of both the primary codes and a rereading of the passages that comprise the codes.

Limitations

The categories of description that were developed in these analyses were primarily based on the primary researcher's interpretation of the data. Another science education researcher reviewed the findings and methodological procedures; however, a thorough check based on an analysis of primary level data was not performed. Similarly, there was not an opportunity to perform a "member check" (Creswell, 1994) to ensure that a student's response is being interpreted accurately and fully reflects his or her thinking about the nature of science.

Summary

A six-item open-ended nature of science questionnaire, adapted from Lederman et al.'s (2002) Views of Nature of Science (*VNOS-C*), was administered as part of a larger curriculum evaluation study. The 298 nature of science responses were collected from a sample representing a large and diverse population of high school students. A phenomenographic methodological framework was used to organize and interpret the data. This phenomenographic approach focused on identifying variations in the key aspects of students' conceptions of the nature of science.

CHAPTER 4

ANALYSIS OF DATA

This chapter provides the results of this study, organized according to the first and second iteration of analysis. A brief introduction summarizes the purpose and the major findings of this work.

Introduction

The goal of this study is to describe the qualitatively different ways high school chemistry students think about the nature of science using open-ended student response data. This work attempts to reveal students' understanding using open-ended student response data from a questionnaire that probes the following aspects of the nature of science:

- Purpose of science
- Tentativeness of scientific knowledge and the nature of theories
- Creativity & imagination
- Aim & structure of experiments

This chapter provides the findings from two iterations of analysis that were performed to better understand students' thinking about these four aspects of the nature of science.

The first iteration focused on the purpose of science and the aim and structure of experiments. This first iteration of analysis organized and interpreted student response data by questionnaire item. Although the researcher believed this method yielded accurate conceptions about the ways students think about science, it tended to atomize thinking and emphasize the questionnaire items rather than the qualitatively different ways students think about science. Three of the six questionnaire items were analyzed using this organizational and interpretative framework.

The second iteration of analysis organized and interpreted the data by student. For instance, the researcher carefully read, analyzed, and coded a student's written response to all six questionnaire items, before moving on to the next student's responses. This type of analysis emphasized each student's thinking and allowed for a more holistic analysis that highlighted the differences between students rather than questionnaire items. One hundred students' responses were analyzed this way, resulting in 39 primary level codes and 14 themes, called categories of description. The categories were then mapped to the four aspects of the nature of science which were being investigated with the questionnaire probes.

The third iteration of analysis simply compared and confirmed the results of the two previous methods in an attempt to identify congruent, discrepant, and/or missing themes or categories of description between the two analyses. This confirmation analysis also helped identify a fundamental difference in the way students tend to think about the nature of science. The findings from these analyses are presented in detail below.

Analysis: Iteration 1—Interpreting Data Across Questionnaire Items

This study maps out the cognitive realm of understanding using an emergent phenomenographic research approach. As described in Chapter 3, the objective of phenomenographic research is to identity the variations in the key aspects of a phenomenon at the group level. This is accomplished by developing structured sets of "categories of description." The questionnaire items were designed to probe differing aspects of the students' understanding of the nature of science. In other words, each item provided a window from which to view the conceptual space of chemistry students' views of the nature of science. This first iteration of analysis organized and interpreted student response data by questionnaire item. The questionnaire items were:

(2) What is an experiment?

(3) Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.

(6) What in your view is science? and What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?

A more detailed description of how this analysis was performed is provided in Chapter 2 of this work. The findings from this analysis are provided below.

Questionnaire Item 6

Questionnaire Item 6 was originally designed to probe students' thinking about the purpose of science. It was analyzed first because several previous studies (Aikenhead & Ryan, 1992; Driver et al., 1996; Lederman et al., 2002) suggest that students' thinking about the purpose of science is a fundamental component in understanding their thinking about other aspects of the nature of science. The researcher believed that student responses to this question would help reveal their epistemological and ontological assumptions about science. Understanding these assumptions could help the researcher understand their thinking about other aspects of the nature of science (e.g., aim and structure of experiments, the tentativeness of scientific theories).

As described above, 100 random student responses were selected and then resorted by questionnaire item. Some students did not respond to every question. The following chart is based on the analysis of the written responses of 94 students to questionnaire Item 6: *What in your view is science?* and *What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?* Student responses to this probe were categorized into seven concepts. The chart below provides the categories or themes, a short description of the category and several supporting statements.

Table 3.

Questionnaire Item 6 Categories of Description

Category and Description	Supporting Statements: Science is …
Science is Everything	
Many students use a catchall phrase such as, "science is the study of everything," to describe their view of science. The Everything Concept is usually characterized with loose and ambiguous verbiage such as, [Science is] "anything that could be explained in words" or "everything around us or inside of us."	• "anything that could be explained in words" • "everything around us or inside of us" • "the study of earth and how things work" • "the study of life and other things"

Category and Description	Supporting Statements: Science is …
Science is Proof	
In this category students characterize science as being a purely objective activity that results in the “proof” of ideas. As one student writes, science “can either be proved correct or incorrect making it either right or wrong.” Some students framed scientific knowledge as being beyond question or debate because it is “proved right,” whereas, “religion and philosophy can be argued” because these ideas are “personal matters.” Many students describe experiments as the reason why science is based on facts and proof.	• “Science can either be proved correct or incorrect making it either right or wrong.” • “Science is backed by data and experiments making it right or wrong.” • “It’s different from others because there are sets of facts & rules not up for interpretation or opinion.”
Science is the Act of Discovery	
This category describes science with verbs such as discovering, exploring, and asking. Here the emphasis is on inquiry or the process of science rather than the products of science (e.g., knowledge—theories, laws, principles).	• “science to me is all about experiments & learning new solutions & finding out things that the human eye can’t see or something like that.” • “Science is a gift that we have today, it's the gift of knowing more about the world and its discoveries. Science is made by science discoveries and the knowledge to know more about things we never knew.”
Science is Helpful	
A few students distinguished science from other disciplines of inquiry because they saw it as helpful to mankind. Students who have this utilitarian view describe science in terms of it being beneficial to society because it is intended to solve problems.	• “It is finding the answers for things that can later help us in the future.” • “You could help people in many ways with the science by either curing a disease or convicting a killer.” • “Technology.”

Category and Description	Supporting Statements: Science is …
	Science is Not Different
These responses might vary in their description of what science is, but all describe science as not really being different from religion or philosophy. Usually, this reasoning was centered on the idea that science is based on beliefs in the same way as religion.	• "Science is not much different than religion. People form their own opinions on how things were and stick to it just like they do in religion." • "Science is a way of interpreting things. I think it is a bunch of theories about world just like religion & philosophy are theories. And, both scientific and religion there are things I believe & do not believe—no matter if they are 'FACT' or not—it's simply an interpretation."
	Contextual Science
The responses in this category describe science in terms of a specific set of experiences associated with school and the classroom or explain science within the narrow boundaries of a particular discipline, such as chemistry or biology. Note: the questionnaire used in this study was administered as part of a dry chemistry laboratory activity.	• "What's different about science is that there is more hands-on than bookwork … and it's never boring like history or math." • "Science is a very hard course overall." • "Science is labs & experiments which make it fun." • "Science is the ability to combine elements."
	Science is an Orderly Explanation
(This category is not as distinct) These responses tend to focus on science being an explanation of things. Science is distinct because it is based on organized, orderly, or realistic reasoning or thinking, as opposed to religion, which is based on beliefs.	• "Science is the study of our universe and its happenings of significance. It is more orderly and organized than religions and philosophies." • "In my view science is another way of explaining life and matter etc. Science has a more realistic approach than religion." • "Science requires thought."

As described in Chapter 3, categories of description are pieces of the researcher's model of how a phenomenon is experienced (Bowden, 1995). Taken together, the categories of description are considered by Marton (1986) as representing the "outcome space" that describes the qualitatively different ways a given phenomenon could be experienced or thought about. The outcome space is a diagrammatic representation of the logical relationship between categories of description. The diagram below represents the structured collection of ways that the students in this study think about the nature of science questionnaire probes, *What in your view is science?* and *What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?*

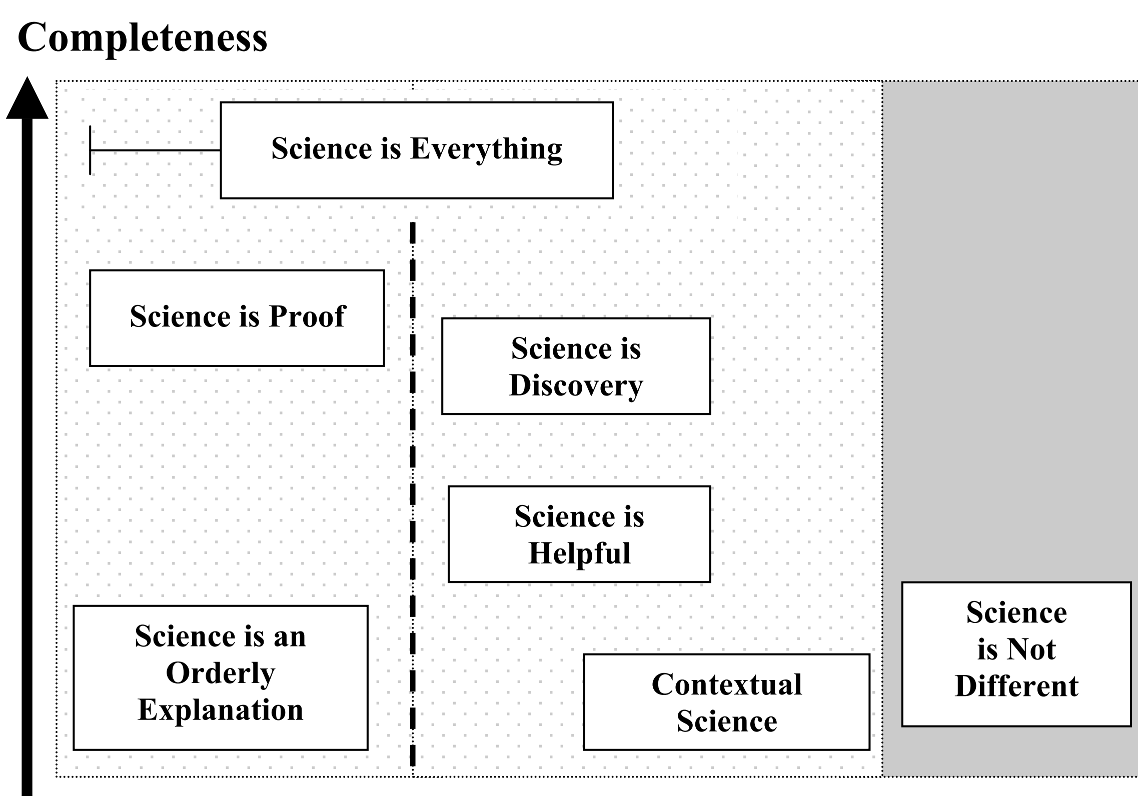

Figure 1. Questionnaire Item 6 Outcome Space

Completeness of the categories within the outcome space increases from the bottom to the top of the diagram. Completeness refers to the stability of the category; the more complete categories reflect themes that are characterized by a greater number of student responses and/or responses that tend to be more cohesive in the way the students describe the phenomenon in question. For instance, the responses that comprise the *Science is Everything* category are cohesive and hang together as a tight grouping because they sound very similar. Students tend use the same language to express their thinking about science being the study of everything in the world. Therefore, the *Science is Everything* category is more complete relative to the other categories that occupy the outcome space. The categories are structured logically and hierarchically to reflect their internal relationship to the given aspect of the nature of science and to each other. The hierarchical arrangement uses completeness as the organizing criteria to place some categories higher on the outcome space than other categories. Categories at the top of the outcome space also represent broader or more encompassing ways to think about the phenomena. For instance, a category toward the top of the outcome space may be best structured as inclusive of other, more specific categories toward the bottom (e.g., *Science is Discovery*, *Science is Helpful*, and *Contextual Science*). As described in greater detail below, the responses in these three categories reflect a varying sense of inquiry and investigation, from rather explicit in *Science is Discovery* to more implicit in *Contextual Science*.

The placement of categories on different backgrounds is intended to highlight how categories are logically related to each other and the phenomena in question. Put another way, the difference in the backgrounds is designed to show how the categories of description expose the qualitatively different ways students think about science and what science is. For instance, the outcome space is intended to show that students, on a broad level, tend to think science is everything, or about fact, or about discovery; to a lesser extent, some students think science is not different than other disciplines. The *Science is Not Different* category is less complete relative to most of the categories that comprise this outcome space. Categories within the same background tend to be more logically related than those on different backgrounds and reflect a similarity in the way students think about science (e.g., varying degrees of inquiry and investigation). The categories of description and their relationships reflect the “outcome space.” The outcome space represents the variation in the key aspects of students’ conceptions of the phenomena at the group level. The outcome space is comprehensive in the sense that nothing in the collective sense is left unspoken. That is, all possible dimensions or aspects of students’ thinking about the phenomena in question are reflected in the categories that comprise the outcome space. Any given student may not express all of the different aspects of the phenomena, but taken collectively, all the qualitatively different ways to think about the phenomena are represented by the categories of description that make up the outcome space.

The *Science is Everything* category is the most complete and distinct relative to the other categories, and is therefore placed at the top of the outcome space diagram on a background that differs from the other categories. The word “everything” is used in most of the passages that comprise this category, and many of the student responses sound strikingly similar in the way they describe science as all-encompassing. Table 3 provides a description of this category and examples of typical student responses.

Although the *Science is Everything* category is very complete and distinct, some of the passages within this category reflect a significant dichotomy in the way students think about science. Many of the student responses to the questionnaire probes (i.e., *What in your view is science?* and *What makes science different from other disciplines of inquiry?*) suggest a fundamental difference in the way students think about science.

Students tend to either think about science as being about *facts and proof* or as an act of *discovery*. The placement of these categories in the outcome space—the vertical, horizontal, and crosshatched backgrounds and the dashed line—attempts to capture the relationship between these categories of description. As you will see, this dichotomy in student thinking appears in the response data from multiple questionnaire items and in other analyses.

The *Science is Proof* category is characterized by student responses that frame science as an endeavor to "prove" something as "right or wrong," and once "proven" it is beyond question or debate because it is "fact." This type of thinking is evidenced in the following student quotes: "Science is backed by data and experiments making it right or wrong"; "It's different from others because there are sets of facts & rules not up for interpretation or opinion." In these responses, "fact" is often used in a way that suggests it is the end product of doing science. The *Science is Proof* category is the more complete of the two dichotomous categories because this is a more common conception, and is placed slightly higher in the outcome space diagram. It is more complete because more student responses reflect this type of thinking and the responses tend to use language that is more similar.

The responses that comprise the other part of the dichotomy make up the *Science is Discovery* category. These responses tend to describe science with verbs such as *discovering* and *exploring* and frame science as being about asking questions. This type of thinking is typified in the following quotes: “Science is about discovering everything in our universe”; “Science is the discovery of life and learning how things work and why certain things happen.” Without actually using the word, student responses tend to reflect the meaning of “inquiry,” similar to the way Inquiry and the National Science Education Standards: A Guide for Teaching and Learning (2000) describes what inquiry in the science classroom involves (e.g., making observations, posing questions, evaluating information and planning and performing investigations through gathering and interpreting data). There also is a more positive and exciting tone in these responses, e.g., “Science is a gift that we have today, it's the gift of knowing more about the world and its discoveries.” The placement of these two categories (i.e., *Science is Proof* and *Science is Discovery*) on differing backgrounds attempts to highlight this fundamental difference in the way students think about the purpose of science.

The *Science is Discovery* category is relatively complete compared to the other categories and inclusive of other emergent themes in the response data. For instance, as several students describe science as act of discovery, they also distinguish science from other disciplines of inquiry because they see it as helpful to mankind. This cluster of student responses represents the *Science is Helpful* category. These student responses reflect a sense that science has a strong utilitarian underpinning. Table 3 provides a description of this category and examples of typical student responses. These students think about science in terms of it being beneficial to society because it is intended to solve problems and results in solutions and benefits (e.g., cures for diseases) and things that can be used (e.g., technology).

A less complete, yet distinct, category is *Contextual Science*. This category is less complete because there are a smaller number of student responses that reflect this theme and the responses that comprise this category are less cohesive in the way they describe science. These responses generally describe science in terms of a specific set of experiences associated with school and the classroom or explain science within the narrow boundaries of a particular discipline, such as chemistry or biology. Table 3 provides a description of this category and examples of typical student responses.

The responses in the *Science is Discovery*, *Science is Helpful*, and *Contextual Science* categories reflect a varying sense of inquiry and investigation, from rather explicit in *Science is Discovery* to more implicit in *Contextual Science*. The *Science is Discovery* category typically reflects responses that are broad, general statements. The *Science is Helpful* category is typically supported by more specific responses that suggest science leads to discoveries that help humans, such as inventions and cures. The *Contextual Science* category is typified by responses that relate science to school experiences such as laboratory assignments and investigations. However, most of the responses that typify these categories convey some sense of inquiry and discovery.

Although the *Contextual Science* responses tend to reflect a relationship with the *Science is Discovery* category, they do not reflect an association with the *Science is Everything* category. This category is not located under the umbrella of the *Science is Everything* category because the passages describe science much more narrowly and in no way suggest that science is all encompassing.

Another less complete, yet distinct category is *Science is an Orderly Explanation*. These responses tend to focus on science being an explanation of things. Science is distinct because it is based on *organized*, *orderly*, or *realistic* reasoning or thinking, as opposed to religion, which is based on beliefs. Table 3 provides a description of this category and examples of typical student responses. This category is related to the *Science is Proof* category because the language students use to describe science as an orderly process relates scientific reasoning to end products of science, such as models and theories, which are similar to, but distinct from, end products that are perceived to be facts or proof. The placement of this category near the bottom of the outcome space diagram and within the same background or field as the *Science is Proof* category attempts to capture these relationships. Some of these passages do reflect thinking that science is an all-encompassing endeavor, so it could be placed under the *Science is Everything* umbrella.

One of the least complete, yet distinct, categories is *Science is Not Different*. The incompleteness of this category is due to few student responses that reflect this thinking, However, it warrants distinction because the category is different than the others, These responses vary in their description of what science is, but all describe science as not really being different from religion or philosophy. Usually, this reasoning was centered on the idea that science is based on opinions and interpretations in the same way one might hold an opinion or have interpretation about religion. Table 3 provides a description of this category and examples of typical student responses. The distinction is the way these students tended to think about both science and religion as being narratives or interpretations that someone "sticks to" like a belief. The placement of this category on a separate background or field is intended to convey the idea that this category is fundamentally different than the other categories.

Questionnaire Items 2 and 3

Similar to Table 3 and the process described above, the table below is based on the response data from two questionnaire items about the nature of science: (2) *What is an experiment?* and (3) *Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.* These responses were interpreted together because they are both designed to probe the way students think about the aim and structure of experiments. Table 4 is based on the analysis of 91 student responses to questionnaire Item 2 and 88 student responses to questionnaire Item 3. Students' responses to these probes were categorized into seven concepts. Table 4 provides the categories or themes, a short description of the category, and several supporting statements.

Table 4.

Questionnaire Items 2 and 3 Categories of Description

Category and Description	Supporting statements
Experiments Prove	
These responses describe experiments as the basic vehicle or a necessary step to "prove" a hypothesis. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, knowledge is framed as facts or proven information.	• "Without experiments science can only be taken for face value & not actual proven information." • "Experiments are needed to prove facts about life and of new findings." • "…an example is when Ernest Rutherford performed the 'gold foil experiment. This experiment proved that the gold foil contained many small dense positively charged nucleus surrounded by electrons."
Experiments Confirm	
These responses describe experiments as the basic vehicle or a necessary step to generate data that support an idea or confirm a hypothesis, as opposed to proving an idea to be fact. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, knowledge is not framed as facts or proven information.	• "Yes, to support their findings and hypothesis. For example, the rotation of the earth. Scientists had to conduct experiments to help defend what they thought." • "Yes, because you wouldn't confirm anything if you didn't test it." • "Yes, so they can check their positions and views."

Category and Description	Supporting statements
Ways to Learn New Things	
These responses describe experiments as the basic vehicle or a necessary step in making scientific discoveries. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, the emphasis is on the act of discovery and learning new information.	• "Yes, because without experiments it would be a lot harder to learn new things." • "The development of scientific knowledge is heavily dependent on experiments because the information gathered and the discoveries made through experimentation are what fuel that development. Many vitally important discoveries in the world of science have been made through experimentation (alpha, beta & Gamma Rays)."
Experiments Lead to Inventions	
These responses describe experiments as necessary to science because they result in helpful products and lead to inventions. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, the emphasis is on a product such as a cure for a disease or a piece of new technology.	• "Yes, because experiments are how scientists grow and make inventions and innovation to existing things like the VCR, now there's the DVD player or cloning proved because of an experiment on sheep." • "Yes it does. If there were no experiments then there would be no light bulbs. It was because Edison tried and tried. Even though he failed a couple of times he kept experimenting. And if we don't keep experimenting how are we going to find a cure for AIDS & cancer."
Methods for Collecting Data	
These responses describe experiments in terms of an activity, such as procedures or steps. Some of the responses frame this activity as part of the scientific method.	• "An experiment is the scientific method. It includes many steps, including creating a hypothesis, observing/collecting data, performing the experiment, then creating theories all based on their hypothesis."

As previously described, the categories of description are pieces of the researcher's model of how a phenomenon is experienced (Bowden, 1995). Collectively the categories of description are considered by Marton (1986) as representing the "outcome space" that reflect the variations of understanding or experiencing a given phenomenon. Dahlin (2007) explains phenomenography as a creative exploration and the categories of description as variations of conceptions for a given phenomena. He goes on to describe the outcome space as a conceptual space that maps out the conceptions reflected by the categories of description in a way that reveals the structural relationships between them. He writes that the outcome space is a map of the mind, in the mind.

In this work, the researcher presents the outcome space in a diagrammatic representation of the categories of description. The diagram below represents the structured collection of ways that students in this study think about the nature of science questionnaire probes, *What is an experiment?* and *Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.* The categories are structured logically and hierarchically to reflect their internal relationship to the given aspect of the nature of science and to each other. For instance, a category may be best structured as inclusive of other, more specific categories (e.g., *Experiments Prove* and *Experiments Confirm*). The outcome space diagram below represents the qualitatively different ways students think about the aim and structure of scientific experiments.

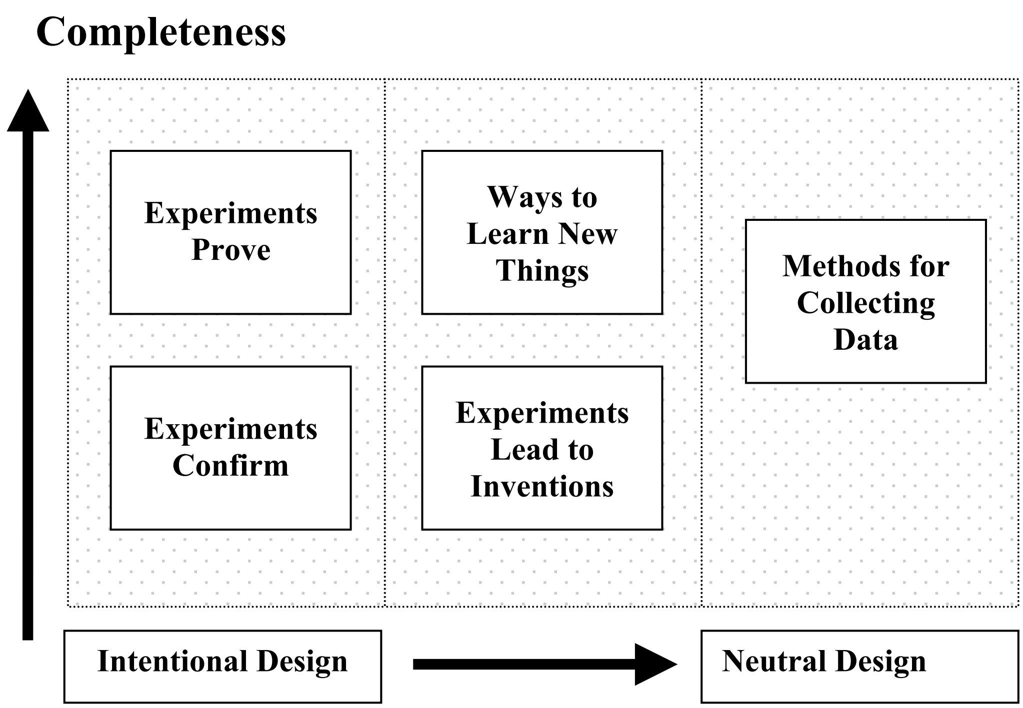

Figure 2. Questionnaire Item 2 and 3 Outcome Space

As described earlier, completeness of the categories within the outcome space increases from the bottom to the top of the diagram. Completeness, at least in part, refers to how well the categories of description are grounded or substantiated by the student response data. The more complete categories reflect themes that are characterized by a greater number of student responses and responses that tend to be more cohesive in the way the students describe the phenomenon in question. The difference in the background is designed to highlight how the categories of description expose the qualitatively different ways students think about science and the aim and structure of experiments. Categories within the same background tend to be more logically related that those in different backgrounds, and reflect a similarity in the way students think about science.

The categories of description and their relationships reflect the "outcome space." The outcome space represents the variation in the key aspects of students' conceptions of the phenomena at the group level. The outcome space was arranged to highlight a difference in the way some students frame their thoughts about experiments. The categories on the left side of the outcome space tend to reflect passages where students discuss designing experiments with a specific intent in mind. These passages tend to describe experiments similar to an argument: a way to persuade others that a given idea is right or wrong. The following passages reflect this intentionality: "An experiment is a series of tests performed to prove a point"; "An experiment is a project in which you try to prove something about a hypothesis you made." These students do not seem to be describing designing experiments and interpreting results as an objective truth-seeking effort.

The categories on the right side of the outcome space tend to frame experiments as a series of procedures or tests, emphasizing the gathering of evidence rather than an a priori conclusion. These passages tend to imply a purpose for the experiment, but are explicit regarding an outcome that could either confirm or reject the prediction of a hypothesis. The following passages reflect this more neutral tone: "The gathering of evidence to see if something is true or false"; "It is a series of tests to prove or disprove a hypothesis of a problem a problem."; "It is the observation of a reaction."

The responses that comprise the *Experiments Prove* category describe experiments as the basic vehicle or a necessary step to "prove" a hypothesis. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, knowledge is framed as facts or proven information. This category is relatively complete compared to the other categories because it is inclusive of other emergent themes in the response data and is grounded in a large number of responses. The *Experiments Confirm* category is less complete, yet remains distinct. These responses describe experiments as the basic vehicle or a necessary step to generate data that support an idea or confirm a hypothesis, as opposed to proving an idea to be fact. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, knowledge is not framed as facts or proven information. Table 4 provides a description of these categories and examples of typical student responses that contrast these similar, yet distinct categories.

Ways to Learn New Things is another relatively complete category. Similar to the *Experiments Prove* category, it is relatively complete compared to the other categories because it is inclusive of other emergent themes in the response data and is grounded in a large number of responses. These responses describe experiments as the basic vehicle or a necessary step in making scientific discoveries. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge. However, the emphasis is on the act of discovery and learning new information. As with the above, this category is inclusive of other emergent themes in the response data. The *Experiments Lead to Inventions* category is less complete, yet remains distinct because of how these students focus on the utilitarian end products of scientific experiments. These responses describe experiments as necessary to science because they result in helpful products and lead to inventions. These responses reflect thinking that considers experiments as a required element in the generation of scientific knowledge; however, the emphasis is on a product such as a cure for a disease or a piece of new technology. Table 4 provides a description of these categories and examples of typical student responses that contrast these similar, yet distinct categories.

As described in Chapter 3, the process of interpreting students' written responses by questionnaire item emphasized the questionnaire items, rather than the students' thinking. The researcher believed this "silo-ed" approach to analyzing the data revealed accurate conceptions of how students think about specific aspects of the nature of science; however, it did not readily allow one to make broad interpretations about how a student or groups of students think about the nature of science in a holistic way. Organizing the written responses by student and reading and interpreting a student's entire written response would place the students and their thinking in the center of the analysis rather the questionnaire item intended to probe their thinking. This organizational strategy is more likely to reveal variations in students' thinking about the nature of science.

Analysis: Iteration 2—Interpreting Data Across Students

The second approach to analyzing the data was to organize the students' free writing responses by student. The researcher randomly selected another sample of 100 student responses from the 298 responses that comprised the dataset. Using Nvivo qualitative analysis software, the responses to all six questionnaire items were carefully read, analyzed, and coded for a given student. In most cases all six questions were answered. The length and detail of responses tended to vary; however, most students responded to the questions with sufficient detail to reveal their thinking about the nature of science. A close reading of how a student answered each item allowed the researcher to inductively build an interpretation of the student's conceptions of science from multiple items. Student responses were typically read and coded in sets of 5 or 10 students. The researcher would then reexamine the primary codes against the running list of codes and then add, modify, and/or collapse the codes as needed. The initial reading and analysis typically would take approximately 1 to 2 hours for sets of 5 or 10 student responses, respectively. The responses were sorted according to these codes in an Nvivo Nodes report (see Appendix C). This initial report was carefully read and re-read and checked against the student response data to ensure the code themes and open-ended student responses were well aligned. These code themes were created and/or modified to allow for discrepancies.

While interpreting the data and drawing conclusions, the original primary codes were again revisited and several more primary codes were collapsed and modified. The Nvivo Nodes report (Appendix C) reflects primary level themes emerging from the data. This analysis resulted in 39 primary level codes, listed in the chart below.

Table 5.

Analysis II Primary Codes

	Node #	Node Description	Passages
1	15	experiments provide proof	33
2	6	creativity required for designing experiments	23

	Node #	Node Description	Passages
3	12	experiments test a hypothesis	21
4	22	scientific knowledge requires experiments	20
5	27	science is finding out	19
6	13	experiments are helpful procedures	18
7	39	types of experiments (examples of specific experiments)	17
8	16	(scientists are) fairly certain about (the structure of) atoms	14
9	31	science is the study of life or everything	14
10	7	creativity is useful for making new ideas	13
11	33	theories change because of discovery & new information	13
12	1	science is different because it's not about beliefs or faith	13
13	11	experiments test an idea	13
14	3	scientists are certain because of experiments	12
15	4	certain about the structure of atoms because of microscopes	12
16	35	theories change because they are not fact	11
17	14	experiments help discover	10
18	30	science is proven	10
19	8	(theories change because of) different or better scientists	8
20	37	theories do not change	8
21	26	science is based fact	7

	Node #	Node Description	Passages
22	34	theories change because experiments change	7
23	36	theories change because they are proven wrong	7
24	19	no creativity because science is fact	6
25	25	science is about discovery	6
26	28	science is helpful (e.g., create medicine)	5
27	21	not informative (nonsense and not interpretable)	5
28	9	experiments are the study of an object	4
29	10	experiments are required because they are hands-on	4
30	20	(scientists are) not certain about an atom	4
31	24	science is a logical perspective	4
32	2	science is certain because it's taught	3
33	5	creativity generates questions	2
34	17	(we understand atoms because the) model matches theory	2
35	29	science is not different (than other disciplines of inquiry)	2
36	18	theories do not change—tested many times	1
37	23	science is different because it does not have rules	1
38	32	science subjects are different	1
39	38	(theories do not change) theories improve	1
		Total Coded Passages	374

* Code descriptions in Nvivo were limited to 50 characters. The descriptions in the chart above have been slightly modified to eliminate shorthand and abbreviations.

A total of 374 passages were identified and coded from the student responses that were analyzed. The frequency of passages associated with these codes ranges from 33 passages comprising the *Experiments Provide Proof* code (node 15) to several codes that are comprised of a single passage (nodes 18, 23, 32, and 38). This list represents stable themes or a "saturation point" for the coding scheme. This is the point where the selection of new student responses does not require the generation of a new code because the student response can be adequately reflected in one of the existing codes. There are four primary codes that consist of one passage. Three of the four instances reflect reasoning that is very distinct and does not show up in other responses (node 18, 23, 38). The other instance (node 32) is a primary code that reflects a very narrow observation about science. It is conceivable that more student responses might reveal more nuanced thinking and generate additional primary codes.

The 39 codes represent many nuances in how students think about the nature of science. Some of the codes reflect rather slight differences in thinking within a specific aspect of the nature of science; however, the variation between these primary level codes is still evident. In an effort to distill the essence of how students qualitatively think differently about the nature of science, the researcher collapsed the 39 codes based on the similarity of responses. This analysis was accomplished through both a close reading of the codes themselves and a rereading of the passages that comprise the codes. Table 6 is the result of this analysis and represents broader, more stable categories of description that reflect the qualitatively different ways these students think about the nature of science. The analysis revealed 14 categories of description. These categories represent variation in student thinking ranging from rather common conceptions associated with multiple questionnaire probes to less common conceptions typically related to a specific probe. Table 6 is discussed in more detail below; it depicts the Nvivo node number, the node description, the number of passages associated with the node, and the broader level category represented by the grouping. The table is organized according to the number of passages that comprise a category of description. This ranges from the 67 passages that comprise the most common category, *Theories Change*, to the less common *Science as a Perspective* category, comprised of six passages.

Table 6.

Analysis II Categories of Description

	Node	Node description	Passages
		Theories Change (67 passages)	
1	16	Scientist are fairly certain about the structure of atoms	14
2	33	Theories change because of discovery & new information	13
3	35	Theories change because they are not fact	11
4	8	Different or better scientists	8
5	34	Theories change because experiments change	7
6	36	Theories change because they proven wrong	7
7	20	Scientists are not certain about the structure of an atom	4
8	17	Model (of the atom) matches theory	2
9	38	Theories improve	1
		Experiments Prove (65 passages)	
10	15	Experiments provide proof	33

	Node	Node description	Passages
11	22	Scientific knowledge requires experiments	20
12	3	Certain because of experiments	12
		Experiments Test (44 passages)	
13	12	Experiments test a hypothesis	21
14	11	Experiments test an idea	13
		Science is about Facts and Proving (30 passages)	
15	1	Beliefs or faith	13
16	30	Science is proven	10
17	26	Science is based on fact	7
		Science is about Finding Out (26 passages)	
18	27	Science is about finding out	19
19	25	Science is about discovery	6
20	23	Science different because there are few rules	1
		Theories do Not Change (24 passages)	
21	4	Certain (about atom structure) because of microscopes	12
22	37	Theories do not change	8
23	2	Certain because it is taught	3
24	18	No change because theories are tested many times	1
		Science is helpful (23 passages)	
25	13	Experiments are helpful procedures	18
26	28	Science is helpful/creates medicine	5
		Creativity with Experiments (23 passages)	
27	6	Creativity required for designing experiments	23

	Node	Node description	Passages
		Science is everything (15 passages)	
28	31	Science is the study of life or everything	14
29	32	Science subjects are different	1
		Creativity with ideas (15 passages)	
30	7	Creativity is useful for making new ideas	13
31	5	Creativity generates questions	2
		Experiments Discover (10 passages)	
32	14	Experiments help discover	10
		Experiments are procedures (8 passages)	
33	10	Experiments are required because they are hands-on	4
34	9	Experiments are a study of an object	4
		No Creativity (6 passages)	
35	19	No creativity because science is fact	6
		Science as a perspective (6 passages)	
36	29	Science is not different	2
37	24	Science is a perspective	4

Theories change

This category is comprised of nine nodes and 67 student passages. The passages that comprise this category are largely responses to the following two questionnaire items:

1. *Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles)*

with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

2. *After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain why or why not. Defend your answer with examples*.

Many of the responses are not specific about how or why a scientific theory might change; many simply imply that scientists are not certain about the structure of an atom, or that theories are not fact. This category is comprised of responses that reflect a range in the tentativeness of scientific theories and a variety of reasons why theories might change. However, despite the variety of responses, all suggest that scientific knowledge is not absolute or certain. The responses that suggest a reason or mechanism for change in scientific theories can largely be grouped into the following subcategories:

- Theories change because scientists learn more and discover new information
- Theories change because of new or better scientists
- Theories change because of new experiments and technology

The following quotes typify the thinking associated with these subcategories: “yes, [theories change] because they come up with better ways to test things”; “yes, theories change along with understanding and technology. A theory is the answer to a question given a particular time and understanding. In ancient times it was believed the sun orbited the Earth, in their time and understanding of the world this was the right answer, technology advanced (telescopes, geometry, etc.) this theory changed." Many responses explicitly state that theories change because they are not "fact" or "proven." This type of thinking is typified in the following passage:

> Yes, because a theory is a hypothesis not yet proven. For example the kinetic molecular theory. This theory explains how the idea that particles of matter are always in motion. Because it is named a theory not a proven fact or law it could change or be proven wrong. Although it is yet to have been changed.

A few passages suggest, although not explicitly, that theories change as they improve and can explain more about the phenomena in question.

Experiments Prove

This category is comprised of three nodes and 65 student passages. The passages that comprise this category are largely responses to the following three questionnaire items:

1. *Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.*
2. *What is an experiment?*
3. *Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?*

These passages suggest science is proven through experiments. This type of thinking is typified in quotes such as:

> Yes, the development of scientific knowledge requires experiments because without them we wouldn't be able to know things for sure or prove them to anyone. Without experiments people wouldn't be able to know things for sure or prove them to anyone.

These passages frame science as a rigid process of producing knowledge that is absolute and certain. The certainty of scientific knowledge is the result of experiments. This certainty is an inherent and defining characteristic of knowledge that is produced through experiments. Proving is often described as the purpose and driver of scientific endeavors, and proof is the product of doing science.

Experiments Test

This category is comprised of two nodes and 44 student passages; most passages are responses to the questionnaire item, *What are experiments?* These passages describe experiments as activities designed to test an idea or hypothesis. These passages emphasize that experiments are used to make summative judgments about a scientific idea. The passages highlight the evaluative nature of experiments to draw a conclusion or make a determination. This conception about experiments is evidenced in the following quotes: "An experiment is a test [sic] controlled conditions that is made to demonstrate a known truth, examine a validity of a hypothesis, and demonstrate the efficacy or something previously untried"; "Something performed to prove a hypothesis. Experiments involve scientific tools, formulas, and methods used to carry out a though or idea having to do with science." Many of the passages suggest experiments are required by the process or method of doing science. The actual word *test* appears in almost all passages.

Science is about Facts and Proving

The category is comprised of three nodes and 30 passages. Most of the responses are to the questionnaire item, *What in your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?* The three nodes that comprise this category all reflect student thinking that frames science as being about fact and certainty. The "*beliefs and faith*" node is comprised of passages that explicitly compare science with religious beliefs or faith. Seven of these 13 passages describe the difference between science and other disciplines of inquiry as being that science is about *proving or fact* whereas religion is about *beliefs or believing*. The "*beliefs and faith*" passages describe science as being different from other disciplines of inquiry, and most passages are grounded in the idea that science has to do with proving and facts or understanding the physical world, while religion is about beliefs and faith. The passages suggest that science is based on empirical or measurable evidence, whereas that type of evidence is not a requirement of religion. This type of thinking about science is typified in the following quotes: "Religion is a belief, philosophy is an opinion and science is a fact"; "science relies on logic, math, and the physical world to determine truth, whereas religion & philosophy rely on people's interpretation of the world"; "Science is proven material. Religion and philosophy are things we believe."

Generally, all of the passages in this category frame science as a rigid process of producing knowledge that is absolute and certain. This certainty is described as an inherent and defining characteristic of scientific knowledge. Proving is often described as the purpose and driver of scientific endeavors, and proof is the product of doing science. This conception of science is evidenced in the following student quotes: "Science is the straight facts. There is nothing that will go unexplained. Which compared to religion is the complete opposite. Religion is based solely on belief. Some things are not explained in religion. That will not happen in science"; "Science is all based on experiments and facts. Religion might be based on experiments and facts but no one knows if they are for sure real and science is proven through experiments. Religion can be different and have different beliefs in different countries, but science is all the same, everywhere."

Science is about Finding Out

This category is comprised of three nodes and 26 passages. Most of the responses are to the questionnaire item, *What in your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?* The three nodes that comprise this category associate science with discovery and finding out new information. The passages associated with this category tend to frame science as a process to understand the world, and discovering new information is seen as the driver or motivation for doing science. These responses describe experiments as the activity or mechanism that scientists engage in to discover new information. In general, the passages that comprise these nodes tend to convey more of a sense of activity through the use of action verbs such as *discovering*, *exploring*, and *figuring* relative to the more static language associated with the *Science is about Fact and Certainty* category. This conception of science is evidenced by the following student quotes: “Science for me is exploring finding information around us, finding out who lived before us, what happened to them, how are we doing in the word”; “Science is discovering everything about our universe”; “Well, we don’t know everything yet. So until then we will have to rely on experimentation to discover what we haven’t yet.”

Theories Do Not Change

This category is comprised of four nodes and 24 student passages. The passages that comprise this category are responses to the following questionnaire items:

1. *After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change? Explain why or why not. Defend your answer with examples.*
2. *Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?*

All these passages are reflective of thinking that views scientific theories as proven, unchanging concepts that are treated and understood as fact. Many of the passages are responses to the questionnaire item about the representation of an atom. The 12 passages that comprise Node 4 explicitly state that scientists are certain about the structure of an atom because of microscopes. Many of these passages suggest that scientists can directly view the particles of an atom similar to viewing a cell with a light microscope. This thinking is typified in the following passages: “I think that scientists are very certain on the structure of an atom because for several years this has been proved. For past years I have seen and used microscopes that show me the nucleus and I am able to view protons and neutrons inside the nucleus as well as viewing the electrons on the orbits of the atom”; “Very certain/they have studied atoms under a microscope.” For these students, the certainty of atomic structure is grounded in the empirical idea of literally viewing an atom with what many students describe as a “*high powered*” microscope. A few passages connect the certainty of the representation of an atom to fact that is taught in school. This type of thinking is evidenced in the following passage: “I think that scientists are pretty certain about the structure of the atom. First of all I don't think students would be learning it in school if it was like a guess and check thing. So I think they are pretty sure about it.” Regardless of the reasoning, this category reflects thinking that does not describe scientific theories as tentative knowledge, but rather in terms of proven information that is not subject to change.

Science is Helpful

The notion that science is helpful and has a utilitarian value is the dominant theme associated with this category, as opposed to the more neutral primary category, that science is about discovering new information. These passages describe science and scientific activities (specifically, experiments) as having an intention of social good that benefits humanity. The category is comprised of two nodes and 23 passages. Most of the passages are responses to the questionnaire item, *What are experiments?* and to a lesser extent, *What is science?* Many of the passages describe experiments as procedures or activities that discover new technologies and solve social problems such as cures for diseases. The following quote exemplifies this type of thinking: “I think that it is important for people to know about science, because science allows things to be safer and allows everyone to be able to help people and the environment.”

Creativity with Experiments

The one node and 23 passages that comprise this category are all responses to the questionnaire item, *Scientists perform experiments/investigations when trying to find answers to questions they put forth. Do scientists use their creativity and imagination during their investigations? Explain why or why not. Illustrate your answer with an example.* These students believe that scientists use creativity during their investigations, but limit their scope of how scientists use creativity specifically to designing experiments, as opposed to other scientific endeavors such as interpreting and making sense of data or generating hypotheses. This conception about if and how creativity is used by scientists is embodied in the following quote: “Scientists have to have creativity and imagination to be able to create good experiments. They have to be able to come up with a creative way to do the experiment more than once, so I think good scientists use their imagination and creativity.”

Science is Everything

This category is comprised of one node and 14 passages that are all responses to the questionnaire item, *What in your view is science? What makes science (or a scientific* *discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?* Many of these passages sound strikingly similar. Nine of the 14 passages use the phrase *study of* to construct a view or definition of science. Similarly, three passages describe science as the way we "learn" or come to know how things work. Eight of the 14 student passages specifically use the word *everything* in their effort to define science; the other passages use similar phrases such as *all things living and non-living*. This concept of science is evidenced in the following passage: "Science is the study of life, in general, because you study matter, animals, human nature. Science is just everything." Many of these passages suggest that science is an all-encompassing activity and that any act of inquiry falls within the realm of scientific activity.

Creativity with Ideas

This category is composed of two nodes and 15 passages that all respond to the questionnaire item, *Scientists perform experiments/investigations when trying to find answers to questions they put forth. Do scientists use their creativity and imagination during their investigations? Explain why or why not. Illustrate your answer with an example.* This category is different from *Creativity with Experiments*, discussed earlier, because these passages go beyond designing experimental procedures to describe how scientists use creativity. Several passages describe creativity and imagination as the inspiration or motivation behind hypotheses. Some passages describe creativity and imagination as important or necessary because they allow scientists to consider different or alternative possibilities. Several passages cite forensic examples, e.g., scientists using creativity and imagination to solve crimes and mysteries. Most of the passages frame creativity and imagination as important characteristics of scientists that afford them the ability to carry out scientific investigations, i.e., to do science. This type of thinking about creativity and imagination is evidenced in the following quote:

> I think scientists do use their imaginations to conduct investigations for the sole reason that it is our imaginations that allows humans to manifest different possibilities than set for before. The investigations of planets and star orbits are examples. Instead of going along with the norm, the sun and planets orbit the Earth, someone imagined differently.

Experiments Discover

This category is comprised of one node and 14 passages. These are mostly responses to the questionnaire item, *Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.* These responses describe experiments as the activity or mechanism that scientists engage in to discover new information. This conception of science is evidenced in the following student quotes: “Experimentation lets us find out new things. Experimentation lets us develop new things that help out a lot in the community”; “Well, we don’t know everything yet. So until then we will have to rely on experimentation to discover what we haven’t yet.”

Experiments are Procedures

The passages that comprise this category describe experiments in terms of laboratory activities or procedures often emphasizing an object of study. Many of the passages suggest these students’ conceptions of science are informed by traditional verification-oriented laboratory experiences. The category is comprised of two nodes and eight passages. Most of the passages are responses to the questionnaire item, *What are experiments?* This type of narrow, classroom contextualized thinking about experiments is evidenced in the following quotes: "Experiments are vital to the scientific process. Science would be boring without labs. You have to have hands on stuff to actually want to learn good things about chemistry, or it's boring"; "an experiment is when you study an object and have an opinion and describe what happened and find out what you're trying to find out."

No Creativity

This category is comprised of one node and six passages that all respond to the questionnaire item, *Scientists perform experiments/investigations when trying to find answers to questions they put forth. Do scientists use their creativity and imagination during their investigations? Explain why or why not. Illustrate your answer with an example.* These students describe scientists as not being creative in their endeavors because science is about proving and facts. This conception of science is embodied by the following quote: "Scientists shouldn't use imagination because if they are just going to imagine the results how can we be so certain that what is being performed is so right or such proven fact."

Science as Perspective

This category is comprised of two nodes and six passages that are responses to the questionnaire item, *What is your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g., religion, philosophy)?* These passages describe science as perspective, or a way of understanding or viewing the world. Two of the passages suggest this perspective or way of knowing is not unlike religion or philosophy. This category stands alone because each of the passages emphasize that science is simply a lens through which to understand or explain the world as opposed to some set of truths or a process to discover truths. The following quotes exemplify this type of thinking about science: “I think some aspects of religion and science don’t agree, but it’s good to have different perspectives on things to a have a good opinion”; “Religious people have a way of explaining the creation of the earth, but scientists have their own theory.”

Node 39 in Table 5 captured every instance of a student referencing a specific scientific experiment or procedure. The passages are simply a listing of specific classic experiments (e.g., cathode ray, gold foil) or specific classroom activities, as opposed to a conceptual element related to a student’s epistemological assumption about the nature of science. Therefore, this node was not included in the thematic analysis that produced the categories of description. However, the passages that comprise Node 39 were also interpreted in the context of the entire student response and are reflected in other categories of description. Node 21 in Table 5 contains five passages that are not informative or nonsensical and not included in further analysis.

The following is the list of categories of description that resulted from the second iteration of analysis, in which the researcher was reading, interpreting, and coding responses to all six questionnaire items one student at a time (analyzing responses across students), as opposed to the first iteration of analysis, in which the researcher was reading, interpreting, and coding all the responses for a given questionnaire item (analyzing responses across questionnaire items).

Categories of Description:

1. Theories Change
2. Experiments Prove
3. Experiments Test
4. Science is about Facts and Proving
5. Science is about Finding Out
6. Theories Do Not Change
7. Science is Helpful
8. Creativity with Experiments
9. Science is Everything
10. Creativity with Ideas
11. Experiments Discover
12. Experiments are Procedures
13. No Creativity
14. Science as a Perspective

The researcher analyzed these categories of description to construct the diagram below representing the structured collection of ways that the students in this study think about the nature of science. As described earlier, this diagrammatic representation of the logical relationship between categories of description is called the phenomenographic outcome space. The categories of description and their relationships reflect the outcome space. The outcome space represents the variation in the key aspects of students' conceptions of the phenomena at the group level.

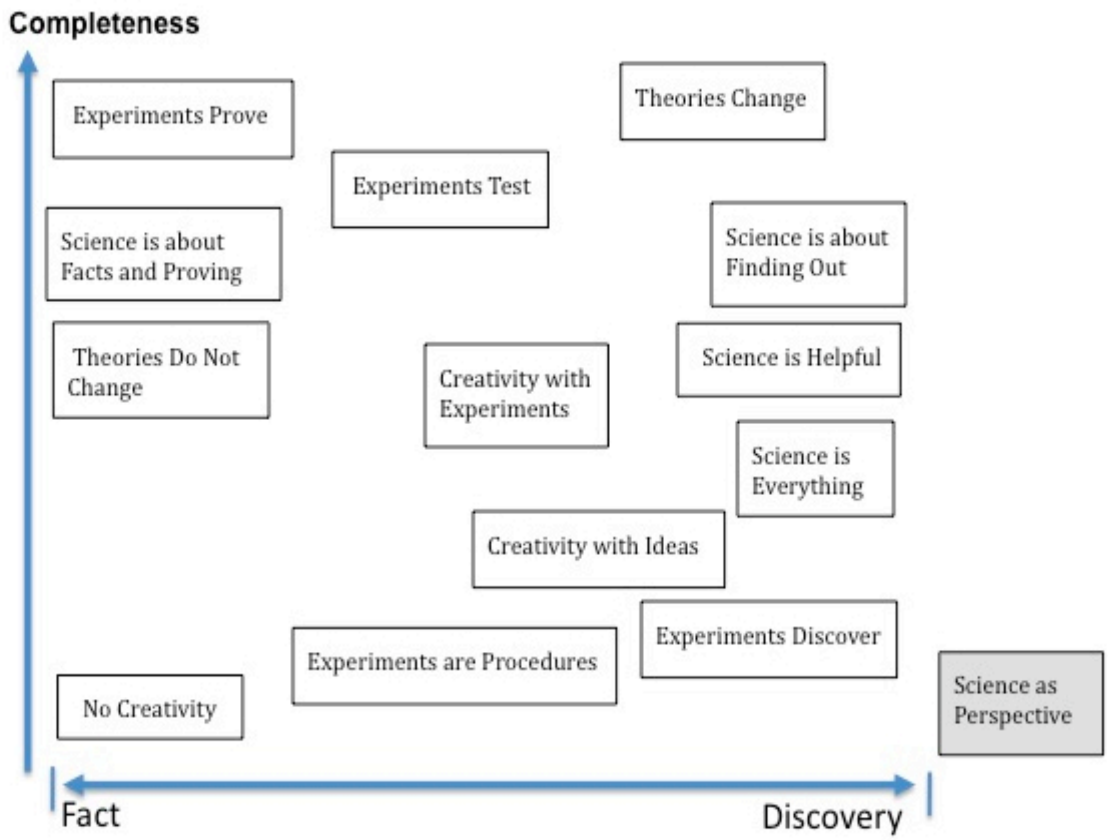

Figure 3. Analysis II: Outcome Space of Categories of Description

The outcome space is arranged horizontally to highlight a fundamental difference in the way the students in this study tend to think about the nature of science. Students tend to think about science either in terms of facts and a process grounded in proving something, or in terms of discovery and a process grounded in finding something out. Most of the categories of description (13 of 14) that emerged from this analysis can be placed along this continuum of thinking about the nature of science. The *Science as Perspective* category cannot be logically placed along this continuum, so it is highlighted to note the difference and placed outside of the continuum, on the right side of the outcome space.

The left side of the diagram is anchored by fact- and proving-oriented thinking. This includes both facts as the product of doing science and proving as the activity that characterizes science. The passages associated with this category reflect student thinking that describes science as a rigid process of proving ideas and concretizing knowledge. Experiments are described as the mechanism that concretizes the knowledge, and certainty and proof are seen as the outcomes of the process. Scientific theories are not seen as tentative but rather as proven, unchanging concepts that are treated and understood as fact. Similarly, scientists are not seen as using creativity in any meaningful way during the process of doing science. The student thinking associated with this category seems grounded in an ontological assumption about the world that is characterized by a single, knowable truth.

The right side of the diagram is anchored by discovery- and inquiry-oriented thinking. This includes both discoveries and new information as the product of doing science and inquiry as the activity that characterizes science. Many of the passages are grounded in verbiage that reflects activity that is similar to the notion of scientific inquiry; however, students use words and phrases such as “finding out” and “exploring” and “figuring out why something happens” when describing science. These passages credit science as the process that humans use to discover new information about the world and the vehicle that produces technological advances. Many of these passages suggest these students understand and think about science in terms of a utilitarian human endeavor. The student thinking reflected by these categories describes theories and scientific knowledge as tentative and subject to change as new information is discovered.

These students also see creativity as a quality that scientists possess which assists them in designing experiments and interpreting information.

Thirteen of the 14 categories of description are arranged along this continuum to reflect the qualitatively different ways students think about science. *Experiments Prove*, *Science is about Facts and Proving*, *Theories Do Not Change*, and *No Creativity* are placed at the far end of the fact side of the continuum because many of the passages describe science as being about proving and having to do with facts about the physical world. Theories are described as unchanging knowledge because they are proved through experiments. Creativity is not seen as a quality that scientists possess or exercise because they are concerned with certainty and proof.

Experiments Test, Creativity with Experiments, Creativity with Ideas, and *Experiments are Procedures* are placed in the center of the continuum. *Experiments Test* and *Experiments are Procedures* are placed in the center, but toward the fact side of the continuum because of their emphasis on experiments as the mechanism that scientists use to prove and produce facts about the physical world. The difference between the categories is based on how students describe experiments, either emphasizing experiments as tests to make evaluative judgments or experiments as laboratory procedures. *Creativity with Experiments* is placed in the center of the continuum because the passages describe creativity as a quality that scientists possess. These students do not think about science as a rigid endeavor where facts and certainty are both the means and the ends of the scientific process, the type of thinking that characterizes the far fact side of the continuum, although there is an emphasis on experiments and experiments are often described as the mechanism to ultimately prove an idea or produce facts. *Creativity with Ideas* is placed in the center, but toward the discovery side of the continuum because these students have a broader view of the way scientists use creativity and imagination in their work. This thinking describes creativity as a cognitive element that might help scientists figure out novel ways to ask questions or interpret results. However, this category is not reflective of the thinking that characterizes the far discovery side of the continuum that is grounded in explicit notions of discovery and "finding out."

Theories Change, *Science is about Finding Out*, *Science is Helpful*, *Science is Everything* and *Experiments Discover* are placed on the far discovery end of the continuum because the passages that comprise these categories are grounded in the notion that science is essentially about discovering information. Each of these categories describes science as a process of inquiry that results in new knowledge or technology. However, despite the similarity in the overall orientation of the categories toward discovery and inquiry, they remain distinct from each other because they emphasize different aspects of the nature of science (e.g., tentativeness of scientific knowledge, role of experiments). The *Theories Change* category is placed slightly toward the center, rather than at the far end of the discovery continuum, because these passages tend to be less explicit in the way they describe science as act of inquiry or discovery. For instance, new or better scientists are sometimes credited with changing established theories, as opposed to a statement that explicitly credits the discovery of new information.

The *Science as a Perspective* category is not placed along the Fact-Discovery continuum and has a shaded background, to highlight the qualitative difference between it and the categories that fall along the continuum. The *Science as a Perspective* category is separate because it describes science as a lens through which to understand or explain the world as opposed to a process to prove or discover something or an absolute set of truths or facts.

The outcome space is arranged vertically based on the completeness of the categories of description. Completeness of the categories within the outcome space increases from the bottom to the top of the diagram. The more complete categories reflect themes that are characterized by a greater number of student responses and/or responses that tend to be more cohesive in the way the students describe the phenomenon in question. This hierarchical arrangement uses completeness as the organizing criterion to place some categories higher on the outcome space than others. The most complete categories are *Theories Change* and *Experiments Prove*; the least complete categories are *Science as a Perspective* and *No Creativity*. Based on the number of passages that comprise each category there is a range of completeness, between 67 passages associated with the most complete category and six passages associated with the least complete categories.

Results Mapped to the Nature of Science Aspects

As discussed in Chapter 3, the questionnaire items were designed to primarily focus on one of the aspects of the nature of science described above; however, responses are likely to reveal a student's conceptions about any aspect of the nature of science. The 14 categories of description that emerged from the second iteration of analysis were mapped to the four aspects of the nature of science that the questionnaire was designed to probe. The table below depicts the relationship between the categories of description and the aspects of the nature of science. The heading of each column indicates the aspect of the nature of science, and the related categories of description are below. The parenthetical number indicates the number of passages that comprise the category of description. The total number of passages associated with each nature of science aspect is totaled across the bottom row.

Table 7.

Mapping Categories Across Aspects of the Nature of Science

Aim & Structure of Experiments*	Purpose of Science*	Tentativeness of Scientific Knowledge and the Nature of Theories	Creativity & Imagination
Experiments Prove (65) *FACT*	Science is about Facts and Proving (29) *FACT*	Theories Change (67) *DISCOVERY*	Creativity with Experiments (23)
Experiments Test (44)	Science is about Finding Out (26) *DISCOVERY*	Theories Do Not Change (24) *FACT*	Creativity with Ideas (15)
Experiments Discover (10) *DISCOVERY*	Science is Helpful (23)		No Creativity (6) *FACT*
Experiments are Procedures (8)	Science is Everything (14)		
	Science as a Perspective (6)		
127	98	91	44

* The first iteration of analysis involved these aspects of the nature of science

Overall, the distribution of categories of description across the nature of science aspects ranges between 2 and 6. There are four categories and 127 passages associated with the nature of science aspect that addresses the aim and structure of experiments. Two questionnaire items probed a student's understanding of the role of experiments in the production of scientific knowledge.

Five categories of description and 98 passages are associated with the nature of science aspect that addresses the purpose of science. Although only one questionnaire item specifically addressed how students describe the purpose of science, it is comprised of the greatest and most diverse number of categories. The number of passages associated with each category is more evenly distributed relative to the other categories of description.

Two questionnaire items were devoted to the aspect that addresses the tentativeness of scientific knowledge and the nature of theories; however, only two distinct categories of description emerged. There are 91 passages associated with this aspect.

Three categories of description and 44 passages are associated with the nature of science aspect that addresses creativity and imagination. One questionnaire item was devoted to the role of creativity and imagination.

Two prominent themes emerged across the four aspects of the nature of science investigated in this study. As noted above in the discussion of Figure 3, students tend to think about science either in term of facts and a process grounded in proving something or in terms of discovery and a process grounded in finding something out. The categories characterized by the fact- and proving-oriented theme are in red and denoted with "*FACT"* in superscript; the categories characterized by the discovery- and finding out-oriented theme are in blue and denoted with *"DISCOVERY"* in superscript. This fundamental difference in the way students' thinking is oriented about the nature of science is evidenced in the two most common categories. The *Theories Change* category is comprised of 67 passages—more than any other category—and is related to the *DISCOVERY* oriented theme. The *Experiments Prove* category is comprised of 65 passages—the second highest number—and is related to the *FACT* oriented theme. There are total of 124 passages associated with the *FACT* oriented theme and 103 passages associated the *DISCOVERY* oriented theme. A total of 227 passages directly align with the *FACT* or *DISCOVERY* oriented themes, compared to 133 passages that are not aligned with one of these two themes. The categories not denoted by *FACT* or *DISCOVERY* do not directly and explicitly align with one of these themes; however, they might reflect related ideas or ideas that are neutral with respect to the *FACT* or *DISCOVERY* oriented theme.

There is a *FACT* oriented category associated with each aspect of the nature of science. The category associated with the *aim and structure of experiments* aspect focuses on experiments as the mechanism to prove an idea. Some of the passages within this category reflect thinking that considers experiments as an activity that generates scientific knowledge often described as "facts." The category associated with the *purpose of science* aspect reflects thinking that distinguishes science as different because it is an empirical endeavor with an aim to prove something about the world. The *Theories Do Not Change* category is characterized by thinking that describes scientific theories as unchanging, concretized knowledge. The *No Creativity* category reflects thinking that does not see a role for imagination and creativity within the practice of science because scientists are concerned about facts and certainty. Many of the responses that comprise these *FACT* oriented categories explicitly use the word "fact" to describe science. However, "fact" is used in a variety of ways, such as "science is a collection of facts," "science is a fact," and "science uses facts." These students often use the word "fact" to describe science and think of "facts" as both an input and output of science.

There are three *DISCOVERY* oriented categories across the four aspects of the nature of science. The category associated with the *aim and structure of experiments* aspect focuses on experiments as the primary mechanism for discovering new information and producing new technology. The *Science is about Finding Out* category is associated with the *purpose of science* aspect and focuses on science as the primary vehicle for discovering new information about the world. The *Theories Change* category emerged from the *tentativeness of scientific knowledge and the nature of theories* aspect of the nature of science. This category reflects thinking that implies science is composed of ideas that can shift and change. Instead of describing the structure of an atom or other scientific theories as immutable facts, as was a characteristic of the *FACT* oriented categories, these three *Discovery* oriented categories are comprised of passages that credit new information and discoveries as the reason why theories change. These categories frame science as inquiry, grounded in activities such as "discovering" and "finding out."

Internal Validation—Comparing Categories of Description between Analysis I and II

In order to help confirm the findings of this study, the researcher compared the results of the first and second iterations of analysis. As discussed earlier, the organizational scheme differed between these two sets of analyses. The first iteration arranged the raw data according to the questionnaire item. Two aspects of the nature of science (i.e., the Aim and Structure of Experiments and the Purpose of Science) were examined in this manner. The second iteration arranged the raw data by the student responding to the questionnaire item, to help emphasize the individually different ways that a student or a group of students think about science. Responses to all six of the questionnaire items were included in the second iteration of analysis.

The table below compares the categories of description associated with the *aim and structure of experiments* aspect of the nature of science. The five categories that emerged as part of analysis I are aligned with the four categories that emerged from analysis II. The alignment is based on the similarity of categories and was accomplished through both a close reading of the primary codes and a rereading of the passages that comprise the codes.

Table 8.

The Aim and Structure of Experiments: Comparing Analysis I and II

First Iteration of Analysis	Second Iteration of Analysis
Experiments Prove	Experiments Prove (65)
Experiments Confirm	Experiments Test (44)
Ways to Learn New Things, Lead to Inventions	Experiments Discover (10)
Methods for Collecting Data	Experiments are Procedures (8)

The strong alignment between the categories in Table 8 suggests the first and second iteration of analysis yielded similar results. Both iterations resulted in an

Experiments Prove category. In both analyses the *Experiments Prove* category was the most common or complete category for this aspect of the nature of science. All of the passages that comprise the *Experiments Prove* category focus on experiments as the mechanism that proves an idea to be true or certain. Some of the passages reflect thinking that considers experiments as an activity that generates scientific knowledge often described as "facts."

Experiments Confirm and *Experiments Test* are analogous categories between the two sets of analyses. These categories describe experiments as scientific activities designed to test or confirm a hypothesis. Both of these categories place in the mid-range of completeness in their respective outcomes spaces. The passages associated with the *Experiments Confirm* category tend to use language indicating experiments validate or help verify an idea rather than prove something or produce a fact. However, passages from both of these categories use similar language and convey similar notions of experiments.

The *Ways to Learn New Things* and *Lead to Inventions* categories from the first analysis are analogous to the *Experiments Discover* category from the second analysis. These categories reflect thinking that credits experiments as the primary mechanism that leads to new information and technologies. All three of these categories place in the lower to mid-range of completeness in their respective outcomes spaces. The *Learn New Things* and *Experiments Discover* categories tend to focus on the creation of new knowledge and the *Lead to Inventions* category tends to focus on technologies; however, there is much conceptual overlap between all three categories.

Methods for Collecting Data and *Experiments are Procedures* are analogous categories between the two sets of analyses because they both reflect thinking that frames experiments as procedures. Some passages in both categories describe experiments as a step in the scientific method of collecting data. In both analyses these were relatively incomplete categories based on the number of responses associated with other categories.

The table below compares the categories of description associated with the *purpose of science* aspect of the nature of science. The seven categories that emerged as part of analysis I are aligned with the five categories that emerged from analysis II. The alignment is based on the similarity of categories and was accomplished through both a close reading of the primary codes and a rereading of the passages that comprise the codes.

Table 9.

The Purpose of Science: Comparing Analysis I and II

First Iteration of Analysis	Second Iteration of Analysis
Science is Proof	Science is about Facts and Proving (29)
Science is the Act of Discovery	Science is about Finding Out (26)
Science is Helpful	Science is Helpful (23)
Science is Everything	Science is Everything (14)
Science is an Orderly Explanation	Science as a Perspective (6)
Contextual Science	
Science is Not Different	

Table 9 depicts the strong congruency between the categories that emerged between the first and second iteration of analyses. The similarity between categories suggests the analyses yielded similar results. The *Science is Proof* and *Science is about Facts and Proving* categories focus on science as either a collection of facts or the fact-producing process that proves ideas and concretizes knowledge. In both analyses, these categories are very complete relative to other categories associated with the purpose of science. These categories reflect thinking that distinguishes science as different because it is an empirical endeavor with an aim to prove something about the world.

Science is an Act of Discovery and *Science is about Finding Out* are analogous categories. Both of these categories frame science as an investigative endeavor, grounded in notions of "discovering" and "finding out" about the world. These categories were both placed in the upper portion of their respective outcome spaces because they are relatively common or complete categories.

Both the first and second iteration of analysis yielded a *Science is Helpful* category. These categories are comprised of passages that have a utilitarian view of science. These categories all focus on the useful products of science, often citing cures to disease and technology. Both of these categories were placed in the mid-level of their respective outcome spaces.

The two *Science is Everything* categories are analogous. These two categories both reflect thinking that considers science to be an all-encompassing activity such as "science is everything" or "science is the study of everything." These categories reflect thinking that puts little to no boundary on what constitutes science or scientific inquiry.

Despite their similarity in language, these categories were placed in different areas of their respective outcome spaces because they reflect differing degrees of completeness. The first analysis placed the *Science is Everything* category high in the outcome space because it had a relatively high degree of completeness. In the first analysis, *Science is Everything* was described as very complete because the passages sounded very similar and often seemed to encompass other conceptions of the purpose of science. In the second analysis, *Science is Everything* was placed in the middle of the outcome space. The passages were described as very similar in verbiage; however, the responses were not as common relative to some of the other categories, and it was not interpreted as encompassing other conceptions of the purpose of science.

Science is an Orderly Explanation and *Science is a Perspective* are analogous categories of descriptions. These categories focus on science as being an explanation of things or as a perspective for understanding world. Both categories reflect a conception of science as an *organized* or *orderly* way of reasoning or viewing the world as opposed to religion, which is based on beliefs or a conception of science grounded in a set of proven truths. Both of these categories were placed in the lower level of their respective outcome spaces because they were not common conceptions of science.

The *Contextual Science* category that emerged in the first iteration of analysis does not have an analogous category in the second iteration of analysis. *Contextual Science* reflects a conception of science in terms of a specific set of experiences associated with school or explains science within the narrow boundaries of a particular discipline, such as chemistry or biology. Although there is not a directly analogous category related to the *purpose of science* aspect, some passages that comprise the *Methods for Collecting Data* and *Experiments are Procedures* categories associated with the *aim and structure of experiments* aspect of science also reflect this narrow, school-oriented conception of science. This category is relatively incomplete because the responses are not very common.

The *Science is Not Different* category that emerged in the first iteration of analysis does not have an analogous category in second iteration of analysis. The responses that comprise this category vary in description, but all describe science as not really being different from religion or philosophy. This reasoning is usually centered on the idea that science is based on opinions and interpretations in the same way one might hold an opinion or have interpretation about religion. This category is relatively incomplete because the responses are not very common.

Tables 8 and 9 depict similar results between the first and second iteration of analyses. These analyses were conducted approximately 4 years apart and were based on different organizational schemes for interpreting the data. The strong similarity in results suggests that the analyses yielded valid findings regarding the qualitatively different ways student think about the nature of science.

Summary

This study, specifically the second analysis, suggests these high school chemistry students think about science in a variety of qualitatively different ways. These 14 different conceptions reflect a wide range of understanding about science. To a limited extent, this range in conceptual understanding reflects two different orientations toward the nature of science. Some high school chemistry students orient their thinking about science in terms of an activity driven to prove or make certain, characterized by a collection of facts, whereas other students orient their thinking about science in terms of a finding out activity that results in discovering new information. The results of this study help reveal the nuanced conceptions within these two broad orientations that students have toward science. In addition, these analyses suggest there is more variation or nuanced thinking associated with some aspects of the nature of science relative to other aspects. Understanding that at a group level students' thinking about the nature of science can be described with these 14 conceptions, and that thinking is often oriented in these two qualitatively different ways, could have implications for high school science curricula, instruction, assessment and future research efforts.

CHAPTER 5

FINDINGS AND IMPLICATIONS

This chapter will provide a brief summary of the study, relate findings to prior research, address implications for classroom practices and suggest possible directions for future studies.

Summary of the Study

The goal of this study is to describe, using an emergent phenomenographic research approach, the qualitatively different ways high school chemistry students think about the nature of science. This work attempts to reveal students' understanding via the use of open-ended response data from a questionnaire that probes the following aspects of the nature of science:

- Purpose of science
- Tentativeness of scientific knowledge and the nature of theories
- Creativity & imagination
- Aim & structure of experiments

There are two iterations of analysis that help support the conclusions of this work. The initial analysis organized and interpreted student response data by questionnaire item. Approximately 100 responses for a given questionnaire item were randomly selected, read and analyzed. Three of the six questionnaire items were analyzed using this organizational approach to the data. This initial analysis resulted in 12 categories of description. The researcher determined that another type of organizational scheme would lead to a more holistic interpretation of the data, one that placed the students and their thinking in the center of the analysis rather than the questionnaire item.

This second analysis was more extensive, organizing and interpreting the data by student. One hundred student responses were randomly selected. The responses to all six questionnaire items were read and analyzed for a given student before moving to the next set of student responses. Organizing and interpreting the data in this way emphasized the individually different ways that students or groups of students think about the nature of science. This analysis yielded 39 primary level codes, which were then collapsed based on the similarity of responses. This distillation revealed 14 categories of description. The categories reflect the qualitatively different ways students think about the nature of science and represent a range of conceptions, from rather common ones grounded in many student passages to less common—yet distinct—conceptions comprised of just a few passages.

A diagrammatic representation of the categories, called a phenomenographic outcome space (Figure 3), was constructed to help depict the logical relationships between these emergent categories. Mapping the 14 categories to the four aspects of the nature of science (Table 7) highlighted the variation in students' thinking and helped reveal students' nuanced conceptions within the four aspects of the nature of science. This comparison also distinguished two ways that students orient their thinking about science: either in terms of facts and a process grounded in proving something, or in terms of discovery and a process grounded in finding something out.

Comparing the results from the first and second analyses revealed a strong alignment between the categories of description. These analogous categories suggest that the analyses yielded credible findings regarding the qualitatively different ways student think about the nature of science.

Methodological Implications

In-depth interview data versus open-ended survey data

The results of this study are congruent with the assumptions inherent to the phenomenographic research tradition. As previous phenomenographic research (Marton, 1986) and research investigating variations in students' prior knowledge (Finely, 1985; Heller and Finely, 1992; Driver et al., 1994; Wandersee et al., 1994) suggest, there are a limited number of ways that the key aspects of a phenomenon such as the concept of the nature of science could be experienced or thought about. The Relation to Prior Research section later in this chapter establishes that the results of this study are congruent with previous nature of science research (Akerson and Hanuscin, 2007; Bell et al, 2003; Chen, 2006; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Khishfe and Lederman, 2006; Lederman et al., 2002). However, the large sample size of open-ended response data and the analytical procedures employed in this work have resulted in more emergent themes than in similar studies. This work suggests that there are 14 conceptions that students hold when thinking about the aspects of the nature of science this study was designed to probe (i.e., purpose of science, tentativeness of scientific knowledge, creativity and imagination, and aim and structure of experiments). Previous phenomenographic research in a variety of disciplines suggests there are usually 4–6 categories of description associated with a given phenomenon (Marton, 1986; Ebenezer and Erickson, 1996). The 14 categories resulting from this analysis might be an artifact of analyzing a large amount of open-ended response data, as opposed to the smaller number of interview responses more typical in phenomenographic studies. This possible methodological implication might be a consideration for future phenomenographic investigations. It should be noted that Butcher and Prosser (1993) support the use of large amounts of open-ended response data; however, their findings did not note more or more nuanced categories of description.

As described in Chapter 3, categories of description are pieces of the researcher's model of how a phenomenon is experienced (Bowden, 1995). Taken together, the categories of description are considered by Marton (1986) as representing the "outcome space" that describes the qualitatively different ways a given phenomenon could be experienced or thought about. The outcome space is a diagrammatic representation of the logical relationship between categories of description. Organizing categories along a continuum (as opposed to discreet points on which students must fit) can help represent the degree of thinking or understanding. Figures 2 and 3 represent outcome spaces in which the researcher arranged the categories along a horizontal continuum to better depict an underlying theme within the data; however, arranging categories horizontally to reflect a range of thinking along a conceptual or thematic continuum is not common in phenomenographic literature. Phenomenographic researchers may consider this work and the work of Micari et al. (2009) for examples of how to better visually represent categories of description.

Relation to Prior Research

The VNOS Questionnaire

As mentioned in Chapter 3, the research instrument used in this study is adapted from Lederman et al. (2002), Views of Nature of Science (*VNOS-C*). The original VNOS instrument(s) were designed to identify aspects of the nature of science that are grounded in historical and philosophical notions of science (e.g., deterministic/absolutist or empiricist) and then evaluate the correctness of pre-service science teachers' views within these identified aspects of the nature of science. The VNOS instrument has been adapted for use with high school students (Bell et al, 2003; Khishfe and Lederman, 2006), middle school students (Khishfe 2008); and elementary school students (Akerson and Hanuscin, 2007).

The VNOS studies (Akerson and Hanuscin, 2007; Bell et al, 2003; Khishfe 2008; Khishfe and Lederman, 2006; Lederman et al., 2002) approach an understanding of the nature of science with an *etic* type of methodological frame. The purpose of these studies is aimed at evaluating the correctness of nature of science conceptions based on the researchers' philosophical position within these identified aspects. Even without consideration of the previously mentioned VNOS research, many nature of science studies that focus on students spend more time reporting on the correctness of their conceptions (Chen, 2006; Dogan and Abd-El-Khalick, 2008; Hu and Adey, 2002), rather than explicating student thinking. These efforts are largely driven to support national science education reform efforts (e.g., AAA 1990, 1993; Millar & Osborne, 1998; NRC,

1996) that wish to evaluate students' notion of science against these historical and philosophical frames.

This study approaches students' understanding of the nature of science with a phenomenographic methodology that is inherently more of an *emic* frame. The researcher described and analyzed conceptual schemes and categories on the terms of the students participating in the study, rather than imposing traditional historical/philosophical assumptions of science onto students' thinking. For instance, Lederman and his colleagues wrote that in many cases respondents' views were fluid, fragmented, and compartmentalized. They concluded that these students had naïve (or uninformed) ideas about science because they lacked an overarching, consistent framework for their views on the nature of science. Instead of evaluating students' ideas as "informed" or "naive," the aim of the present study was to describe all the qualitatively different ways these students think about the nature of science, intentionally trying to reflect their thinking in terms of the language and schema in which they exist. This work adds to the VNOS literature (and, more generally, nature of science research) by identifying more nuanced conceptions within four of the VNOS aspects.

Lederman et al. (2002) provided a list of illustrative examples, in the form of verbatim quotes, typifying the thinking of the participants (science teacher candidates) in their study. They categorize these quotes as "More Naïve Views" or "More Informed Views" of the nature of science. There is a striking similarity in the actual response data between the present study and this VNOS work. The findings of this study tend to be similar to the thinking and language associated with the "More Naïve Views." Appendix

D compares passages from this study with a selection of “More Naïve View” quotes from the VNOS work. The similarities in the response data suggest these populations are similar enough to draw comparisons. Generalizing ideas and drawing comparisons between studies is supported by other phenomenographic work because the analysis is focused at the group level (Stefani and Tsaparlis, 2009; Schmidt and Volke, 2003)

Table 7 maps the 14 categories of description that emerged from this study to the four aspects of the nature of science that were investigated in this work. This organizational scheme will be used to relate the findings of this study to prior research.

Purpose of Science

Five of the 14 categories of description reflect the various ways that students in this study conceived the purpose of science:

1. Science is about Facts and Proving
2. Science is about Finding Out
3. Science is Helpful
4. Science is Everything
5. Science as a Perspective

The categories *Science is about Facts and Proving* and *Science is about Finding Out* are very similar to Ryan and Aikenhead’s (1992) findings. They report the following:

- 28% of students in their study indicated that science is difficult to define because it is primarily a “body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, life).”

- 24% of students indicated that science is difficult to define because it is primarily “exploring the unknown and discovering new things about our world and universe and how things work.”

In their discussion, they describe students as more or less divided between these two perspectives (19% of students—the next most common response—indicated science cannot be defined), and this division generally reflects how science educators frame the teaching of science.

Driver et al. (1996) conducted a study that investigated how students characterize the image of science. This widely cited study specifically investigated how students perceived the purpose of science. One of the primary findings from their work suggests that students perceive the purpose of science as answering questions that can be investigated empirically. They saw the scientist’s role as identifying cause and effect relationships with observable features of a phenomenon or making empirically derived generalizations. This image of science is congruent with the *FACT* and *DISCOVERY* themes that characterized how students in this study oriented their thinking towards science. The Purpose of Science categories of description that are aligned with these themes are *Science is about Fact* and *Proving* and *Science is about Finding Out*, respectively. Students’ thinking as reflected by the *FACT* oriented themes places emphasis on the empirically derived knowledge *product* of science; that is, science and scientific knowledge look like facts and are characterized by a high degree of certainty because they are derived from sense-experience. Students’ thinking as reflected by the *DISCOVERY* oriented themes places emphasis on the empirically based *process* of doing science; that is, science is characterized by discovery and finding out because the essence of science is about investigating phenomena through sense-based experiences.

This type of thinking, characterized by empirically bound assumptions of science, is consistent with other research. Bell et al. (2003) found high school students' conceptions of the empirical nature of science did not change after participating in science apprenticeship. Lederman et al. (2002) reported that 67% of the teacher candidates whom they profiled as novice thinkers described science as the search for objective truth and emphasized empiricism.

Stein and McRobbie (1997) conducted a very similar research project to this study. They also used a phenomenographic approach based on the analysis of open-ended response data to investigate students' conceptions of the nature of science. High school and middle school students were asked to provide written responses to the following questions:

- What is science?
- What activities do scientists engage in? How do you think they go about those activities?
- What do you think scientific knowledge is?

The *Science is Everything* category is very similar to Stein and McRobbie's *Science is a Study of the World* category. Several of the quotes that Stein and McRobbie cite in their work are almost verbatim to student quotes in this study. Both categories reflect thinking that describes science as the primary method of investigating the living and non-living world. There is very little difference between these categories; however, the *Science is the Study of the World* category emphasizes that science is the accumulation of knowledge about the natural world, whereas the *Science is Everything* category illuminates students' conceptions of science that are so all-encompassing that every act or product of inquiry can be considered science. Also, the category *Science is about Figuring Out* is related to the *Science is a Study of the World* category because they both emphasize student thinking that identifies science as an act of inquiry.

The *Science is Helpful* category is similar to Stein and McRobbie's *Consumable Product* Category. These categories are grounded in a utilitarian view of science that describes it in terms of being beneficial to society because it solves problems and results in products that are consumed by mankind. These students hold an *instrumentalist* view of science; they consider its primary purpose to be a means of improving the human condition by way of technological inventions. These findings reflect thinking that conflates science and technology to the point that little or no distinction can be made. This is also consistent with Driver et al. (1996, pp. 139), who found that high school age students hold a beneficent view of scientists as people who work to address important problems relevant to society, and with Aikenhead & Ryan (1992), who reported that students think the purpose of science is to make the world a better place. Holbrook and Rannikmae (2007) make similar observations in their discussion of nature of science teaching outcomes and the difficulty of distinguishing scientific and technological literacy within a school context.

The *Science as Perspective* category describes science as a perspective or a way of understanding or viewing the world. This category is distinct because each of the passages associated with it emphasize that science is a lens through which to understand or explain the world, as opposed to some set of truths or a process to discover truths. This conception does not explicitly appear in the nature of science literature; however, it sounds most similar to the more sophisticated ideas held by students regarding constitutive and contextual values of sciences described by Ryan and Aikenhead (1992). This conception also appears consistent with ideas described by VNOS-based research (Lederman et al., 2002; Bell et al., 2003) as more informed views of theory-laden aspects of the nature of science.

Aim and Structure of Experiments

Four of the 14 categories of description reflect the various ways that students in this study conceived the aim and structure of experiments.

1. Experiments Prove
2. Experiments Test
3. Experiments Discover
4. Experiments are Procedures

The *Experiments Prove* category reflects thinking that describes experiments as the mechanism that proves scientific knowledge. This thinking tends to frame science as a rigid process of producing knowledge that is absolute and certain. The certainty of scientific knowledge is the result of experiments. This certainty is an inherent and defining characteristic of knowledge that is produced through experiments. Proving is often described as the purpose and driver of scientific endeavors, and proof is the product of performing an experiment. Bell et al. (2003) describe this type of “absolute” and "proof" oriented thinking as persisting among high school students even after completing a science apprenticeship. This is consistent with Driver et al. (1996), who muse that this type of thinking should not surprise science educators, because students are too often only provided laboratory experiences where scientific knowledge flows directly and logically from a contrived observation. These types of verification laboratory "experiments" lead students to a simple epistemological understanding that obvious conclusions can be easily and directly drawn from data. Hofstein and Lunetta (1982) discuss similar findings regarding traditional laboratory activities that are primarily composed of verification experiments.

The passages that comprise the *Experiments Test* category seem to occupy a middle ground between the passages that Lederman et al. (2002) use to typify "More Naïve" and "More Informed" views of the NOS aspect that addresses the *Role of Prior Expectations in Experiments*. The "More Naïve" passages reflect thinking that leaves little room for a scientist to hold a priori ideas, while "More Informed" thinking reflects more sophisticated thinking concerning how a priori ideas or expectations are needed to design an experimental procedure. In both studies, experiments are conceived as activities designed to test an idea or hypothesis. This category emphasizes that experiments are used to make summative judgments about a priori scientific ideas. Some of the passages Stein and McRobbie (1997) cite as typifying their *Science is a Process* category sound similar to the passages that comprise the *Experiments Test* category in this work. Both categories highlight the evaluative nature of experiments to draw a conclusion or make a determination, and both suggest experiments are a requirement of the process or method of doing science.

The *Experiments Discover* category reflects thinking that characterizes experiments as the activity or mechanism that scientists engage in to discover new information. There are not many clear examples in the nature of science literature that specifically indicate that students think about experiments in terms of a discovery activity. However, based on passages within this work, students' conception of the role experiments play in science is likely reflected in the way they describe the purpose of science. As mentioned above, Ryan and Aikenhead (1992) reported 24% of students in their study indicated that science is difficult to define because it is primarily "exploring the unknown and discovering new things about our world and universe and how things work." Some of the passages Stein and McRobbie (1997) cite as typifying their *Science is a Process* category sound similar to the passages that comprise the *Experiments Discovery* category in this work. However, they tend to lump together responses that describe experiments as activities that "test" and experiments as activities that help "find out." In contrast, this study highlights this variation in student thinking, because the researcher believes these notions are grounded in different ontological and epistemological assumptions and this variation in thinking was noted in the responses to multiple questionnaire items.

Although Akerson and Hanuscin (2007) did not specifically investigate the role of experiments, some of their results suggest elementary school students' conceptions of science reflect this discovery notion of science. However, it is surprising that this discovery or exploratory notion was not more present in these elementary students' views of science. Previous research (Bell et al., 2003; Driver et al., 1996; Khishfe 2008; Osborne et al., 2003) suggests students begin with this type of process-oriented thinking toward science and that it gradually shifts toward a "collection of facts" or science content notion as they accumulate more classroom science experiences.

Experiments are Procedures is similar to Stein and McRobbie's category *Science is Done or Learnt at School* category. Both sets of categories reflect conceptions about science that are limited to school science experiences such as specific courses of study (e.g., chemistry or biology) or classroom or laboratory activities. These categories reflect thinking that contextualizes science as a school-related phenomenon. This type of thinking does not connect the school subjects (e.g., chemistry, biology) or science activities (e.g., forming a hypothesis, conducting an experiment) to disciplines of inquiry that exist independently in the broader world. Other nature of science research studies have cited this contextualized school-science thinking in their findings, especially among primary and middle school students (Aikenhead & Ryan, 1992; Driver et al., 1996), which suggests this thinking is a common conception across populations of school-age children. This does not necessarily indicate that students are unable to hold these more worldly conceptions, just that they do not readily fall back on such conceptions when probed about the nature of science in the context of these studies. Reverting back to naïve, more secure and/or initial conceptions of science was reported by Leach et al. (2002) and Khishfe (2008), even after students were engaged in nature of science curricular experiences.

Tentativeness of Scientific Knowledge and the Nature of Theories

Two of the 14 categories of description reflect the ways students in this study conceived the tentativeness of scientific knowledge and the nature of theories.

1. Theories Change
2. Theories Do Not Change

The *Theories Change* category reflects thinking that describes scientific knowledge as not being absolute or certain, that it is capable of changing. Despite some specific probes, some of the responses that comprise this category are not specific about how or why a scientific theory might change; many simply imply that scientists are not certain about the structure of an atom, or that theories are not fact. Khishfe (2008) reports that 7th grade students' thinking regarding the tentativeness of scientific theories moved from 17% having an informed view (i.e., theories can change) before explicit nature of science instruction to 44% after the instruction. However, little effort is made to report what changed in students' thinking or the reasons they attribute as to why scientific knowledge has the capacity to change. Bell et al. (2003) reported that all of the 10th and 11th grade students who participated in the scientific apprenticeship initially expressed a view that scientific theories can change; however, all attributed such change to new empirical evidence, rather than a reinterpretation of existing data. Upon completion of the apprenticeship only 1 of the 10 students expressed a more sophisticated view of the tentativeness of scientific theories. The students in this study revealed more about their thinking regarding why theories change than the two aforementioned studies. The students in this study expressed a variety of reasons as to why scientific theories might change; however, their thinking can largely be grouped into these three subcategories:

- Theories change because scientists learn more and discover new information
- Theories change because of new or better scientists
- Theories change because of new experiments and technology

Like the students in the apprenticeship study most of their reasoning attributes theoretical change to new empirical evidence. However, there are a few passages associated with the *Theories change because of new or better scientists* category that suggest these students understand that scientists may put forth competing theories based on different interpretations of data.

Stein and McRobbie's *Science is Dynamic Knowledge* category closely aligns with the *Theories Change* category in this study. Both sets of categories describe scientific knowledge as having the capacity to change because of the introduction of new ideas, discoveries, and/or technology. The passages that Stein and McRobbie use to typify their students' thinking in this category are very similar to student responses in this study. However, in their narrative description of their students' understanding of this tentative feature of scientific knowledge, they write, "Some change occurs accidentally, but the major cause of change in scientific knowledge is due to the outcome of experimentation leading to an accumulation of information and ideas and the emergence of newer and more viable theories and proofs." Although I do not disagree with this aspect of the nature of scientific knowledge, few of the quotes they use to support this assertion about their students' thinking suggest their students view changes in scientific theories as based on an accumulation of evidence built up over time. Rather, their student quotes are constructed of words such as *breakthroughs* and *discoveries*, which are similar to the responses in this study that suggest students do not think about changes in scientific knowledge in terms of a relatively slow process, based on an accumulation of evidence from a community of scientists.

These findings are consistent with Driver et al. (1996), who report that most students do not see science as a social enterprise. Students have little or no conception of a scientific community that collectively establishes scientific knowledge. Most of the responses that indicate theories change because of "smarter" or "better" scientists focus on the work of individual scientists as change agents, as opposed to a community of scientists accumulating evidence that challenges or changes theories. For the most part, the students involved in this study think about science in terms of lone individuals working in isolation on proving ideas or discovering new information.

The *Theories Do Not Change* category is reflective of thinking that views scientific theories as proven, unchanging concepts that are treated and understood as fact. Many of the responses that comprise this category explicitly state that scientists are certain about the structure of an atom because of microscopes. Many of these passages suggest that scientists can directly view the particles of an atom similar to viewing a cell with a light microscope. These students' conception that theories do not change is grounded in and bound by their empirical notion of scientific knowledge. This conception appears congruent with the naïve (or less informed) notions of the tentative nature or science reported in the VNOS research literature (Lederman et al, 2002; Bell 2003; Khishfe, 2008).

Creativity & Imagination

Three of the 14 categories of description reflect the various ways that students in this study conceived the role of creativity and imagination in the science.

1. Creativity with Experiments
2. Creativity with Ideas
3. No Creativity

The *Creativity with Experiments* category reflects thinking that limits the way scientists might be creative and imaginative in their work. These students believe that scientists use creativity during their investigations, but limit their scope of *how* scientists use creativity specifically to designing experiments, as opposed to other scientific endeavors such as interpreting and making sense of data or generating hypotheses. This is very similar to findings of Bell et al. (2003), who note that even after participating in the science apprenticeship program, "apprentices tended to limit the role of creativity in their understanding of science by restricting it to the initial stages of experimental design." Khishfe (2008) reports that the percentage of 7th grade students having an informed view (i.e., scientists use creativity) regarding the role of creativity and imagination in science increased from 22% before explicit nature of science instruction to 50% after the instruction. However, there is little to no explication of what constitutes an informed understanding of how creativity and imagination are used in the science.

The *Creativity with Ideas* category is different from *Creativity with Experiments* (discussed above) because it reflects thinking that goes beyond designing experimental procedures to describe how scientists use creativity. Several passages describe creativity and imagination as the inspiration or motivation behind hypotheses. Some passages describe creativity and imagination as important or necessary because they allow scientists to consider different or alternative possibilities. Neither Bell et al. (2003) nor Khishfe (2008) reported this type of thinking among the students they studied. This type of thinking is more similar to the quotes that Lederman et al. (2002) use to typify more informed views of the creativity and imagination aspect than to the quotes used to typify more naive views.

The *No Creativity* category reflects the thinking that it is not appropriate for scientists to be creative or imaginative in their work. These students see scientists as not being creative in their endeavors because science is about proving and facts. Khishfe (2008) reports that the percentage of students having a naïve view (i.e., scientists do not use creativity) regarding the role of creativity and imagination in science decreased from 50% before explicit nature of science instruction to 28% after the instruction. This study reported that many students seemed to hold on to their naïve views because the thinking is ground in empirical notions of science (e.g., scientists must "see" something) or because creativity would "distort the perfection of science." Similar ideas were expressed among the students in this study.

Implications for Science Education

In Bowden (1995) and Micari's (2007) explanation of the *developmental phenomenographic* tradition, they describe phenomenography as an applied research tool, as opposed to phenomenological traditions that focus on the lived experience and are more exploratory in nature. They describe three assumptions that make phenomenographic studies particularly well suited for evaluating and improving educational programs and student learning (e.g., educational initiatives, curricular programs of studies, classroom learning experiences):

1) there are differences in the ways people conceive of and approach learning in particular environments;
2) some of these different ways are more conducive to learning than others;
3) through life experiences or training, people can change their conceptions.

This notion of phenomenography as an applied research tool fits well in science education. This is particularly true in the body of literature that addresses students' misconceptions or alternative conceptions, because it is well documented that students often hold preexisting conceptions of science-related phenomena. As an illustration, this phenomenographic study identified the qualitatively different ways that students think about the role experiments play in the practice of doing science (i.e., *Experiments Prove*, *Experiments Test*, *Experiments Discover*, and *Experiments are Procedures*). An understanding of the variation in students' thinking about the role of experiments in science can assist educators in designing specific conceptual hooks that engage students based on their preexisting conceptions. This type of differentiation, based on students' conceptual understanding, is one way to resolve the egalitarianism in education, where all students receive exactly the same educational experiences rather than being offered equal *opportunity* to actualize their learning potential (Winebrenner, 1999). Helping teachers translate this type of research into science classroom practice is at the heart of Sondergeld and Schultz's (2008) discussion of science standards and content differentiation. This also supports Dogan and Abd-El-Khalick's (2008) argument that curricular interventions should be embedded in a "learning as conceptual change" model. The more nuanced findings from this work are a logical starting point for creating scaffolding based on the qualitatively different ways that students conceptualize science. Curriculum based on variations in student thinking can be used to design assignments and lessons that are more effective and efficient at moving students' thinking to a more sophisticated level of understanding. Addressing issues of instructional efficiency and effectiveness might be particularly important because of competing curricular demands. Research suggests that teachers who feel they do not have enough time to cover all of the curricular topics selectively drop elements of the curriculum that address the nature of science in order to focus on "content" or discipline-based standards (e.g., chemistry, biology, physical science) that are perceived as more important (Hipkins, 2005).

Micari et al. (2007) describe a process of using the purely qualitative findings from phenomenographic research as the basis for constructing quantitative measures of learners' conceptions. Quantitative assessment instruments can be constructed based on the categories of description from phenomenographic studies. Pre- and post- instruments could be designed to measure the change in students' conceptions over time. For instance, the results of this study might be used to construct an understanding of how creativity and imagination are utilized in scientific investigations. Many students reported that creativity is not used during scientific investigations, and many of the students that did report that creativity is utilized in scientific investigations limited its use to designing experiments. Few students were able to articulate how creativity and imagination might play a role in the interpretation of data or the development of a model or theory. Understanding this variation in student thinking and the language students use to articulate these thoughts can inform the development of assessments (e.g., rubrics, tests, surveys) that capture this difference in thinking. For example, a rubric designed to assess a student's understanding of the nature of science might include an item that specifically addresses the role of creativity in scientific investigations. The criteria for that specific item would reflect the differing levels of understanding, from little to no understanding of the role of creativity, to a limited understanding (e.g., when scientists are designing experiments), to a more sophisticated level of understanding that reflects how scientists rely on creative and innovative ways to interpret data or construct models and theories in unconventional ways. Creating assessments that specifically address common variations in the way students think about a given concept provides more accurate information regarding the effectiveness of curricular and instructional efforts.

Future Research

As discussed earlier in this chapter, there are similarities between the response data collected in this work and other nature of science research conducted on populations at different age points. Future research might investigate how conceptions and variations in thinking shift and differ by age point or level of school science experience. This research might illuminate when and how conceptions develop. For instance, elementary and middle school students might be more likely to hold notions of science that are congruent with the categories associated with the *DISCOVERY* oriented theme (e.g., *Experiments Discover*, *Science is about Finding Out*). This orientation in thinking might shift toward the *FACT* theme as students encounter school science experiences that require them to memorize terms and facts or which engage them in verification types of laboratory activities. A longitudinal study that tracks how a particular group of students' thinking about the nature of science develops over time would be particularly interesting, especially if it can provide insight on how conceptions of science influence attitudes toward science. Connecting students' conceptions of science with their attitudes toward science is a pressing issue, since research on student interest in and attitudes towards science suggests that middle school is the point where many students, particularly girls, lose interest in science (Jones, et al, 2000; Weinburgh, 1995).

The findings from this study combined with Blalock et al.'s (2008) underlying assumption that attitudes toward science help steer career options might be the basis for a line of research that investigates whether students' conceptions of science can predict their career interests and ultimately their career choices. One of the most complete categories that emerged from this study was *Science is about Finding Out*, and several categories were aligned with a *DISCOVERY* oriented theme. In a study of undergraduate student characteristics, McGee and Keller (2007) noted, "the most demonstrable theme that consistently predicted those students who persisted toward research after college was a curiosity to discover the unknown." The way students conceive the purpose of science (e.g., *Science is about Finding Out*) may, in fact, reflect their attitude toward science. If so, understanding when and how these conceptions of science develop and change might help foster K-12 and college educational experiences that attract students to—and retain students in—STEM-related fields.

In a comprehensive review of literature on science attitude instruments, Blalock et al. (2008) have a category specifically devoted to nature of science instruments. Although the reasoning for including the nature of science category is not obvious, their analysis is legitimate. The Nature of Science category included five instruments designed to measure students' understanding of the nature of science. The VNOS instrument (Lederman, 2002) adapted for this study tied with another instrument (Ruba et al., 1981) for highest ranked nature of science instrument. However, the need for more research in this area is clearly evidenced in their conclusion:

> The information provided for these instruments [Lederman, 2002; and Ruba et al., 1981] originated from single studies so further evaluation of the instruments is needed for more validity evidence. In addition, a high score of 7 for the nature of science category is unimpressive when the maximum possible score is 28. The question is raised of why instruments within this category showed such weak psychometric evidence.

According to their analysis, VNOS scored 3 out of a possible 6 points on dimensionality. The more nuanced findings of this study might be used to improve the dimensionality of VNOS and other nature of science instruments. The 14 categories of description that emerged from this study illuminate finer distinctions in the way students think about the four VNOS aspects addressed in this work. These categories of description provide a higher resolution lens for understanding how students perceive science.

Given the VNOS findings (Abd-El-Khalick & Lederman, 2000; Lederman et al., 2002) that pre-service science teachers often hold more naïve views as opposed to more informed views of the nature of science, one might investigate possible teacher effects. In fact, the VNOS line of research is based on the assumption that teachers cannot possibly teach nature of science concepts effectively if they do not understand these concepts themselves. The implied professional development to remediate naïve views is rather simplistic and linear—assess a teacher's nature of science knowledge, identify those with more naïve views, provide the training that results in their having a more informed view of the nature of science. This conflicts with other research on teacher beliefs and knowledge that suggests having a more informed view of the nature of science may be necessary, but not sufficient, for changing a teacher's classroom practices (Tsai, 2002; Water-Adams, 2006). This line of research suggests that teachers are not likely to change their classroom practice unless their knowledge of the nature of science is aligned with their general beliefs about how students should be taught and they possess the necessary pedagogical content knowledge (Shulman, 1986) to teach the nature of science. The methodology utilized in this study, which revealed more nuanced student thinking regarding the nature of science, might be applied to better understand the preexisting conceptions of science teachers. It may help reveal relationships between teacher conceptions and how those conceptions influence and perhaps even constrain the translation of nature of science knowledge into classroom practices.

Despite major reform efforts, such as the National Science Education Standards (National Science Council, 1996), to develop and implement curricula designed to improve students’ understanding of the nature of science, research suggests these efforts have met with only limited success (Abd-El-Khalick et al., 2008; Chen, 2006; Dogan and Abd-El-Khalick, 2008; Khishfe 2008; Sutherland et al., 2007). More research is needed to determine what curricular and instructional efforts will result in students having a more sophisticated understanding of the nature of science. The more nuanced categories that emerged from this study might serve as better predictors then simply an informed or naïve understanding of a particular aspect of the nature of science. This is particularly important because research suggests that the way students conceptualize science influences, and in some instances restricts, how they acquire new information about science (Bell et al., 2003; Driver et al., 1996).

There are a variety of questions that future research efforts might address that build from an understanding of the qualitatively different ways that students think about the nature of science. Understanding variations in students’ conceptions of science in the language and conceptual schema in which they are operating better equips future researchers to ask meaningful questions and interpret findings in more appropriate ways. Research on variations in students’ conceptions of science with findings that are clearly reflective of student thinking might be more accessible to classroom practitioners, and more likely to result in translating research on students’ conceptions of science into classroom practices that improve science knowledge and skills and foster a greater degree of science literacy among students.

Summary

The purpose of this study is to describe, using an emergent phenomenographic research approach, the qualitatively different ways high school chemistry students think about the nature of science. This work attempts to reveal students' understanding using open-ended student response data from a six-item questionnaire that probes the following aspects of the nature of science:

- Purpose of science
- Tentativeness of scientific knowledge and the nature of theories
- Creativity & imagination
- Aim & structure of experiments

The primary analysis was based on 100 randomly selected written responses that represent a broad and diverse population of high school students. This analysis yielded 39 primary level codes, which were then collapsed based on the similarity of responses. This distillation revealed 14 categories of description:

- Theories Change
- Experiments Prove
- Experiments Test
- Science is about Facts and Proving
- Science is about Finding Out
- Theories Do Not Change
- Science is Helpful
- Creativity with Experiments

- Science is Everything
- Creativity with Ideas
- Experiments Discover
- Experiments are Procedures
- No Creativity
- Science as a Perspective

These categories reflect the qualitatively different ways students think about the nature of science. The categories represent a range of conceptions, from rather common ones grounded in many student passages to less common yet distinct conceptions comprised of just a few passages. Constructing a phenomenographic outcome space diagram and mapping the 14 categories onto the four aspects of the nature of science suggests that some categories are more complete or common than others. These analyses also suggest students tend to orient their thinking about science either in term of facts and a process grounded in proving something or in terms of discovery and a process grounded in finding something out. The results of this study help reveal the nuanced conceptions within these four aspects of the nature of science.

Understanding this variation in students' conceptions of science in the language and conceptual schema in which they are operating might assist science educators in designing curricula and assessments with more precise conceptual hooks able to engage students based on their preexisting conceptions, These efforts might result in more efficient ways to move students' thinking to more sophisticated levels of understanding.

This study adds to the VNOS research literature (and, more generally, to nature of science research) by identifying more nuanced conceptions within four of the VNOS aspects. The 14 categories of description that emerged from this study provide greater insights into students' thinking, and might serve as more accurate predictors and better assist future researchers in designing studies that take into account more nuanced conceptions of science and interpreting findings in more meaningful ways. Research studies that reflect the qualitatively different ways students think about science might be more accessible to classroom practitioners, and more likely to result in clearer ways of translating research on students' conceptions of science into classroom practices.

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APPENDIX A

NATIONAL SCIENCE TEACHER ASSOCIATION (NSTA)

NATURE OF SCIENCE POSITION STATEMENT

Science is characterized by the systematic gathering of information through various forms of direct and indirect observations and the testing of this information by methods including, but not limited to, experimentation. The principal product of science is knowledge in the form of naturalistic concepts and the laws and theories related to those concepts. Further, the following premises are important to understanding the nature of science.

- Scientific knowledge is simultaneously reliable and tentative. 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.
- Although no single universal step-by-step scientific method captures the complexity of doing science, a number of shared values and perspectives characterize a scientific approach to understanding nature. Among these are a demand for naturalistic explanations supported by empirical evidence that are, at least in principle, testable against the natural world. Other shared elements include observations, rational argument, inference, skepticism, peer review and replicability of work.
- Creativity is a vital, yet personal, ingredient in the production of scientific knowledge.
- Science, by definition, is limited to naturalistic methods and explanations and, as such, is precluded from using supernatural elements in the production of scientific knowledge.
- A primary goal of science is the formation of theories and laws, which are terms with very specific meanings.

    1. *Laws* are generalizations or universal relationships related to the way that some aspect of the natural world behaves under certain conditions.
    2. *Theories* are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.
    3. Well-established laws and theories must:
        - be internally consistent and compatible with the best available evidence;

    - be successfully tested against a wide range of applicable phenomena and evidence;
    - possess appropriately broad and demonstrable effectiveness in further research.

- Contributions to science can be made and have been made by people the world over.
- The scientific questions asked, the observations made, and the conclusions in science are to some extent influenced by the existing state of scientific knowledge, the social and cultural context of the researcher and the observer's experiences and expectations.
- The history of science reveals both evolutionary and revolutionary changes. With new evidence and interpretation, old ideas are replaced or supplemented by newer ones.
- While science and technology do impact each other, basic scientific research is not directly concerned with practical outcomes, but rather with gaining an understanding of the natural world for its own sake.

APPENDIX B

NATURE OF SCIENCE QUESTIONS

Adapted from *VNOS-C*, Lederman et al., 2002

1. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atoms looks like?
2. What is an experiment?
3. Does the development of scientific knowledge require experiments? Explain why or why not. Give an example to defend your position.
4. After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change? Explain why or why not. Defend your answer with examples.
5. Scientists perform experiments/investigations when trying to find answers to questions they put forth. Do scientists use their creativity and imagination during their investigations? Explain why or why not. Illustrate your answer with an example.
6. What in your view is science? What makes science (or a scientific discipline such as chemistry) different from other disciplines of inquiry (e.g. religion, philosophy)?

Items *not* used from *VNOS-C*, Lederman et al., 2002

1. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
2. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?
3. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggested that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

4. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, philosophical values, and intellectual norms of the culture in which it is practiced.

    - If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
    - If you believe that science is universal, explain why. Defend your answer with examples.

APPENDIX C

NVIVO REVISION 2.0.163

Licensee: Jonathan Keiser

Project: NOS 5 08 06 User: Administrator Date: 5/9/2006–11:16:44 PM
DOCUMENT CODING REPORT

Document: NOS-100 random sample by person
Created: 1/8/2006–4:36:12 PM
Modified: 12/27/2009
Description:
2275018 3 3 2 2 1

Nodes in Set: All Free Nodes
Node 1 of 39 beliefs or faith
Passage 1 of 13 Section 0, Para 12, 103 chars.

"Religion and philosophy can't ever be physically proven. They're what you believe and require faith."
Passage 2 of 13 Section 0, Para 140, 70 chars.

"Religion is a belief, philosophy is an opinion and science is a fact."
Passage 3 of 13 Section 0, Para 156, 192 chars.

"Difference in chemistry from religion is that chemistry can be bullied up by proof and it is what it is. Religion is what you believe in and can be changed with no way to prove if it's wrong."
Passage 4 of 13 Section 0, Para 182, 122 chars.

"Science is different from other subjects, because other subjects are mostly about the past. Science is about the future."
Passage 5 of 13 Section 0, Para 204, 110 chars.

"Science is different from religion because religion is the study of God, chemistry is the study of reactions."
Passage 6 of 13 Section 0, Para 266, 154 chars.

"Science relies on logic, math and the physical world to determine the truth, whereas religion & philosophy rely on people's interpretation of the world."
Passage 7 of 13 Section 0, Para 352, 113 chars.

“They test things to find out but religion using the bible we don't need to test we already know what we need to.”

Passage 8 of 13 Section 0, Para 365, 120 chars.

“Chemistry is different from religion because answers come only through human understanding however advanced or obtuse.”

Passage 9 of 13 Section 0, Para 398, 362 chars.

“Science is the discovery of life and learning how things work and why certain things happen. It is different from religion and philosophy because religion is knowing what happened and believing in a higher force knowing that someone is really there but in science we have no idea, we take creative ideas and conduct experiments to discover new things in life.”

Passage 10 of 13 Section 0, Para 444, 291 chars.

“Science is theories you can prove. You can prove anything and everything with science (we just might not have all the technology right now to do what we need). Religion is something you believe in it whether it is real or fake or whether you can prove it or not, you just believe in it.”

Passage 11 of 13 Section 0, Para 524, 243 chars.

“Science is the straight facts. There is nothing that will go unexplained. Which compared to religion is the complete opposite. Religion is based solely on belief. Some things are not explained in religion. That will not happen in science.”

Passage 12 of 13 Section 0, Para 600, 78 chars.

“Science is proven material. Religion and philosophy are things we believe in.”

Passage 13 of 33 Section 0, Para 258, 141 chars.

“Science is different because it has to do with the science & in depth of the world of atoms and chemicals. The other stuff is just beliefs.”

Node 2 of 39 certain because it’s taught

Passage 1 of 3 Section 0, Para 66, 227 chars.

“I think that scientists are pretty certain about the structure of the atom. First of all I don't think students would be learning it in school if it was like a guess and check thing. So I think they are pretty sure about it.”

Passage 2 of 3 Section 0, Para 306, 286 chars.

“I think scientists are very certain about the structure of atoms because they have put it in our textbooks, and I don't think if they weren't certain they would put them in there. I don't think scientists know exactly what atoms look like but they all have pretty much the same idea.”

Passage 3 of 3 Section 0, Para 553, 291 chars.

“Scientists have researched the atom so they know its structure. If they weren't sure about it there wouldn't be labs that deal with atoms. Not just that but atoms are used in everything, everybody, element or any other objects have atoms. They have the electrons, protons and neutrons.”

Node 3 of 39 certain because of experiments
Passage 1 of 12 Section 0, Para 28, 128 chars.

“They are sure. They use evidence about how the atoms work so by that knowledge they can decide where everything is in the atom.”

Passage 2 of 12 Section 0, Para 41, 154 chars.

“I think scientists used an experimental lab about atoms and a whole bunch of scientists got the same data so they decided that's what an atom looks like.”

Passage 3 of 12 Section 0, Para 89, 244 chars.

“Scientists now on days are sure of what the atom looks like because they already sustained a set of rigorous experiments to see the structure. Scientists could have taken a picture of an atom with a high visible spectrum to see the structure.”

Passage 4 of 12 Section 0, Para 102, 342 chars.

“The scientists are very certain about the structure of the atom, because they know that opposites attract, therefore a negative electron and a positive proton attract each other. they used a machine that sent molecules through and they noticed that some of the particles got stuck, showing the difference between negative/positive charges.”

Passage 5 of 12 Section 0, Para 115, 341 chars.

“Scientists are very sure of how atoms look like. Science has evaluated a lot from the first time the world heard about atoms. As time pass the atom changed, but for a long time it has been the same and not another discovery has come out. Plus all of the parts and sections of an atom go with each other and makes sense as you study it.”

Passage 6 of 12 Section 0, Para 290, 60 chars.

“Science is finding the truth by experiments and other stuff.”

Passage 7 of 12 Section 0, Para 355, 379 chars.

“I think scientists are certain of the basic structure of an atom. I know there were experiments done that proved an atom wasn't a solid mass but mostly space. One experiment was firing pieces of matter through gold foil. If the atoms were solid the matter would be stopped by the foil but because of the structure of atoms we know the matter could fly right through the foil.”

Passage 8 of 12 Section 0, Para 388, 129 chars.

“They are pretty sure because from this they have been able to test many things proving over and over that the structure is true.”

Passage 9 of 12 Section 0, Para 408, 120 chars.

“The scientists are pretty sure how atoms look because I think they use different experiments to determine how it looks.”

Passage 10 of 12 Section 0, Para 473, 578 chars.

“Scientists are probably very certain of their findings because they know that protons are positively charged & electrons are negatively charged so they cannot be within a close range or else they will repel each other. They must be apart and since they later found it was hard to separate protons they probably guessed they were centralized & neutrons were also found & wouldn't interfere with the protons so they were probably in the nucleus too. When they found that electrons could be excited they realized they must move, & realized they were arranged in energy levels.”

Passage 11 of 12 Section 0, Para 501, 393 chars.

“I would have to say that scientists are very certain they know how an atom is structured. They probably found this out by the gold foil experiment. They would shoot a beam at the foil and sometimes it went right through the foil when other times it was deflected and a beam somewhere else. So for the beam to be deflected like that it must have hit something hard, which was the nucleus.”

Passage 12 of 12 Section 0, Para 577, 246 chars.

“Scientists are certain about the structure of an atom because they have performed many experiments such as the ""gold foil"" experiment and when Thomson discovered electron while investigating properties of electricity using a cathode ray tube.”

Node 4 of 39 certain-microscope

Passage 1 of 12 Section 0, Para 15, 128 chars.

“What they could do is look at a certain element or compound under a very powerful microscope and be able to view its structure.”

Passage 2 of 12 Section 0, Para 54, 312 chars.

“I think that scientists are very certain on the structure of an atom because for several years this has been proved. For past years I have seen and used microscopes that show me the nucleus and I am able to view protons and neutrons inside the nucleus as well as viewing the electrons on the orbits of the atom.”

Passage 3 of 12 Section 0, Para 220, 91 chars.

“They weren't sure about the structure of the atom until there were microscopes to see them.”

Passage 4 of 12 Section 0, Para 233, 330 chars.

“I think that scientists are somewhat certain about the structure of an atom. The reason is because all the protons and neutrons, along with electrons are moving so rapidly for them to actually get a picture of it. That's why it's represented more like a cloud. The evidence that scientists have are high powered microscopes.”

Passage 5 of 12 Section 0, Para 330, 63 chars.

“I think they used microscopes to look at what atoms look like.”

Passage 6 of 12 Section 0, Para 370, 21 chars.

“Electron microscopes.”

Passage 7 of 12 Section 0, Para 388, 147 chars.

“The evidence proving what an atom looks like is the fact that they have microscopes now so powerful that they are for certain what it looks like.”

Passage 8 of 12 Section 0, Para 514, 88 chars.

“They do know a lot though. Scientists use high powered microscopes to view the atoms.”

Passage 9 of 12 Section 0, Para 527, 270 chars.

“I think scientists aren't really sure about the structure of the atom. They know how it's structured but they have doubts about atoms structure too. They look at the atoms under a microscope, but they can't tell everything, they are still not sure about some stuff.”

Passage 10 of 12 Section 0, Para 540, 114 chars.

“Atoms are too small to see with the naked eye. They use a special machine that is powerful enough for us to see.”

Passage 11 of 12 Section 0, Para 566, 55 chars.

“Very certain/they have studied atoms under a microscope”

Passage 12 of 12 Section 0, Para 590, 141 chars.

“Because atoms are the building blocks of matter, scientists have concluded their size and shape by looking at structure and atomic weight.”

Node 5 of 39 creativity generates questions

Passage 1 of 2 Section 0, Para 442, 323 chars.

“Yes they have to have an imagination because if you didn't then you wouldn't think of any questions to ask or have any reasons to perform investigations. Like in a crime scene when someone finds brown hair you can't just believe it was the victim's. You have to think of the other possibilities of who else's it might be.”

Passage 2 of 2 Section 0, Para 585, 317 chars.

"Yes scientists use their creativity and imagination during their investigations because in order for an experiment idea is to be created you must use your imagination to come up with the hypothesis. The creativity of thinking of using balloons to show how a balloon's air will go out when placed in liquid nitrogen."

Node 6 of 39 creativity required for designing ex
Passage 1 of 23 Section 0, Para 10, 342 chars.

"Scientists would have to use their creativity and imagination to come up with an experiment for the theory or questions. Such creativity would be when the gold foil was thought of. When the scientist used gold instead of silver or aluminum and using light, his creativity and imagination had come up with theory and a way to test it out."
Passage 2 of 23 Section 0, Para 23, 203 chars.

"They could use their imagination for doing experiments so they can somewhat enjoy what they're doing, and it could also help them construct different ways to build the experiment so it could be easier."
Passage 3 of 23 Section 0, Para 36, 85 chars.

"Yes, they use many different things and be creative to create the best experiment."
Passage 4 of 23 Section 0, Para 49, 66 chars.

"Yes because they need to use different things to experiment with."
Passage 5 of 23 Section 0, Para 61, 332 chars.

"Scientists definitely add their own creativity and imagination during their investigations! Each scientist finds things that work best for them and they are able to repeat these things in each or several of their own experiments. This particular scientist adds food coloring so that he can see his experiments and how they change."
Passage 6 of 23 Section 0, Para 74, 246 chars.

"Scientists have to have creativity and imagination to be able to create good experiments. They have to be able to come up with a creative way to do the experiment more than once, so I think good scientists use their imagination and creativity."
Passage 7 of 23 Section 0, Para 97, 135 chars.

"Yes, because they have to experiment to know if what they think is right or wrong. And try different methods to find their results."
Passage 8 of 23 Section 0, Para 138, 399 chars.

"Yes, scientists do use creativity and imagination during investigations. They do this, in some cases, to get the job done easier. If a scientist has an idea that will execute their experiment more accurate and better, then they will use that idea. Not all experiments have to be by the book. Like when we did the hair testing, a scientist though of a good way to determine the weight of hair."

Passage 9 of 23 Section 0, Para 167, 78 chars.

"Yes scientists have to use creativity and imagination in their investigation."

Passage 10 of 23 Section 0, Para 180, 95 chars.

"Yes, because they use creativity and add different problems that could happen in the testing."

Passage 11 of 23 Section 0, Para 228, 114 chars.

"Yes because otherwise they wouldn't get some laws. They have to use their imagination to think up the processes."

Passage 12 of 23 Section 0, Para 256, 63 chars.

"Yes because they want to find out if their experiments worked."

Passage 13 of 23 Section 0, Para 277, 73 chars.

"Yes because they need to have imagination to make experiments and hypotheses."

Passage 14 of 23 Section 0, Para 288, 43 chars.

"Yes they do. This is called a hypothesis."

Passage 15 of 23 Section 0, Para 314, 314 chars.

"Each scientist performs his/her investigations differently according to their creativity and imagination. It may take more evidence to prove something to scientist A than to scientist B. So depending on that they will need to use their creativity and imagination to prove what they are looking for to themselves."

Passage 16 of 23 Section 0, Para 325, 117 chars.

"They do use their creativity by trying to find easier ways of solving investigations. Ex.) Rutherford's experiment."

Passage 17 of 23 Section 0, Para 429, 163 chars.

"Yes, scientists use their imagination during their investigations because they are trying to find out something new, so they have to use a new method to find it."

Passage 18 of 23 Section 0, Para 481, 282 chars.

"Of course scientists must use their imagination. That is how they figure out things or make up experiments that would test their theory. How else would scientists know about particle acceleration, they had to think of the problem & what the results of certain actions would be."

Passage 19 of 23 Section 0, Para 496, 211 chars.

“Yes they do in every experiment or investigation there is always some kind of creativity or imagination. Everyone has their own ways of doing things and they need these things to make the experiment their own.”

Passage 20 of 23 Section 0, Para 509, 295 chars.

“Yes, they would use their creativity and imagination during the investigation. They would do this to try and find the best, most accurate, efficient and proficient results. Why would you want to do an experiment that takes a couple of hours one way if the other way you can do it in minutes.”

Passage 21 of 23 Section 0, Para 522, 400 chars.

“Yes the scientists use their imaginations during these experiments/investigations. To perform an experiment you must have an idea about what is going to happen. TO have an idea you must imagine. A scientists must mix two chemicals together and record the outcome. Although he has a good idea he is not entirely sure what is going to happen. Maybe it will freeze or burst into flames he imagines.”

Passage 22 of 23 Section 0, Para 548, 300 chars.

“I think scientists do use their creativity & imagination because if they didn't they would never get results for unique experiments. There wouldn't be experiments because if the scientists didn't use imagination & creativity they would never want to see the outcome of reactions of different things.”

Passage 23 of 23 Section 0, Para 598, 58 chars.

“Yes, they use creativity to create experiments and labs.”

Node 7 of 39 creatvty useful for making new ideas

Passage 1 of 13 Section 0, Para 85, 179 chars.

“Yes, because when they find animal's bones they imagine the animal alive and started to imagine its movement everything. That's why creativity & imagination does come in handy.”

Passage 2 of 13 Section 0, Para 154, 160 chars.

“Yes they can come up with whatever way they can to explain their answers. For instance Galileo improved the telescope to see the moon and proved people wrong.”

Passage 3 of 13 Section 0, Para 193, 134 chars.

“Yes because they can look at their investigations in many ways and use their creativity to find different ideas in the investigation.”

Passage 4 of 13 Section 0, Para 215, 361 chars.

“They have to. Without imagination we could not predict what was about to happen. Einstein seemed strange but he wasn't that far off. When I put creativity into the experiment I am thinking outside the box. The atom was far beyond our comprehension until someone was imaginative. John Dalton said there had to be an invisible small particle which there is."

Passage 5 of 13 Section 0, Para 264, 59 chars.

"Yes, a hypothesis is a creative and imaginative question."

Passage 6 of 13 Section 0, Para 301, 125 chars.

"Without creativity or imagination there would be no science. In what other manner would people think of making an airplane."

Passage 7 of 13 Section 0, Para 338, 292 chars.

"Yeah they need to be creative and imaginative. If there was a scientist with no creativity they would be the lamest scientist ever. Scientists need to imagine new things. So they can keep experimenting with new ideas. Scientists are always trying to make new weapons of mass destruction."

Passage 8 of 13 Section 0, Para 363, 365 chars.

"I think scientists do use their imaginations to conduct investigations for the sole reason that it is our imaginations that allows humans to manifest different possibilities than set forth before. The investigation of planets and star orbits are examples. Instead of going along with the norm, the sun and planets orbit the Earth, someone imagined differently."

Passage 9 of 13 Section 0, Para 396, 392 chars.

"Yes, because without an imagination we would never have new ideas on how something works or have the motivation to conduct experiments if they don't feel something may come of it. Or have an image about what may happen then man would have no reason to investigate. If man ever wondered what things were made of there would be no such thing as an atomic bomb & Einstein would be a nobody."

Passage 10 of 13 Section 0, Para 416, 251 chars.

"Yes scientists use their imagination during investigation. Let's say a person is doing a shooting so using their imagination they put themselves in the crime and reenact the events being more sure where the shooter shot, where he was standing, etc."

Passage 11 of 13 Section 0, Para 455, 44 chars.

"They have to be able to think up something."

Passage 12 of 13 Section 0, Para 468, 186 chars.

"Yes, like for an example if trying to solve a murder case you kind of have to think like the criminal and repeat things the killer did to try and figure out things or even to solve it."

Passage 13 of 13 Section 0, Para 612, 39 chars.

"Yes, you have to think of what to do."

Node 8 of 39   different or better scientists
Passage 1 of 8 Section 0, Para 59, 465 chars.

"Once scientists develop scientific theories their theory is normally not changed by themselves. A scientific solution is approached and practiced several times with several changes made. A theory is generally developed once a solution has proved to work time and time again. Different scientists may take your method and alter it in a way that changes your method and alter it in a way that changes your method, but that then becomes this new person's theory."

Passage 2 of 8 Section 0, Para 95, 144 chars.

"Yes it does change because other scientists might find other results and prove it to a major scientist. That scientist might change his theory."

Passage 3 of 8 Section 0, Para 152, 110 chars.

"Better scientists do your experiment and come up with a theory different from yours. The theory is changed."

Passage 4 of 8 Section 0, Para 286, 92 chars.

"Yes the theory changes because some other person can have a better theory than someone else."

Passage 5 of 8 Section 0, Para 312, 307 chars.

"I don't think scientists change their own theories unless some huge piece of evidence comes up. But different scientists have different theories than others. Like with evolution different people believe different things. Like the theory of humans coming from monkeys & with others who don't believe that."

Passage 6 of 8 Section 0, Para 336, 353 chars.

"I think they do. Let's say someone makes a theory at a certain time. A few years later some other scientist might find out some new stuff to prove that theory wrong. Like if someone made a theory that the world was not round and if you were to walk to the end that you would fall off and die. Some person might explore the world and prove him wrong."

Passage 7 of 8 Section 0, Para 453, 102 chars.

"Yes, because other scientists have theories too & scientists can be proven wrong—i.e. cold fusion."

Passage 8 of 8 Section 0, Para 460, 249 chars.

"It has took many years and the very good scientists study the atom and take data and probably the closets out of so many scientists. They could compare the data they have and keep on until every scientist feels that what is said is up to knowledge."

Node 9 of 39 exper study of an object
Passage 1 of 4 Section 0, Para 79, 125 chars.

"An experiment is when you study an object and have opinion and describe what happen and find what you're trying to find out."
Passage 2 of 4 Section 0, Para 148, 189 chars.

"Experiment is process of testing a something to see what it does when reacted with something else outside of its own make-up of its structure. It includes many observations and recordings."
Passage 3 of 4 Section 0, Para 174, 132 chars.

"An experiment is a test (usually different types) to figure something out. You usually test a certain material, object, chemical."
Passage 4 of 4 Section 0, Para 347, 124 chars.

"Yes, figure out about something like if they find a new element they will test it with others to see what it reacts with."

Node 10 of 39 exper required because hands-on
Passage 1 of 4 Section 0, Para 70, 200 chars.

"Experiments are vital to the scientific process. Science would be way boring without the labs. You have to have hands on stuff to actually want to learn good things about chemistry, or it's boring."
Passage 2 of 4 Section 0, Para 258, 76 chars.

"The other stuff is just beliefs. Science is not a belief, it is hands on."

Passage 3 of 4 Section 0, Para 345, 61 chars.

"Experiment is when you use materials to figure out something."
Passage 4 of 4 Section 0, Para 436, 193 chars.

"An experiment is when you have a theory and you take tools or objects and try to prove your theory. Ex.—when you take H2O2 and put it through a decomposition reaction it turns into H2O & O2."

Node 11 of 39 exper tests an idea
Passage 1 of 13 Section 0, Para 117, 199 chars.

"An experiment is doing something to see what happens and to see if you were right or wrong. It's doing things to understand why they are the way they are and how they work. And to make new things."

Passage 2 of 13 Section 0, Para 161, 95 chars.

"Testing maybe a theory, an idea or an element by making a test or experiment out of an idea."

Passage 3 of 13 Section 0, Para 308, 98 chars.

"An experiment is a test. You do experiments on things to test what their results are going to be."

Passage 4 of 13 Section 0, Para 436, 193 chars.

"An experiment is when you have a theory and you take tools or objects and try to prove your theory. Ex.—when you take H_2O_2 and put it through a decomposition reaction it turns into H_2O & O_2."

Passage 5 of 13 Section 0, Para 449, 62 chars.

"Something a scientist uses to test his theory about something."

Passage 6 of 13 Section 0, Para 483, 401 chars.

"Science is the logical search for answers using things that can be proven in numbers, or logical theories. Science is different than philosophy or religion because in the latter they can dip into human evolution or spirit or other things that can't be proven by humans. To answer questions, they don't have to obey the laws of nature to answer their questions, they also don't test their theories."

Passage 7 of 13 Section 0, Para 518, 360 chars.

"The development of scientific knowledge does require experiments. Without testing you only have an idea. It is when you prove something that you obtain knowledge. It takes the same amount of time for a bowling ball and a grape to hit the ground if dropped from the same level at the same time. You would never be able to figure that out without testing it."

Passage 8 of 13 Section 0, Para 522, 197 chars.

"Yes the scientists use their imaginations during these experiments/investigations. To perform an experiment you must have an idea about what is going to happen. TO have an idea you must imagine."

Passage 9 of 13 Section 0, Para 555, 196 chars.

"An experiment is a process that is came up with so that something could be tested or invented. An experiment is a scientific method to come up with the answers that are needed by the scientists."

Passage 10 of 13 Section 0, Para 606, 35 chars.

"A way to test a theory or question."

Passage 11 of 13 Section 0, Para 610, 57 chars.

"Yes, because they do experiments to test their theories."

Passage 12 of 13 Section 0, Para 32, 62 chars.

"Not always, because tests can tell you a lot about science."

Passage 13 of 13 Section 0, Para 237, 326 chars.

"I think the development of scientific knowledge does require experiments, but only to some extent. For example when dinosaurs were discovered, it was a great scientific discovery. But there was no need for experiments and when they said that the freezing point was 0 degrees C, they had to do an experiment more than once."

Node 12 of 39 experiment tests a hypothesis

Passage 1 of 21 Section 0, Para 4, 125 chars.

"An experiment is where you apple a theory by testing different possibilities to acquire knowledge or gain an accurate result."

Passage 2 of 21 Section 0, Para 30, 93 chars.

"You use things to find results. You have a hypothesis. Includes one control and variables."

Passage 3 of 21 Section 0, Para 55, 54 chars.

"An experiment is a procedure that tests a hypothesis."

Passage 4 of 21 Section 0, Para 68, 298 chars.

"An experiment is something that is being tested. We are testing it to see what the final results will be. If we're mixing this with this, what will happen kind of thing. So, usually we will predict what is going to happen, like what we think before and it's fun to see if you're right or not."

Passage 5 of 21 Section 0, Para 104, 38 chars.

"There are also tests and a hypothesis."

Passage 6 of 21 Section 0, Para 106, 137 chars.

"Yes the development of scientific knowledge requires experiments, because experiments determine if their hypothesis is correct or not."

Passage 7 of 21 Section 0, Para 132, 291 chars.

"An experiment is a way to find an answer to your question. An experiment consists of a hypothesis, data, tests (more than one), results, and other things. An experiment determines what you are wondering. Once you're done with an experiment, you can use the results to see what happened."

Passage 8 of 21 Section 0, Para 148, 190 chars.

"Experiment is process of testing a something to see what it does when reacted with something else outside of its own make-up of its structure. It includes many observations and recordings."

Passage 9 of 21 Section 0, Para 150, 214 chars.

"Yes, you must know as well as see if what you're testing is true to gain the knowledge of what you're studying, i.e. you test catalyst on potato, you must get and record observations to understand what it means."

Passage 10 of 21 Section 0, Para 152, 220 chars.

"Yes it does. Other scientists study the theory and find different <illegible> until it is proved correct but more time the theory is changed, e.g. you test an experiment many times and you come up with theory from it."

Passage 11 of 21 Section 0, Para 187, 67 chars.

"An experiment is the process of a hypotenuse to find a conclusion."

Passage 12 of 21 Section 0, Para 198, 49 chars.

"In an experiment the hypothesis is being tested."

Passage 13 of 21 Section 0, Para 222, 34 chars.

"A test of a law or to make a law."

Passage 14 of 21 Section 0, Para 357, 67 chars.

"An experiment is the act of trying to find an answer to a question."

Passage 15 of 21 Section 0, Para 372, 33 chars.

"A test to find out a hypothesis."

Passage 16 of 21 Section 0, Para 390, 98 chars.

"An experiment is a set up designed to test something for a specific reason & to test a hypothesis."

Passage 17 of 21 Section 0, Para 423, 87 chars.

“An experiment is when you have a hypothesis & you test it in a controlled environment.”

Passage 18 of 21 Section 0, Para 475, 186 chars.

“An experiment is a situation in which you are presented w/ a problem. You create a hypothesis & you test the hypothesis (this is the experiment part), gather data & form a conclusion.”

Passage 19 of 21 Section 0, Para 529, 188 chars.

“An experiment is a test controlled conditions that is made to demonstrate a known truth, examine a validity of a hypothesis, and demonstrate the efficacy or something previously untried.”

Passage 20 of 21 Section 0, Para 542, 175 chars.

“An experiment is the outcome of someone's hypothesis. For example, ""What does X mixed with ZW cause? What happens?"" By mixing X, Z, W you are conducting an experiment.”

Passage 21 of 21 Section 0, Para 579, 168 chars.

“Something performed to prove a hypothesis. Experiments involve scientific tools, formulas and methods used to carry out a thought or idea having to do with science.”

Node 13 of 39 experiments—helpful procedures

Passage 1 of 18 Section 0, Para 17, 126 chars.

“An experiment is a procedure that can help decide, or to prove if a certain substance can be better than another substance.”

Passage 2 of 18 Section 0, Para 43, 44 chars.

“A trial run to see what the outcome will be.”

Passage 3 of 18 Section 0, Para 55, 54 chars.

“An experiment is a procedure that tests a hypothesis.”

Passage 4 of 18 Section 0, Para 81, 299 chars.

“Yes, experiment help you make sure of the objects you're using. How about you get a liquid. You don't know what it is. You use it not properly you can get hurt. Experiments help find out about stuff you want to use like a liquid. You study it, found the liquid is dangerous, you don't use it.”

Passage 5 of 18 Section 0, Para 91, 170 chars.

“An experiment is a procedure that allow you to discover new things. An experiment can help to make sure a substance is or is not harmful to people or any living object.”

Passage 6 of 18 Section 0, Para 104, 137 chars.

"An experiment is a problem about a situation that has a procedure to help figure out the answer. There are also tests and a hypothesis."

Passage 7 of 18 Section 0, Para 189, 118 chars.

"Yes, science knowledge requires experiments because it takes many ideas and procedures to determine one experiment."

Passage 8 of 18 Section 0, Para 235, 87 chars.

"An experiment is a procedure that is logged in order to prove a theory right or wrong."

Passage 9 of 18 Section 0, Para 273, 1 chars.

Passage 10 of 18 Section 0, Para 295, 104 chars.

"An experiment is a series of steps used to explain an occurrence of some sort, or to solve a problem."

Passage 11 of 18 Section 0, Para 321, 122 chars.

"Yes, because without experiments we wouldn't have found what new things we have today without doing certain procedures."

Passage 12 of 18 Section 0, Para 390, 98 chars.

"An experiment is a set up designed to test something for a specific reason & to test a hypothesis."

Passage 13 of 18 Section 0, Para 401, 212 chars.

"An experiment is an analysis repeated in order to determine a consistent result. The procedure includes materials, a procedure, purpose, discussion, data, calculations, observation, results and a conclusion."

Passage 14 of 18 Section 0, Para 410, 135 chars.

"An experiment is something with a procedure and a conclusion. Where you ask a question and find out the answer by a series of things."

Passage 15 of 18 Section 0, Para 490, 115 chars.

"A way to take materials and put it into action to form a reaction out of the chemicals or materials that you have."

Passage 16 of 18 Section 0, Para 516, 157 chars.

"An experiment is a series of tests performed to prove a point. An experiment is not exclusive to science either. There are many other kinds of experiments."

Passage 17 of 18 Section 0, Para 531, 398 chars.

“Scientists need to experiment, and see what's happening and how everything reacts. They have to check is everything safe for using, then if something is wrong they have to take notes and redo everything so it's perfectly safe for people. I know that because my group and I are doing a project right now. We have to check everything twice, to make sure no one from viewers is going to get hurt.”

Passage 18 of 18 Section 0, Para 568, 100 chars.

“An experiment is a hands on activity to help you better understand how something reacts with others.”

Node 14 of 39 experiments help discover

Passage 1 of 10 Section 0, Para 117, 198 chars.

“An experiment is doing something to see what happens and to see if you were right or wrong. It's doing things to understand why they are the way they are and how they work. And to make new things.”

Passage 2 of 10 Section 0, Para 282, 24 chars.

“To find out the unknown.”

Passage 3 of 10 Section 0, Para 297, 129 chars.

“Well, we don't know everything yet. So until then we will have to rely on experimentation to discover what we haven't yet.”hek

Passage 4 of 10 Section 0, Para 321, 122 chars.

“Yes, because without experiments we wouldn't have found what new things we have today without doing certain procedures.”

Passage 5 of 10 Section 0, Para 334, 128 chars.

“Experimentation lets us find out new things. Experimentation lets us develop new things that help out a lot in the community.”

Passage 6 of 10 Section 0, Para 347, 124 chars.

“Yes, figure out about something like if they find a new element they will test it with others to see what it reacts with.”

Passage 7 of 10 Section 0, Para 392, 230 chars.

“And from experiments scientists discover new things beyond our realm. If scientists had never discovered electricity or the flow of energy and more were continued to take place after that we would never move forward in the world.”

Passage 8 of 10 Section 0, Para 403, 233 chars.

"Yes, scientific knowledge requires experiments. An answer can look apparent or you may come to a certain answer the first time around, but experiments are done to assert effectiveness. In the process you discover new information."

Passage 9 of 10 Section 0, Para 555, 196 chars.

"An experiment is a process that is came up with so that something could be tested or invented. An experiment is a scientific method to come up with the answers that are needed by the scientists."

Passage 10 of 10 Section 0, Para 557, 204 chars.

"Yes without the experiments how will scientists be able to gain any knowledge of the experiments being made. New discoveries won't ever be discovered. So with experiments scientists will gain knowledge."

Node 15 of 39 experiments provide proof

Passage 1 of 33 Section 0, Para 6, 423 chars.

"Yes, if something wasn't experimented and an idea, theory, or law was stated without proof, it would be just as someone thought of something and said what it was. It would be the same as me saying I was president. Scientists discovered what an atom was composed of by using experiments. If experiments weren't conducted, all the theories of an atom that were proved to be incorrect would still be believed as correct."

Passage 2 of 33 Section 0, Para 17, 126 chars.

"An experiment is a procedure that can help decide, or to prove if a certain substance can be better than another substance."

Passage 3 of 33 Section 0, Para 19, 176 chars.

"I would say yes because experiments can prove and provide information about certain substances that were uncertain about before but may have a better understanding to it also."

Passage 4 of 33 Section 0, Para 45, 71 chars.

"Yes because in order to find the outcome you need to do the experiment."

Passage 5 of 33 Section 0, Para 81, 39 chars.

"No experiment no information or data."

Passage 6 of 33 Section 0, Para 93, 248 chars.

"The development of scientific knowledge requires experiments because if you don't experiment you won't have back up for your suppose knowledge. Like if you discover a new metal reaction you need to prove it to other people so they can believe you."

Passage 7 of 33 Section 0, Para 119, 285 chars.

“It does require experiments because how else would you know that your right and not wrong. Experiments are the prove of what your saying because other might contradict what you said. If I didn't have known this before, I would have said that water can not travel through a string.”

Passage 8 of 33 Section 0, Para 150, 214 chars.

“Yes, you must know as well as see if what you're testing is true to gain the knowledge of what you're studying, i.e. you test catalyst on potato, you must get and record observations to understand what it means.”

Passage 9 of 33 Section 0, Para 211, 237 chars.

“Yes, because without definite proof there is no way you can predict what the outcome is with experiments you have to do them so you can record anything unexpected (which happens a lot). These surprises are what make the developments.”

Passage 10 of 33 Section 0, Para 235, 86 chars.

“An experiment is a procedure that is logged in order to prove a theory right or wrong.”

Passage 11 of 33 Section 0, Para 262, 80 chars.

“Yes. Almost every major scientific discovery has required experiments to prove.”

Passage 12 of 33 Section 0, Para 282, 1 chars.

Passage 13 of 33 Section 0, Para 310, 319 chars.

“Yes the development of scientific knowledge requires experiments because they would have no proof to back it up. If someone told me that you could tell a blood stain from a different stain just by spraying a liquid on it, I wouldn't believe it. I would ask if they had proof and I am sure everyone else would also.”

Passage 14 of 33 Section 0, Para 332, 183 chars.

“It is an action that you do to prove something. If you wanted to find out what reacted with HCl, you would do some experiments, like reacting it with different chemicals and such.”

Passage 15 of 33 Section 0, Para 359, 263 chars.

“I believe the development of scientific knowledge does require experiments. If people didn't conduct experiments no one would know for sure if their theories hold up in the real world. The idea of the basic structure of an atom was clarified after experiments.”

Passage 16 of 33 Section 0, Para 374, 58 chars.

“Yes because nothing can be proven for sure without proof.”

Passage 17 of 33 Section 0, Para 383, 109 chars.

“Yes scientific knowledge requires experiments because you have to prove or be able to show how things happen.”

Passage 18 of 33 Section 0, Para 392, 159 chars.

“Yes because through experiments you prove things to either be correct or wrong. If not for experiments all things in life would be theories instead of facts.”

Passage 19 of 33 Section 0, Para 398, 111 chars.

“but in science we have no idea, we take creative ideas and conduct experiments to discover new things in life.”

Passage 20 of 33 Section 0, Para 403, 234 chars.

“Yes, scientific knowledge requires experiments. An answer can look apparent or you may come to a certain answer the first time around, but experiments are done to assert effectiveness. In the process you discover new information.”

Passage 21 of 33 Section 0, Para 425, 254 chars.

“Yes, the development of scientific knowledge requires experiments because without them we wouldn't be able to know things for sure or prove them to anyone. Without experiments people did with atoms we wouldn't know what we're leaning about them today.”

Passage 22 of 33 Section 0, Para 438, 353 chars.

“Yes the development of scientific knowledge requires experiments because if we didn't do experiments then we would be living by just thoughts and no real evidence what we are saying is true. An example is when Thompson thought an atom looked like this <drawing> without a nucleus. Rutherford did the gold foil experiment to prove there was a nucleus.”

Passage 23 of 33 Section 0, Para 451, 147 chars.

“Yes, because if you just keep making theories nothing will be right. If no one proved that 1 + 1 didn't equal 3 then our world would go nowhere.”

Passage 24 of 33 Section 0, Para 464, 339 chars.

“Yes, because even if you think you could give someone an answer about because you believe in your mind it is right. You might still want to do an experiment because you never know that something in your calculations could be wrong. But not every experiment is not exactly right because it is always a little less or a little more but not a whole lot.”

Passage 25 of 33 Section 0, Para 477, 359 chars.

“Yes, this is because knowledge must be tested to find out if it is true. You can't just assume things to be right & build the rest of your knowledge on that. For example, you can't just guess or hypothesize that bread will mold if left out in the open for a while & build scientific knowledge around that, you must test it out before you start building."

Passage 26 of 33 Section 0, Para 492, 350 chars.

"Yes, because they have to experiment different things to see how they work. they can't just guess. They have to actually determine what is really going to happen. If they need to determine which chemicals have a reaction and which ones don't. They need to experiment by putting the chemicals together to see what happens (if they react or no)."

Passage 27 of 33 Section 0, Para 505, 193 chars.

"Yes the development of scientific knowledge requires experiments. If you just make a theory you don't know if it is real or false. So you have to experiment to prove that it is false or real."

Passage 28 of 33 Section 0, Para 516, 157 chars.

"An experiment is a series of tests performed to prove a point. An experiment is not exclusive to science either. There are many other kinds of experiments."

Passage 29 of 33 Section 0, Para 544, 176 chars.

"Scientific knowledge is based on experiments. How else can you prove theories if you don't try the experiment on your own? You need experiments to gain scientific knowledge."

Passage 30 of 33 Section 0, Para 579, 168 chars.

"Something performed to prove a hypothesis. Experiments involve scientific tools, formulas and methods used to carry out a thought or idea having to do with science."

Passage 31 of 33 Section 0, Para 581, 336 chars.

"Yes because experiments help prove and bring facts to the hypothesis a scientist may have. An example is when Ernest Rutherford performed the ""gold foil experiment."" This experiment proved that the gold foil contained many small dense positively charged nucleus surrounded by electrons. This helped develop scientific knowledge."

Passage 32 of 33 Section 0, Para 592, 27 chars.

"A test to prove something."

Passage 33 of 33 Section 0, Para 594, 60 chars.

"Yes, because how can we prove anything without testing it."

Node 16 of 39 fairly certain about atoms

Passage 1 of 14 Section 0, Para 2, 177 chars.

"I believe the scientists are fairly certain considering the facts they've gathered from experiments, but since an atom is so small I don't think they'll ever be 100% certain."

Passage 2 of 14 Section 0, Para 130, 156 chars.

"Scientists are not positive about the structure of the atom. It is not a for sure answer about what an atom's structure is, but they are fairly certain."

Passage 3 of 14 Section 0, Para 146, 140 chars.

"Scientists are pretty sure about the structure of an atom. They can now have super cameras to get pretty good picture what they look like."

Passage 4 of 14 Section 0, Para 159, 268 chars.

"Scientists are never really 100% certain about something. I mean they may have a pretty good idea or so about something but there is always room for improvement and I think that things change so they don't always have the answers. After all they are only human too."

Passage 5 of 14 Section 0, Para 172, 121 chars.

"They don't know for sure. They just have been able to barely see the outline of them through very powerful microscopes."

Passage 6 of 14 Section 0, Para 185, 64 chars.

"Scientists aren't certain about the atom because it can change."

Passage 7 of 14 Section 0, Para 207, 334 chars.

"Pretty sure. They can test their hypothesis by using electromagnetic, magnetic or electronic methods to separate protons, electrons & neutrons. We can heat them, put them into circuitry, find out how much of it is in a mole. We can put the atoms on other types, see if they bond or react. We can see them in high powered scoped."

Passage 8 of 14 Section 0, Para 248, 37 chars.

"75%. The splitting up of the atoms."

Passage 9 of 14 Section 0, Para 261, 157 chars.

"Scientists are fairly sure but it is impossible to see one without an electron microscope; therefore, it's impossible to know what one exactly looks like."

Passage 10 of 14 Section 0, Para 269, 116 chars.

"I believe they have a lot of good facts on protons but they don't have enough technology to figure it out for sure."

Passage 11 of 14 Section 0, Para 447, 62 chars.

"I think they are quite certain; although it is just a theory."

Passage 12 of 14 Section 0, Para 514, 171 chars.

“Scientists know a lot about the atom, but I believe there is a lot more to learn. They do know a lot though. Scientists use high powered microscopes to view the atoms.”

Passage 13 of 14 Section 0, Para 527, 270 chars.

“I think scientists aren't really sure about the structure of the atom. They know how it's structured but they have doubts about atoms structure too. They look at the atoms under a microscope, but they can't tell everything, they are still not sure about some stuff.”

Passage 14 of 14 Section 0, Para 604, 18 chars.

“Pretty certain?”

Node 17 of 39 model matches theory

Passage 1 of 2 Section 0, Para 293, 226 chars.

“There are many different types of models that show the structure of an atom. The only reason why the current idea of orbiting e- and a central nucleus prevails is because it matches very well with theories and stuff, right?”

Passage 2 of 2 Section 0, Para 434, 414 chars.

“They are still doing research but the scientists are sure it looks something like this <drawing>. They know that it has a nucleus and electrons and protons, but they aren't totally positive that it looks exactly like that. They know this because Thompson discovered a magnet bends a cathode ray so there has to be positive charges and the gold foil experiment proving there is a nucleus with positive charges.”

Node 18 of 39 no change-tested many times

Passage 1 of 1 Section 0, Para 121, 266 chars.

“A theory is a theory and it does not change. Experiment after experiment is what makes a theory that has the same results. We all know that water is made up of H2O and that's like a theory to me because it would never change unless something else is called water.”

Node 19 of 39 no creative because science is fact

Passage 1 of 6 Section 0, Para 110, 148 chars.

“No, because the investigations need to be factual, and they have to be real answers, and real questions that can actually be answered with facts.”

Passage 2 of 6 Section 0, Para 123, 129 chars.

“They do not use their creativity and imagination because they have stay with the facts or their result and answers will be wrong.”

Passage 3 of 6 Section 0, Para 202, 164 chars.

"No, scientists can not use their imagination during their investigation because when testing and experiment imagination is not going to help the scientist at all."

Passage 4 of 6 Section 0, Para 351, 79 chars.

"No, there is not time for games. You need to find out what you need to know."

Passage 5 of 6 Section 0, Para 378, 85 chars.

"No because if they use their imaginations they will not come up with an exact answer."

Passage 6 of 6 Section 0, Para 561, 179 chars.

"Scientists shouldn't use imagination because if they are just going to imagine the results how can we be so certain that what is being performed is so right or such a proven fact."

Node 20 of 39 not certain about an atom

Passage 1 of 4 Section 0, Para 319, 180 chars.

"They really don't know what an atom of anything looks like because they have never been able to break it down. There really isn't an experiment that you could do to find the atom."

Passage 2 of 4 Section 0, Para 421, 151 chars.

"Scientists know where the nucleus is & what it's made of. They don't know exactly where electrons are located or what any of the particles look like."

Passage 3 of 4 Section 0, Para 434, 413 chars.

"They are still doing research but the scientists are sure it looks something like this <drawing>. They know that it has a nucleus and electrons and protons, but they aren't totally positive that it looks exactly like that. They know this because Thompson discovered a magnet bends a cathode ray so there has to be positive charges and the gold foil experiment proving there is a nucleus with positive charges."

Passage 4 of 4 Section 0, Para 488, 258 chars.

"Scientists can't be very certain about the structure of the atom due to the fact that the atom is really small and they can't actually see the actual structure of it. They take what you can see and what they know to determine the structure. (I'm guessing.)"

Node 21 of 39 not informative

Passage 1 of 5 Section 0, Para 457, 21 chars.

"Science is a science."

Passage 2 of 5 Section 0, Para 535, 103 chars.

“They are too smart and sometimes that's not good, when they have a really easy project they evaluate.”

Passage 3 of 5 Section 0, Para 574, 43 chars.

“Science is the ability to combine elements.”

Passage 4 of 5 Section 0, Para 608, 54 chars.

“Yes, you can just say ""leppricons made rainbows.”

Passage 5 of 5 Section 0, Para 412, 56 chars.

“No because knowledge is something that comes naturally.”

Node 22 of 39 sci knldg requires experiments

Passage 1 of 20 Section 0, Para 57, 253 chars.

“I think that scientific knowledge can be acquired from others who have performed experiments, but to truly attain scientific knowledge I feel it is important to experience things first hand, see the reactions and help understand what actually happens.”

Passage 2 of 20 Section 0, Para 70, 66 chars.

“I'm thinking yes, how else would we develop scientific knowledge?”

Passage 3 of 20 Section 0, Para 93, 248 chars.

“The development of scientific knowledge requires experiments because if you don't experiment you won't have back up for your suppose knowledge. Like if you discover a new metal reaction you need to prove it to other people so they can believe you.”

Passage 4 of 20 Section 0, Para 106, 137 chars.

“Yes the development of scientific knowledge requires experiments, because experiments determine if their hypothesis is correct or not.”

Passage 5 of 20 Section 0, Para 119, 285 chars.

“It does require experiments because how else would you know that your right and not wrong. Experiments are the prove of what your saying because other might contradict what you said. If I didn't have known this before, I would have said that water can not travel through a string.”

Passage 6 of 20 Section 0, Para 150, 215 chars.

“Yes, you must know as well as see if what you're testing is true to gain the knowledge of what you're studying, i.e. you test catalyst on potato, you must get and record observations to understand what it means.”

Passage 7 of 20 Section 0, Para 163, 409 chars.

"Yes, the development of scientific knowledge does require experiments for many logical reasons. The fact that if you have an experiment, a theory or an idea about something then you learn more about it by gathering information and by practicing. For example if I wanted to see if one shampoo or soap worked better or more than another (maybe expensive brand) of soap or shampoo you need to experiment and"

Passage 8 of 20 Section 0, Para 176, 109 chars.

"Yes, the development of scientific knowledge does require experiments, because everything has to be proved."

Passage 9 of 20 Section 0, Para 189, 118 chars.

"Yes, science knowledge requires experiments because it takes many ideas and procedures to determine one experiment."

Passage 10 of 20 Section 0, Para 224, 68 chars.

"Yes, because you wouldn't confirm anything if you didn't test it."

Passage 11 of 20 Section 0, Para 252, 67 chars.

"Yes because scientific don't know facts until they do experiments."

Passage 12 of 20 Section 0, Para 334, 67 chars.

"Yes it does. Where would we be now if we didn't do any experiment."

Passage 13 of 20 Section 0, Para 374, 58 chars.

"Yes because nothing can be proven for sure without proof."

Passage 14 of 20 Section 0, Para 383, 110 chars.

"Yes scientific knowledge requires experiments because you have to prove or be able to show how things happen."

Passage 15 of 20 Section 0, Para 392, 389 chars.

"Yes because through experiments you prove things to either be correct or wrong. If not for experiments all things in life would be theories instead of facts. And from experiments scientists discover new things beyond our realm. If scientists had never discovered electricity or the flow of energy and more were continued to take place after that we would never move forward in the world"

Passage 16 of 20 Section 0, Para 403, 235 chars.

"Yes, scientific knowledge requires experiments. An answer can look apparent or you may come to a certain answer the first time around, but experiments are done to assert effectiveness. In the process you discover new information."

Passage 17 of 20 Section 0, Para 438, 352 chars.

“Yes the development of scientific knowledge requires experiments because if we didn't do experiments then we would be living by just thoughts and no real evidence what we are saying is true. An example is when Thompson thought an atom looked like this <drawing> without a nucleus. Rutherford did the gold foil experiment to prove there was a nucleus.”

Passage 18 of 20 Section 0, Para 451, 148 chars.

“Yes, because if you just keep making theories nothing will be right. If no one proved that 1 + 1 didn't equal 3 then our world would go nowhere.”

Passage 19 of 20 Section 0, Para 464, 339 chars.

“Yes, because even if you think you could give someone an answer about because you believe in your mind it is right. You might still want to do an experiment because you never know that something in your calculations could be wrong. But not every experiment is not exactly right because it is always a little less or a little more but not a whole lot.”

Passage 20 of 20 Section 0, Para 570, 59 chars.

“Yes, to better know how something works experiments help.”

Node 23 of 39 science different because - no rules
Passage 1 of 1 Section 0, Para 63, 299 chars.

“Science is different from other disciplines of inquiry such as religion and philosophy because there are few ruled in science. You make assumptions, produce experiments, and search for answers. There is no right or wrong way to discover new things, no guidelines or rules that you have to follow.”

Node 24 of 40 science is a logical perspective
Passage 1 of 4 Section 0, Para 76, 137 chars.

“I think some aspects of religion and science don't agree, but it's good to have different perspectives on things to have a good opinion.”

Passage 2 of 4 Section 0, Para 125, 103 chars.

“Religious people have a way of explaining the creation of Earth, but scientists have their own theory.”

Passage 3 of 4 Section 0, Para 266, 154 chars.

“Science relies on logic, math and the physical world to determine the truth, whereas religion & philosophy rely on people's interpretation of the world.”

Passage 4 of 4 Section 0, Para 483, 401 chars.

“Science is the logical search for answers using things that can be proven in numbers, or logical theories. Science is different than philosophy or religion because in the latter they can dip into human evolution or spirit or other things that can't be proven by humans. To answer questions, they don't have to obey the laws of nature to answer their questions, they also don't test their theories.”

Node 25 of 39 science is about discovery
Passage 1 of 6 Section 0, Para 143, 49 chars.

“Everything in science is discovered by accident.”
Passage 2 of 6 Section 0, Para 211, 49 chars.

“These surprises are what make the developments.”
Passage 3 of 6 Section 0, Para 303, 53 chars.

“Science is discovering everything about our universe.”
Passage 4 of 6 Section 0, Para 398, 94 chars.

“Science is the discovery of life and learning how things work and why certain things happen.”
Passage 5 of 6 Section 0, Para 398, 111 chars.

“but in science we have no idea, we take creative ideas and conduct experiments to discover new things in life.”
Passage 6 of 6 Section 0, Para 511, 255 chars.

“To me science is something that is here to find out why certain things come from, how they happen, why they happen. What makes science very different from other disciplines of inquiry is that science is all based on facts and things that can be proven.”

Node 26 of 39 science is based fact
Passage 1 of 7 Section 0, Para 38, 130 chars.

“Science to me is how things work (Nature, Chemistry, Physics). It is more exciting and everything is based on data and results.”
Passage 2 of 7 Section 0, Para 112, 303 chars.

“Science is all based on experiments and facts. Religion might be based on experiments and facts but no one knows if they are for sure real and science is proven through experiments. Religion can be different and have different beliefs in different countries, but science is all the same, everywhere.”
Passage 3 of 7 Section 0, Para 279, 54 chars.

“Technology. It's diff. because of the facts and theories.”

Passage 4 of 7 Section 0, Para 380, 29 chars.

“Proven facts based on science”

Passage 5 of 7 Section 0, Para 405, 266 chars.

“Science is the study of life, picking apart all living and nonliving things. Different to other subjects, sciences can be proven to find consistent answers. (1+1 is always 2; there are always 16.0 g in oxygen.) History is based on approximated times and events.”

Passage 6 of 7 Section 0, Para 511, 255 chars.

“To me science is something that is here to find out why certain things come from, how they happen, why they happen. What makes science very different from other disciplines of inquiry is that science is all based on facts and things that can be proven.”

Passage 7 of 7 Section 0, Para 524, 243 chars.

“Science is the straight facts. There is nothing that will go unexplained. Which compared to religion is the complete opposite. Religion is based solely on belief. Some things are not explained in religion. That will not happen in science.”

Node 27 of 39 science is finding out

Passage 1 of 19 Section 0, Para 38, 65 chars.

“Science to me is how things work (Nature, Chemistry, Physics).”

Passage 2 of 19 Section 0, Para 86, 147 chars.

“Science for me is exploring finding information around us, finding out who lived before us, what happened to them, how are we doing in the world.”

Passage 3 of 19 Section 0, Para 125, 109 chars.

“Science to me is telling me the true and facts of why are something the way they are and why they happened.”

Passage 4 of 19 Section 0, Para 134, 277 chars.

“Without experimenting, then you can not find out information which in turn would not let you develop scientific knowledge. Without testing and getting results, you won't get anywhere. Therefore you have to do many tests and find results to those tests by gaining knowledge.”

Passage 5 of 19 Section 0, Para 163, 409 chars.

“Yes, the development of scientific knowledge does require experiments for many logical reasons. The fact that if you have an experiment, a theory or an idea about something then you learn more about it by gathering information and by practicing. For example if I wanted to see if one shampoo or soap worked better or more than another (maybe expensive brand) of soap or shampoo you need to experiment and"

Passage 6 of 19 Section 0, Para 174, 132 chars.

"An experiment is a test (usually different types) to figure something out. You usually test a certain material, object, chemical."

Passage 7 of 19 Section 0, Para 209, 405 chars.

"An experiment is a test that is undergone to analyze a certain subject to gain more intel. from it. Experiments lead to the continuation of our knowledge. Without experiments we don't have any valid explanation. When I make an experiment I try to make a constant present in my test. A constant allows for a safe range of grading. If I am a good experimenter I can tell when something is good or not."

Passage 8 of 19 Section 0, Para 217, 243 chars.

"Science is the study of things that are. Studies in our daily life that explain why things or persons happen. Why, is the question science answers. Science is the study of things that we can use. Science is a part of our every day lives."

Passage 9 of 19 Section 0, Para 271, 26 chars.

"It is a way to find info."

Passage 10 of 19 Section 0, Para 273, 35 chars.

"Yes because experiments give more info."

Passage 11 of 19 Section 0, Para 290, 60 chars.

"Science is finding the truth by experiments and other stuff."

Passage 12 of 19 Section 0, Para 352, 161 chars.

"To study the earth and if things the better us. They test things to find out but religion using the bible we don't need to test we already know what we need to."

Passage 13 of 19 Section 0, Para 365, 169 chars.

"Science is trying to find answers to the unknown. Chemistry is different from religion because answers come only through human understanding however advanced or obtuse."

Passage 14 of 19 Section 0, Para 418, 170 chars.

"Science is linked to everything. The way the world was made is a theory to some. Math problems have some science involved. I look at science as a need to know subject."

Passage 15 of 19 Section 0, Para 431, 103 chars.

"Science is different because the whole point is to find something new, & to change ideas from before."

Passage 16 of 19 Section 0, Para 462, 180 chars.

"An experiment is something you do when you are trying to compare or find difference in something over a certain amount of time whether you are just curious or it needs to be known."

Passage 17 of 19 Section 0, Para 470, 324 chars.

"Science is something in my mind that is very unique. I love the curiosity it can give you. You could help people in many ways with the science by either curing a disease or convicting a killer. It is different from religion but from me I can't explain way. I know I like the rush in science and I had the smarts for it."

Passage 18 of 19 Section 0, Para 537, 125 chars.

"Personally I don't like science, but what amazes me is how humans can make a bomb, experiments and other stuff sciences do."

Passage 19 of 19 Section 0, Para 587, 146 chars.

"The study of everything we know and that exist. Science is formulas, ideas, experiments, etc. What makes science is curiosity and imagination."

Node 28 of 39 science is helpful ~create medicine~
Passage 1 of 5 Section 0, Para 76, 81 chars.

"Science, in my view is the reason why we have medicine and cure-alls, you know."

Passage 2 of 5 Section 0, Para 169, 117 chars.

"Science is helpful, it is experimenting and imagining. I think science is <illegible> and takes a lot of examples."

Passage 3 of 5 Section 0, Para 182, 177 chars.

"I think that it is important for the people to know about science, because science allows things to be safer and allows everyone to be able to help people and the environment."

Passage 4 of 5 Section 0, Para 217, 47 chars.

"Science is the study of things that we can use."

Passage 5 of 5 Section 0, Para 470, 324 chars.

"Science is something in my mind that is very unique. I love the curiosity it can give you. You could help people in many ways with the science by either curing a disease or convicting a killer. It is different from religion but from me I can't explain way. I know I like the rush in science and I had the smarts for it."

Node 29 of 39 science is not different
Passage 1 of 2 Section 0, Para 316, 118 chars.

"I think science is like religion & philosophy cause it pretty much deals w/ the same thing but is somewhat different."

Passage 2 of 2 Section 0, Para 498, 382 chars.

"In my view science is a way to learn about the earth and nature and the structure of everything that God made for us. The different types of science that we have lets us learn about it all. Like Biology we can learn about some animals and how they live and we learn about the world also like the planets and the trees and water and EVERYTHING! It's not really all that different."

Node 30 of 39 science is proven

Passage 1 of 10 Section 0, Para 12, 369 chars.

"Science is a form of a knowledge that can be tested and proven. Religion and philosophy can't ever be physically proven. They're what you believe and require faith. With science, you can come up with an idea, test it, and determine if your idea is correct. With other ""disciplines of inquiry,"" you can't take chemicals or elements to prove your idea is correct."

Passage 2 of 10 Section 0, Para 51, 80 chars.

"Religion is more of an idea and science is more of a set in stone type of thing."

Passage 3 of 10 Section 0, Para 112, 303 chars.

"Science is all based on experiments and facts. Religion might be based on experiments and facts but no one knows if they are for sure real and science is proven through experiments. Religion can be different and have different beliefs in different countries, but science is all the same, everywhere."

Passage 4 of 10 Section 0, Para 156, 105 chars.

"Difference in chemistry from religion is that chemistry can be bullied up by proof and it is what it is."

Passage 5 of 10 Section 0, Para 176, 109 chars.

"Yes, the development of scientific knowledge does require experiments, because everything has to be proved."

Passage 6 of 10 Section 0, Para 224, 68 chars.

"Yes, because you wouldn't confirm anything if you didn't test it."

Passage 7 of 10 Section 0, Para 340, 84 chars.

"Science you can prove by facts or experimentation. Religion is all based on books."

Passage 8 of 10 Section 0, Para 444, 291 chars.

"Science is theories you can prove. You can prove anything and everything with science (we just might not have all the technology right now to do what we need). Religion is something you believe in it whether it is real or fake or whether you can prove it or not, you just believe in it."

Passage 9 of 10 Section 0, Para 550, 228 chars.

"Science is what actually challenges religion and philosophy because science will 'prove' if something is true or can happen. Rather than having someone say something and think it's true without actually proof but only words."

Passage 10 of 10 Section 0, Para 600, 78 chars.

"Science is proven material. Religion and philosophy are things we believe in."

Node 31 of 39 science is the study of life or ever

Passage 1 of 14 Section 0, Para 25, 117 chars.

"I believe science is more like the study of life around us and how it works and how we can help better understand it."

Passage 2 of 14 Section 0, Para 63, 129 chars.

"Science is all around us. It is the study of life, earth, space, animals, etc., etc. Everything around us is a form of science."

Passage 3 of 14 Section 0, Para 99, 122 chars.

"Science is the study of life, in general, because you study matter, animals, human nature. Science is just everything."

Passage 4 of 14 Section 0, Para 156, 71 chars.

"Science is everything. Anything you do eat or run deals with science."

Passage 5 of 14 Section 0, Para 195, 123 chars.

"Science is too broad of a topic to put into words. Mostly it's the study of Earth, living things, atoms and experiments."

Passage 6 of 14 Section 0, Para 204, 54 chars.

"Science is the study of life & what goes around us."

Passage 7 of 14 Section 0, Para 230, 32 chars.

"Science is the study of matter."

Passage 8 of 14 Section 0, Para 327, 152 chars.

"Science is the technology around us and everything that makes up the universe. The elements make up science, the study of something makes it science."

Passage 9 of 14 Section 0, Para 398, 95 chars.

“Science is the discovery of life and learning how things work and why certain things happen.”

Passage 10 of 14 Section 0, Para 405, 266 chars.

“Science is the study of life, picking apart all living and nonliving things. Different to other subjects, sciences can be proven to find consistent answers. (1+1 is always 2; there are always 16.0 g in oxygen.) History is based on approximated times and events.”

Passage 11 of 14 Section 0, Para 418, 170 chars.

“Science is linked to everything. The way the world was made is a theory to some. Math problems have some science involved. I look at science as a need to know subject.”

Passage 12 of 14 Section 0, Para 498, 382 chars.

“In my view science is a way to learn about the earth and nature and the structure of everything that God made for us. The different types of science that we have lets us learn about it all. Like Biology we can learn about some animals and how they live and we learn about the world also like the planets and the trees and water and EVERYTHING! It's not really all that different.”

Passage 13 of 14 Section 0, Para 563, 231 chars.

“Science in my view is everything around us. Everything we touch and see deals with science. Our world is centered around the word ""Sciences"" whether we want to believe it or not. Everything that goes on around us is Science.”

Passage 14 of 14 Section 0, Para 587, 146 chars.

“The study of everything we know and that exist. Science is formulas, ideas, experiments, etc. What makes science is curiosity and imagination.”

Node 32 of 39 science subjects are different
Passage 1 of 1 Section 0, Para 316, 161 chars.

“Science is, to me, a bunch of different things. They have biology, physics, chemistry, anatomy. Each one of those has something to do with different things.”

Node 33 of 39 theories change because discovery & info
Passage 1 of 13 Section 0, Para 21, 190 chars.

“I would say that theories can be changed because the ideas the scientists came up with can't keep up with changes over time—such as the evolution theory, it's always changing with time.”

Passage 2 of 13 Section 0, Para 47, 121 chars.

“That particular theory doesn't change but other theory will arise. Like the evolution theory and the Adam & Eve theory.”

Passage 3 of 13 Section 0, Para 159, 175 chars.

“I mean they may have a pretty good idea or so about something but there is always room for improvement and I think that things change so they don't always have the answers.”

Passage 4 of 13 Section 0, Para 178, 176 chars.

“Yes, the theory can change because scientists are always discovering new things, e.g. the periodic table of the elements has been changed many times since it was first made.”

Passage 5 of 13 Section 0, Para 185, 63 chars.

“Scientists aren't certain about the atom because it can change.”

Passage 6 of 13 Section 0, Para 299, 214 chars.

“Of course, at one time Catholicism controlled all scientific though, and everybody believed the earth was the center of the universe. Then came Galileo, used a telescope, and decided it wasn't like that at all.”

Passage 7 of 13 Section 0, Para 323, 294 chars.

“Sure all the time it changes because there are so many different discoveries that they have found that change everything they had thought about their theory. An example is water. They used to think that it was its own element but they come to find out that it has more than one element in it.”

Passage 8 of 13 Section 0, Para 361, 350 chars.

“Yes theories change along with understanding and technology. A theory is the answer to a question given a particular time and understanding. In ancient times it was believed the sun orbited the Earth, in their time and understanding of the world this was the right answer, as technology advanced (telescopes, geometry, etc.) this theory changed.”

Passage 9 of 13 Section 0, Para 414, 186 chars.

“Yes because scientists find out things with new technology that was not at their reach before and with new data and more accurate info, they can be sure and their theory might change.”

Passage 10 of 13 Section 0, Para 494, 388 chars.

“Yes, the theory can change if they find new evidence to support a different theory. Like how many people believe or used to believe that the Earth is flat and they had many reasons to believe this. Then someone actually set out to see if it was really flat. They got in a space ship or whatever and flew outside of Earth's atmosphere and saw that Earth was really round and not flat.”

Passage 11 of 13 Section 0, Para 507, 229 chars.

“I would have to say yes, because when there are more experiments being conducted you may find out something new and real that you would of never thought of before. Plus you get more knowledge to make the theory more credible.”

Passage 12 of 13 Section 0, Para 559, 162 chars.

“Theories can change because new things are discovered. Any theory can change for better or for worse. Something can be proven wrong in a theory and will change.”

Passage 13 of 13 Section 0, Para 572, 48 chars.

“Yes, you can't always be right the first time.”

Node 34 of 39 theories change because experiments change

Passage 1 of 7 Section 0, Para 8, 313 chars.

“Yes, it is only law that doesn't change. One scientist could come up with a theory through conducting an experiment as another scientist could conduct the same experiment with different factors that could affect the results (such as a catalyst, change in temp, etc.) and could come up with a different result.”

Passage 2 of 7 Section 0, Para 95, 144 chars.

“Yes it does change because other scientists might find other results and prove it to a major scientist. That scientist might change his theory.”

Passage 3 of 7 Section 0, Para 191, 106 chars.

“The theory can change because if it's about the earth or the way things grew, the procedure can change.”

Passage 4 of 7 Section 0, Para 226, 245 chars.

“Yes, because they come up with better ways to test the theories. Like how Neanderthals were originally thought to be ancestors of humans but when they started testing DNA they realized that we were closer to chimpanzees than wee are to them.”

Passage 5 of 7 Section 0, Para 349, 96 chars.

“Yes, they can find different evidence to support something trieds not all elements are trieds.”

Passage 6 of 7 Section 0, Para 385, 72 chars.

“Yes because things may happen in a different way than what they thought.”

Passage 7 of 7 Section 0, Para 546, 187 chars.

“The structure of theories never change but the scientists differ how they come across their own theories. Or how they take an old theory and further investigate with better technology.”

Node 35 of 39 theories change because they are not fact
Passage 1 of 11 Section 0, Para 34, 102 chars.

“Yes it can. A theory is only an idea. It isn't a for sure fact. The Big Bang Theory is one example.”
Passage 2 of 11 Section 0, Para 83, 235 chars.

“Yes, because now in day they are finding more and more information that little by little changes information about the world around us. That's why I say yes theory by time changes. But some people believe one thing and that's all.”
Passage 3 of 11 Section 0, Para 159, 268 chars.

“Scientists are never really 100% certain about something. I mean they may have a pretty good idea or so about something but there is always room for improvement and I think that things change so they don't always have the answers. After all they are only human too.”
Passage 4 of 11 Section 0, Para 165, 164 chars.

“Yes even after scientists have developed a scientific theory, the theory has always may have room to change and all just because like I said they are only human.”
Passage 5 of 11 Section 0, Para 239, 149 chars.

“Yes, because a scientific theory is still just a ""theory."" There isn't enough information or enough experiments that give it the correct answer.”
Passage 6 of 11 Section 0, Para 263, 80 chars.

“Yes the scientific theory. For example evolution theory vs. Theory of Creation.”
Passage 7 of 11 Section 0, Para 275, 30 chars.

“Yes because a theory isn't a fact.”
Passage 8 of 11 Section 0, Para 394, 235 chars.

“Yes because that is why it is a theory is because they are not certain that the statement is true so they predict a theory using educated guesses, and then continue to research the topic discovering and learning new things each time.”
Passage 9 of 11 Section 0, Para 440, 153 chars.

“Yes the theory changes. The theory of evolution changed by thinking we were once bacteria that evolved into humans to we evolved into humans from apes.”
Passage 10 of 11 Section 0, Para 466, 72 chars.

“Yes, because no scientist can ever be exact. Because if exact that is wrong.”
Passage 11 of 11 Section 0, Para 583, 310 chars.

“Yes because a theory is a hypothesis not yet proven. For example the kinetic molecular theory. This theory explains how the idea that particles of matter are always in motion. Because it is names a theory not a proven fact or law it could change or be proven wrong. Although it is yet to have been changed.”

Node 36 of 39 theories change because they proven wrong
Passage 1 of 7 Section 0, Para 136, 397 chars.

“Yes, many theories have changed. In most cases, theories have changed because people have proved them wrong or we have received more information to make the theory different. One scientist had a theory that Earth was flat, but he was proved wrong. Another man thought that Earth was the center of the universe, but he was proved wrong. Most theories change over time due to us knowing more.”

Passage 2 of 7 Section 0, Para 213, 448 chars.

“Yes. Just a few years ago a theory was proven false, so they re-did some testing and changed the theory to include their response. This theory that I am talking about is the Big Bang Theory. It used to be that particles were forming out of chance into planets, that there was a field of magnetism that brought these particles into a mass. They proved that there is no field, only high winds and high pressure that packs those atoms together.”

Passage 3 of 7 Section 0, Para 254, 40 chars.

“Yes because they aren't always correct.”

Passage 4 of 7 Section 0, Para 336, 354 chars.

“I think they do. Let's say someone makes a theory at a certain time. A few years later some other scientist might find out some new stuff to prove that theory wrong. Like if someone made a theory that the world was not round and if you were to walk to the end that you would fall off and die. Some person might explore the world and prove him wrong.”

Passage 5 of 7 Section 0, Para 453, 102 chars.

“Yes, because other scientists have theories too & scientists can be proven wrong—i.e. cold fusion.”

Passage 6 of 7 Section 0, Para 479, 400 chars.

“The theory can change after it has been developed. This is why it is a theory & not a law. Theories can be changed after they are proven wrong, but laws have never been proven wrong which is what makes them different than laws. An example of this would be when scientists were trying to figure out how DNA was replicated. There were 3 main theories but they changed once two were proven wrong.”

Passage 7 of 7 Section 0, Para 596, 59 chars.

“Yes it does, if the theory is overruled or proven wrong.”

Node 37 of 39 theories do not change
Passage 1 of 8 Section 0, Para 72, 328 chars.

“I think once it's called a theory, it doesn't change. You can create a different theory but you can't amend an already created one. Like you have the atomic theory, but you (as the scientist) who I predict has been experimenting for years about it could be like oops I forgot this and be like Atomic Theory #2, or something.”

Passage 2 of 8 Section 0, Para 108, 152 chars.

“The theory doesn't change, because the final outcome has been tried over and over again, until it's right, and a hypothesis is proven right, or wrong.”

Passage 3 of 8 Section 0, Para 121, 266 chars.

“A theory is a theory and it does not change. Experiment after experiment is what makes a theory that has the same results. We all know that water is made up of H2O and that's like a theory to me because it would never change unless something else is called water.”

Passage 4 of 8 Section 0, Para 200, 32 chars.

“No, theories haven't changed.”

Passage 5 of 8 Section 0, Para 376, 72 chars.

“No because it is just a theory. They results change but not the theory.”

Passage 6 of 8 Section 0, Para 520, 286 chars.

“The theory does not change. The same basic idea is there consistently. Evolution is a theory that has remained the same. That humans (or other modern creatures) are slowly changing into other life forms. This idea remains but there are more facts and proof being added all the time.”

Passage 7 of 8 Section 0, Para 533, 142 chars.

“I think that they don't change. People who invented them were working really hard, and they made perfect so no one wouldn't say different.”

Passage 8 of 8 Section 0, Para 546, 187 chars.

“The structure of theories never change but the scientists differ how they come across their own theories. Or how they take an old theory and further investigate with better technology.”

Node 38 of 39 theories improve
Passage 1 of 1 Section 0, Para 427, 150 chars.

“Yes, theories change because with more experiments new things are learned, so the theories are added to or corrected. I can't remember an example.”

Node 39 of 39 types of experiments
Passage 1 of 17 Section 0, Para 2, 101 chars.

“Scientists used experiments such as the Cathode Ray Tube, the gold foil experiment, and many others.”

Passage 2 of 17 Section 0, Para 10, 219 chars.

“Such creativity would be when the gold foil was thought of. When the scientist used gold instead of silver or aluminum and using light, his creativity and imagination had come up with theory and a way to test it out.”

Passage 3 of 17 Section 0, Para 89, 102 chars.

“Scientists could have taken a picture of an atom with a high visible spectrum to see the structure.”

Passage 4 of 17 Section 0, Para 102, 1 chars.

Passage 5 of 17 Section 0, Para 119, 99 chars.

“If I didn't have known this before, I would have said that water can not travel through a string.”

Passage 6 of 17 Section 0, Para 207, 319 chars.

“They can test their hypothesis by using electromagnetic, magnetic or electronic methods to separate protons, electrons & neutrons. We can heat them, put them into circuitry, find out how much of it is in a mole. We can put the atoms on other types, see if they bond or react. We can see them in high powered scoped.”

Passage 7 of 17 Section 0, Para 220, 98 chars.

“They knew more about it after they shot light through them and some bounced back and some didn't.”

Passage 8 of 17 Section 0, Paras 248 to 250, 95 chars.

“The splitting up of the atoms.”

“The experiment with the atoms when the gain & lose electrons.”

Passage 9 of 17 Section 0, Para 343, 95 chars.

“The mass of each atom. Electron & neutrons and protons weigh different. They used the charge.”

Passage 10 of 17 Section 0, Para 355, 312 chars.

“I know there were experiments done that proved an atom wasn't a solid mass but mostly space. One experiment was firing pieces of matter through gold foil. If the atoms were solid the matter would be stopped by the foil but because of the structure of atoms we know the matter could fly right through the foil.”

Passage 11 of 17 Section 0, Para 434, 413 chars.

“They are still doing research but the scientists are sure it looks something like this <drawing>. They know that it has a nucleus and electrons and protons, but they aren't totally positive that it looks exactly like that. They know this because Thompson discovered a magnet bends a cathode ray so there has to be positive charges and the gold foil experiment proving there is a nucleus with positive charges.”

Passage 12 of 17 Section 0, Para 436, 92 chars.

“Ex.—when you take H2O2 and put it through a decomposition reaction it turns into H2O & O2.”

Passage 13 of 17 Section 0, Para 438, 161 chars.

“An example is when Thompson thought an atom looked like this <drawing> without a nucleus. Rutherford did the gold foil experiment to prove there was a nucleus.”

Passage 14 of 17 Section 0, Para 501, 393 chars.

“I would have to say that scientists are very certain they know how an atom is structured. They probably found this out by the gold foil experiment. They would shoot a beam at the foil and sometimes it went right through the foil when other times it was deflected and a beam somewhere else. So for the beam to be deflected like that it must have hit something hard, which was the nucleus.”

Passage 15 of 17 Section 0, Para 503, 307 chars.

“An experiment that helped the scientist to determine the structure of an atom was the gold foil experiment. Alpha particles were shot at the foil while others were deflected. So the atom must have a solid center and a penetrable outside. The center being the nucleus and the outside being the electrons.”

Passage 16 of 17 Section 0, Para 577, 247 chars.

“Scientists are certain about the structure of an atom because they have performed many experiments such as the ""gold foil"" experiment and when Thomson discovered electron while investigating properties of electricity using a cathode ray tube.”

Passage 17 of 17 Section 0, Para 581, 336 chars.

“Yes because experiments help prove and bring facts to the hypothesis a scientist may have. An example is when Ernest Rutherford performed the ""gold foil experiment."" This experiment proved that the gold foil contained many small dense positively charged nucleus surrounded by electrons. This helped develop scientific knowledge.”

APPENDIX D

COMPARISON WITH VNOS QUOTES

Primary Code/ VNOS Aspect	Student Quote	VNOS Quote
Certain about the structure of an atom because of microscopes/Inference and theoretical entities	I think that scientists are somewhat certain about the structure of an atom. The reason is because all the protons and neutrons, along with electrons are moving so rapidly for them to actually get a picture of it. That's why it's represented more like a cloud. The evidence that scientists have are high powered microscopes.	Scientists can see atoms with high-powered microscopes. They are very certain of the structure of atoms.
Science is based on fact/Social and cultural embeddedness of science	Science is all based on experiments and facts. Religion might be based on experiments and facts but no one knows if they are for sure real and science is proven through experiments. Religion can be different and have different beliefs in different countries, but science is all the same, everywhere.	Science is about the facts and could not be influenced by cultures and society. Atoms are atoms here in the U.S. and are still atoms in Russia.
Creativity required for designing experiments/Creative and imaginative NOS	They could use their imagination for doing experiments so they can somewhat enjoy what they're doing, and it could also help them construct different ways to build the experiment so it could be easier.	A scientists only uses imagination in collecting data …But there is no creativity after data collection because scientists have to be objective.

Primary Code/ VNOS Aspect	Student Quote	VNOS Quote
Experiments provide proof/Validity of observationally based theories and disciplines	Yes the development of scientific knowledge requires experiments because if we didn't do experiments then we would be living by just thoughts and no real evidence what we are saying is true. An example is when Thompson thought an atom looked like this <drawing> without a nucleus. Rutherford did the gold foil experiment to prove there was a nucleus.	Science would not exist without procedures scientific procedure which is solely based on experiments…The development of scientific knowledge can only be attained through precise experiments.
Empirical NOS/Science is based on facts	To me science is something that is here to find out why certain things come from, how they happen, why they happen. What makes science very different from other disciplines of inquiry is that science is all based on facts and things that can be proven.	Science is concerned with facts. We use observed facts to prove that theories are true …It [science] is based on fact.