An Exploration of Worldview and Conceptions of Nature of Science among Science Teachers at a Private Christian High School

Kara M. Kits
Western Michigan University

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AN EXPLORATION OF WORLDVIEW AND CONCEPTIONS OF NATURE OF SCIENCE AMONG SCIENCE TEACHERS AT A PRIVATE CHRISTIAN HIGH SCHOOL

by

Kara M. Kits

A Dissertation
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Advisors: William W. Cobern, Ph.D.
Reneè S. Schwartz, Ph.D.

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AN EXPLORATION OF WORLDVIEW AND CONCEPTIONS OF NATURE OF SCIENCE AMONG SCIENCE TEACHERS AT A PRIVATE CHRISTIAN HIGH SCHOOL

Kara M. Kits, Ph.D.
Western Michigan University, 2011

Both worldview and conceptions of nature of science (NOS) are important components in teaching and learning science. However, few empirical studies have examined the interplay between both of these components for teachers or students. Therefore, this study examines the possible relationship between worldview and conceptions of nature of science for secondary science teachers who currently teach at a Christian school.

Qualitative methodologies developed a rich description of the worldview beliefs and conceptions of NOS for teachers in this study. Eight secondary science teachers employed at a private Christian school participated in the study. A Views of Nature of Science (VNOS) questionnaire and follow-up interviews elicited participants’ conceptions of NOS. A semi-structured interview and Test of Preferred Explanations (TOPE) questionnaire elicited participants’ worldview beliefs regarding nature and the natural world and causality.

Participants communicated understandings of NOS that ranged from uninformed to informed in various aspects. In addition, while their worldview beliefs and conceptions of NOS reflected their faith beliefs, participants did not have a less informed view of NOS than other science teachers in previous studies. In fact, for several aspects of NOS, these
participants articulated more informed conceptions of NOS than participants in previous studies.

For these participants, faith did not appear to interfere with their ability to think scientifically in regards to their worldview beliefs regarding nature and causality. Rather, faith was incorporated into a scientifically compatible worldview regarding nature and causality that is not much different from other teachers. Other than the fact that these science teachers integrated their faith beliefs into some of their responses regarding worldview and NOS, these teachers did not appear to be much different from other science teachers. That is, there was no predictable pattern between worldview beliefs regarding nature and causality and conceptions of NOS. Therefore, this study provides empirical evidence that it is not necessary to be “devoid” of religious beliefs in order to have a scientifically informed view of the world. Teachers with religious convictions can have very scientific view of the world in terms of their worldview beliefs regarding nature and the natural world and conceptions of NOS.
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Kara M. Kits
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CHAPTER I

INTRODUCTION

Everyone has a worldview. Whether it is well-articulated or tacit, we all have a framework of beliefs about how the world works and our role in it. Because our worldview is a framework that helps to shape the way we think about the world, it also affects how we interact in the world. In his monograph, Cobern (1991b) begins by sharing the responses of Nigerian and American students to the following scenario:

You are out on a lake in a boat with a spouse, a parent, and young son or daughter. Of the four in the boat you are the only one who can swim and the boat has no life preservers. Suddenly the weather turns bad. The boat flounders and all are cast into the water. You quickly realize that with the distance to shore you have hope of saving only one of your passengers, your spouse, your parent, or your child. Which one will you save? (p. 1)

Cobern reports his American students agreed on one answer—saving the child. Similarly, his Nigerian students also agreed on one answer—saving the parent. In this case, the American and Nigerian students were astonished to hear the response of the other group and what different ways they had of seeing the world. The students’ responses illuminated aspects their worldview.

A person’s worldview affects how he or she sees the entire world, including the field of science. History and research has shown that worldviews can have a dramatic effect on a person’s interpretation of science and the nature of science (Aikenhead, 1996; Brickhouse, 1990; Cobern, 1991b; Cobern, 2000a; Cobern & Loving, 2000; Gallagher, 1991; Kilbourn, 1974; Lederman, 1992, 1999; Liu, 2003; McComas, Almazroa, & Clough, 1998; Nott & Wellington, 1998; Pomeroy, 1993; and others). There are numerous examples of historical
interactions between science and various worldviews. For example, the Oxford Debate that followed Darwin’s publication of *The Origin of Species*, the work of Galileo and Newton that supported the Copernican heliocentric account of the solar system, recent Spanish government legislation that grants some traditional human rights (the right to life, the protection or individual liberty and the prohibition of torture) to the great apes, and others (Matthews, 2009). Worldviews can have a significant effect on how a person views the world and the field of science.

The field of science is rapidly growing and continues to have increasing effects on virtually every aspect of human life. Consequently, science education is becoming more important. Science education is also maturing and reforming as it strives to help students develop science literacy (American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], 1996). One focus of reform in science education is a shift from emphasizing the acquisition and memorization of scientific concepts to one of developing scientific literacy and an understanding of the process of scientific inquiry (AAAS, 1990; NRC, 1996). As AAAS states in their call to reform,

> The present science textbooks and methods of instruction, far from helping, often actually impede progress toward science literacy. They emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, reading in lieu of doing...the present curricula in science and mathematics are overstuffed and undernourished. (p. xvi)

Therefore, one aspect of the science education reform movement focuses on developing an understanding of the nature of science.

The nature of science (NOS), or “science as a way of knowing” (Lederman, 1992), refers to the “values and assumptions inherent to the development of scientific knowledge”
These important values and assumptions include (but are not limited to) the ideas of the empirical nature of scientific knowledge, creativity and imagination, subjectivity, tentativeness, and testability (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). These aspects of NOS have been cited as educational outcomes in the United States since 1907 (Lederman, 1992) and are believed to help students develop into scientifically literate citizens (AAAS, 1990; Lederman, 1992; NRC, 1996).

The *Benchmarks for Science Literacy* states, “from their very first day in school, students should be actively engaged in learning to view the world scientifically” (AAAS, 1993, p. 6). This scientific view of the world requires an understanding of the nature of science and an understanding of how science differs from other ways of knowing (AAAS, 1990). This scientific view of the world is a rational, objective, technical, and practical way of understanding how the world works (Liu, 2003). However, as AAAS (1993) notes, “a scientific world view is not something that working scientists spend a lot of time discussing. They just do science. But underlying their work are several beliefs that are not always held by nonscientists” (p. 5).

Nevertheless, recent research on worldview and science education suggests that even science teachers can have variations in their beliefs about science and their understanding of NOS (Brickhouse, 1990; Cobern, 1991b, 2000a; Cobern & Loving, 2000; Gallagher, 1991; Lederman, 1992, 1999; McComas, et al., 1998; Nott & Wellington, 1998; Pomeroy, 1993; and others). In addition, a number of studies highlight the importance of culture in the development of both worldview and understandings of science and conceptions of NOS (Aikenhead, 1996; Cobern, 1991b; Kilbourn, 1974; Liu, 2003). Religious
beliefs are an important aspect of culture and component of worldview (Kearney, 1984; Naugle, 2002; Sire, 2004; Walsh & Middleton, 1984; Wolters, 1985).

Furthermore, there is a body of research and literature that discusses the relationship between aspects of worldview, specifically religious aspects, and science. There are those who promote the integration of science and religion (Brooke, 1991; Calvin, 1536/1986; Cobern, 1988b; Cobern & Loving, 2004; Collins; 2006; Ecklund; 2010; Haarsma & Haarsma, 2007; Hearn, 1987; Hooykaas, 1972; MacKay, 1988; Poole, 1990; Ruse, 2010; Wolters, 1985; and others). For example, Cobern (1988b) cites a foundational integration of Judeo-Christianity and science as put forth by Hooykaas (1972). Cobern describes how science is not only compatible with Christianity, but how much of what we know as Western science is consistent with tenants put forth in the Bible. Cobern explains,

Just how is it that Westerners "see" the world, and in what manner is that vision biblical? After all, not that many Westerners consciously think of their cognitive processes as being biblically influenced. Nevertheless, the Bible has influenced Western thinking in many ways. The influences pertinent to science have to do with the reality and nature of the physical world, the nature and role of mankind, and the value of secular work. Since science is the study of the physical world it is easy to see that only those who are convinced of a "real" physical world will bother to pursue the study of it. Furthermore, one must be convinced that the real physical world is orderly and therefore understandable. Then one must be convinced that humans are capable of such understanding, and that it is proper and profitable to make the attempt. Finally, the efforts (particularly "hands-on" experimenting) made in such attempts must be esteemed in the society. (p. 99)

Furthermore, Cobern asserts that the very philosophical ideas about the nature of the world (and therefore our attempts to understand it) find support in the Bible,

The Bible clearly teaches that there is a real physical world. "In the beginning God created..." the world, and not only that, but God pronounced His creation good. Then He commissioned mankind to subdue and reign over creation (see Genesis 1). Here in these few words one finds the
foundation of a world view that holds to a real physical, understandable world and sanctions the investigation of that world. (p. 99)

In contrast, there are those who challenge the idea that science and religion (or religious education) are compatible (Atkins, 1995; Cunningham, 2010; Dawkins, 2006; Dennett, 1995; Good, 2003; Mahner & Bunge, 1996; Martin, 1997; Suchting, 1994; and others). For instance, philosophers across the years have written of a wide range of assumptions regarding the relationship between science and worldview. For example, in his *The Critique of Pure Reason*, Kant explains, “I have therefore found it necessary to deny knowledge in order to make room for faith” (quoted in Ruse, 2010, p. 6). Likewise, Mahner and Bunge (1996) put forth a thesis that states, “a religious education is detrimental to a scientific one but also the thesis that science and religion are incompatible” (p. 102). In their conclusion, they assert, “whoever wishes to form a comprehensive and consistent worldview must opt for either a religious or a scientific outlook” (p. 116).

As a part of their attempt to discuss why they believe science education and religious education are incompatible, Mahner and Bunge (1996) attempt to define what they consider religion and religious education. For example, they characterize religious education as an education where “students are not just taught some unbiased comparative, historical, philosophical, cultural, and social aspects of religion but are supposed to accept and internalize some or all of the doctrines of a particular religious belief system” (p. 102). They go on to state, “if one is concerned with the education of the public, then the teaching of the religious attitude and value system can only have detrimental effects for adopting a comprehensive scientific outlook and critical attitude” (p. 118). Likewise, they state, “a religious education, particularly at an early age, is a most
effective obstacle to the development of a scientific mentality” and that “a serious moral
problem, however, is posed by a strict fundamentalist education, for there are good reasons
to regard the latter as a form of child abuse” (p. 119).

As Mahner and Bunge (1996) attempt to discuss the compatibility of religion and
science and their thesis that religious education and science education are incompatible,
they do not specifically refer to NOS. However, they do allude to several aspects of NOS (as
articulated in this study) and because they are talking about science, it is a logical
implication that the “science” they discuss would include NOS. Throughout their thesis,
Mahner and Bunge make several assumptions regarding science and NOS. However, as
Mahner and Bunge refer to science and NOS, they articulate, at best, an inconsistent
understanding of NOS. For example, at one point in their thesis, they state, “science is a
social activity” (p. 103). However, a few paragraphs later, they explain that, “basic science is
value-free only in the sense that it does not make value judgment about its objects or
referents. That is, basic science has no external value system or exoaxiology” (p. 104). This
idea runs contrary to a NOS tenant that states that science is subjective and theory-laden
and that science is a human endeavor affected by social and cultural aspects. In a similar
fashion, they articulate a naïve view of the scientific method aspect of NOS as they explain,

We should assert that the scientific method may be conceived of as consisting of the following ordered sequence of cognitive operations:
Identify a problem—search for information, methods instruments—try to solve the problem with the help of those means—if necessary invent new
means, produce new data, or design new experiments—derive the consequences of your solution (e.g., predictions)—check the solution (e.g.,
try to replicate your findings by alternative means)—correct the solution if necessary in repeating the cycle—examine the impact of the solution upon
the body of background knowledge, and state some of the new problems it gives rise to. (p. 104)
Others, such as Atkins (1995), also articulate a similar naïve understanding of NOS as they criticize the notion of the compatibility of science and religion. For example, Atkins states,

Someone with a fresh mind, one not conditioned by upbringing and environment, would doubtless look at science and the powerful reductionism that it inspires as overwhelmingly the better mode of understanding the world, and would doubtless scorn religion as sentimental wishful thinking. Would not that same uncluttered mind also see the attempts to reconcile science and religion by disparaging the reduction of the complex to the simple as attempts guided by muddle-headed sentiment and intellectually dishonest emotion? (p. 123)

However, the idea of a fresh mind, a tabula rasa, and a science that is completely free from subjectivity is not consistent with an informed understanding of NOS (AAAS, 1990; Chalmers, 1999; Feyerabend, 1975; Kuhn, 1996; Lederman, 1999; NRC, 1996; Popper, 1992; and others.

Throughout much of their thesis, Mahner and Bunge (1996) highlight what they consider differences and incompatibilities between science and religion. While they state that, “a mere difference, however, is not necessarily an incompatibility” (p. 107), they assert there are several distinct incompatibilities between science and religion such as doctrinal, metaphysical, and methodological and attitudinal incompatibilities. However, the reasoning and support they provide for these arguments is problematic. For example, when discussing what they view as doctrinal incompatibilities, they make sweeping claims regarding religion and people with religious beliefs (whom they call “religionists”) which undermine their argument that science is incompatible with a broader view of religion. For example, they state that, “whereas the religionists’ faith, i.e., the disregard and disrespect for evidence, is hailed as a virtue in their belief community, scientists are supposed to recognize that personal conviction or psychological certitude is no substitute for cognitive justification” (p.
Furthermore, they state, “on the other hand, they [religionists] cannot be interested in too much knowledge because this could threaten the depth of their religious feelings. Consequently, the religionist’s attitude will, contrary to the scientist’s, approve of deliberate ignorance” (p. 115). However, even Mahner and Bunge site examples of historical scientists who also held religious beliefs (Newton, Boyle, Faraday, and Maxwell), they also acknowledge that many contemporary scientists also hold religious beliefs. Therefore, it appears that their argument is based more on an anti-religious and religious education attitude rather than a sound argument regarding a proposed incompatibility between science and religion.

Martin (1997) also claims that science education and Christian education are incompatible. One possible problem with Martin’s claim is that he tries to support his position by referring to extreme conservative and fundamentalist types of Christian education. For example, he states, “in some extreme conservative sects of Christianity science education was considered to be incompatible with Christian education… fundamentalist Christian educators have opposed the teaching of evolutionary theory” (p. 240). Therefore, his claim of incompatibility is questionable for a broader range of types of Christian education.

As a part of his argument, Martin (1997) highlights both the tentative and empirical aspects of NOS and claims that Christian education disregards these two essential elements of science education. For example, he states,

Another goal of science education is to teach students to have the propensity to be sensitive to evidence: to hold beliefs tentatively in light of evidence and to reject these beliefs in the light of new evidence if rejection is warranted by this evidence. But this propensity conflicts with one way in which beliefs are often taught in Christian education: namely as
fundamental dogmas, rather than as subject to revision in the light of the evidence. (p. 240)

Likewise, he characterizes Christian education as teaching students to following the explicit ethical teachings of Jesus and trying to emulate Jesus as a model of ethical behavior. This alludes to the empirical aspect of NOS. Martin states,

Jesus’ words and actions suggest that he believed that basing one’s beliefs on the evidence is wrong and that faith, both in the absence of evidence and even in opposition to the evidence, is correct. Indeed, Jesus’ behavior seems to indicate that he valued blind obedience. This is hardly an appropriate model for science education. (p. 244)

Both Mahner and Bunge (1996) and Martin (1997) make sweeping claims about science and religion and science education and religious education that do not match what all science and religious educators, philosophers, and historians think. Furthermore, the arguments Mahner and Bunge and Martin present are philosophical arguments not supported by any data. Therefore, this study uses empirical data to analyze those claims.

A person’s worldview, as this study defines it, is composed of aspects of personal religious beliefs, components of cultural values, personal and social norms, understandings of how the natural world works, and more. Therefore, religious beliefs and science intertwine and interconnect within the overall concept of worldview. This also applies to the worldview of an individual person that contains a variety of facets including beliefs about religion, beliefs about nature and the natural world, beliefs about causality, and beliefs about NOS.

Studies have assessed teachers’ conceptions of NOS and whether their conceptions of NOS conform to the currently accepted views of NOS and if teachers understand science as a way of knowing about and understanding the world. A worldview affects the way in
which a person views, interprets, and learns about the world and how the world works. Religious beliefs influence and help to shape a worldview. Therefore, research that explores the relationships between worldview and conceptions of NOS may provide knowledge that can help articulate the relationships between worldview and NOS and inform the process of improving science teaching and learning.

Statement of Problem

Because worldview is the “lens” through which one views the world, it seems likely a person’s worldview may be correlated with his or her understanding of NOS. Therefore, if everyone has a worldview, a perspective, from which he or she views and interacts with the world, what relationship might exist between the worldview of a science teacher, specifically a science teacher at a Christian school, and his or her understanding of NOS? Likewise, if science teachers at Christian schools are scientifically literate with an understanding of science concepts consistent with the current field of science and if understanding NOS is paramount to developing science literacy (AAAS, 1993), how does this understanding of NOS help shape their worldviews?

The purpose of this study is to investigate and characterize any relationship between Christian school science teachers’ worldviews and their understandings of NOS. Exploring and identifying the possible relationships that exist between worldviews and understandings of NOS would help further characterize the ways in which culture (worldview, in this case) and understandings of NOS are possibly related. Furthermore, if the Christian school science teachers in the study are dedicated to helping their students become scientifically literate and develop understanding of NOS, it is important that these teachers identify their understandings NOS and how their worldview (of particular focus and
importance at a Christian school) might relate to their understandings of NOS and how they teach NOS.

This study draws on several claims. First, according to Wolters (1985), everyone has a worldview. Second, science and scientific study have a ubiquitous, but sometimes subtle, influence on almost every aspect of modern day life (McComas et al., 1998). Third, science educators claim an understanding of NOS is crucial to developing scientific literacy (AAAS, 1993). Although each of these claims appears to be independent, upon closer examination, a possible relationship between a person’s worldview and his or her understanding of NOS may exist. Furthermore, this relationship may be a reciprocal relationship such that worldview influences NOS understanding, and NOS understanding influences worldview. Therefore, it is valuable for science educators to look more closely at the relationship between worldview and NOS understanding.

Thus, here are the motivating framework and research questions that guided this study. First, according to the American Religious Identification Survey (ARIS 2008), approximately 80% of the population of the United States self-identifies as religious (Kosmin & Keysar, 2009). Furthermore, according to the National Center for Education Statistics, approximately four million children in the United States attend a religiously sponsored or affiliated school (Broughman, Swaim, & Hryczaniuk, 2011). Second, concerning science education, an understanding of NOS is important to developing scientifically literacy, an essential goal for science education (AAAS, 1990; Lederman, 1992; NRC, 1996). Third, there is disagreement amongst philosophers, educators, and scientists regarding the compatibility of science education and religious education (Haarsma, 2004; Keys, 2004; Mahner & Bunge, 1996; Martin, 1997; Ruse, 2010; Settle, 1996; Wolters, 1985, and others).
Where do those assertions leave us? Are science education and religious education compatible or incompatible? Can a student enrolled in an institution claiming to provide a Christian education receive an adequate science education such that they can become scientifically literate? In order to start looking for answers to these questions, this study focused on teachers at a Christian education institution (secondary school setting). These teachers were very homogeneous in terms of their undergraduate training (six of eight at the same institution), religious beliefs, and church affiliations. Looking at this small, homogeneous population of science teachers, three main research questions were identified:

1. What conceptions of NOS do science teachers at Christian schools hold?
2. What worldview beliefs, specifically two components of worldview, the conceptualizations of Nature and causality, do science teachers at Christian schools hold?
3. Is there a relationship between worldview and conceptions of NOS for science teachers at Christian schools?

These questions point back to the larger question of the compatibility of science education and religious education in that in order to teach science adequately and help students develop scientific literacy, teachers themselves need to be scientifically literate (which includes having informed conceptions of NOS).

**Definitions of Key Concepts**

Before moving into a review of the literature on worldview and NOS, a few key concepts need definition.
**Worldview**

The concept of *worldview* has a long historical and academic development. Many definitions provided for worldview are similar to the one provided by Sire (2004):

> A worldview is a commitment, a fundamental orientation of the heart, that can be expressed as a story or in a set of presuppositions (assumptions which may be true, partially true or entirely false) which we hold (consciously or subconsciously, consistently or inconsistently) about the basic constitution of reality, and that provides the foundation on which we live and move and have our being. (p. 17)

Essentially, as Wolters (1985) articulates, a worldview functions as a guide to life as it shapes the way in which people view and evaluate events, issues, and structures in the world. Because a worldview is a guide that functions to shape how people see the world, some have referred to worldview as the “lens” through which people view the world (Solomon, 1994; Wolters, 1985). This lens is very personal and influences people’s perceptions, actions, and thoughts about every part of life.

**Nature of Science**

When attempting to provide a succinct definition of “nature of science,” it becomes clear there is no succinct definition. However, science educators have frequently agreed upon a general definition of NOS as, “the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge” (Abd-El-Khalick, Bell, & Lederman, 1998). As AAAS (1990) states in *Science for All Americans*, NOS ideas are actually expressions of basic beliefs about the world, how it works, and what can be learned about it through science.

Expanding on this definition, science educators have identified several components of NOS. The following components of NOS provide an overall summary of the concepts
which compose NOS ideas addressed in this study: (1) the empirical nature of scientific knowledge, (2) scientific theories and laws, (3) the creative and imaginative nature of scientific knowledge, (4) the theory-laden nature of scientific knowledge, (5) the social and cultural embeddedness of scientific knowledge, (6) the distinction between observation and inferences, (7) the myth of the scientific method, and (8) the tentative nature of scientific knowledge (Bauer, 1992; Lederman et al., 2002; Lederman, 1999). These components define NOS for the purpose of this study.

**Delimitations and Limitations**

A worldview is a “lens” through which the world is viewed that every person has, whether or not a person clearly articulates those worldviews and understandings. In addition, worldviews are very individual and vary from person to person. However, similarities in worldview exist in people, especially people of similar background and culture. Given this study focused on science teachers teaching at Christian schools, it was likely there would be similarities among the worldviews of all these teachers. Indeed, the teacher participants shared similar religious beliefs and religious affiliations (more on this in the Methodology section). These similarities may have made it easier to identify patterns and themes among elements of worldview in the teachers participating in this study.

Furthermore, because all the participants in the study were science teachers, it is likely they would have similar academic backgrounds and experiences in the sciences. In addition, they may be likely to have similar conceptions of NOS. Because many teachers have very little opportunity during their teacher preparation education to study the history and philosophy of science, most secondary teachers, regardless of their background in science content areas, have limited and naïve views of NOS (Gallagher, 1991; Lederman,
However, this research elicited and highlighted some subtle differences in conceptions of NOS. Because the worldviews and understandings of NOS were somewhat similar among the participants in the study, this made it possible to identify patterns, themes, and relationships that were more subtle and might have been overlooked on a study involving a more diverse sample.

Because of the elusive nature of both worldview and understandings of NOS, it was sometimes difficult to identify clear themes, patterns, or relationships in the responses of the participants. In addition, since this study engaged only a small number of teachers, it may be difficult to generalize some of the results across the entire scope of science teachers. Furthermore, because worldview and understandings of NOS ideas are often tacit, it was, at times, difficult for participant teachers to reflect accurately on how they believe these aspects affect each other or affect their teaching. However, with carefully constructed questionnaires and interviews and in-depth analysis, various themes, patterns, and relationships emerged.

Significance of Study

Several assertions about science education, the role of teachers, the importance of worldview, and the need to have an understanding of NOS ideas were foundational to this study:

1. Students who attend a Christian school are included in the all Americans for whom science literacy is a goal as articulated by AAAS (1990) in *Science for All Americans*.

2. An understanding of NOS is crucial to developing scientific literacy (AAAS, 1993).
3. Teachers and effective teaching are essential to good science education (NRC, 1996).

4. A worldview functions as a guide to life as it shapes the way in which people view and evaluate events, issues, and structures in the world (Wolters, 1985). Identifying the possible relationships that exist among worldviews and understandings of NOS would particularly contribute to the understanding of science as a cultural enterprise and help to further characterize the ways in which culture (worldview, in this case) influences understandings of NOS. Furthermore, if the Christian school science teachers in the study are dedicated to helping their students become scientifically literate and develop understanding of NOS, it is important that these teachers be able to identify their own understandings of NOS and how their worldview (of particular focus and importance at this Christian school) might influence their understandings of NOS and how they teach NOS to their students.

Not only are the results of this study important for the teacher participants in this study, but they are also important for the broader community of science education. For example, this study may identify a relationship between a particular component of worldview and an aspect of NOS. If this relationship shows that a more scientifically compatible aspect of worldview might lead to a more informed understanding of a particular aspect of NOS, then it would be important that both teachers and teacher educators recognize this relationship.
CHAPTER II

LITERATURE REVIEW

One growing area of research in science education is worldview research. This research has focused on trying to characterize various aspects of teachers’ and students’ worldviews and how these worldviews perceive science (Aikenhead, 1996; Allchin, 1999; Cobern, 1991b; Cobern, Gibson, & Underwood, 1995; Kilbourn, 1974). Another area of continuing research in science education focuses on NOS. Researchers concentrating on NOS and various science education reform documents highlight the importance of NOS and call for the improvement of the teaching and learning of NOS (AAAS, 1989; Lederman, 1992; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; McComas et al., 1998; NRC, 1996). One question of particular interest for this study was what type of relationship might exist among differences in worldview and differences in conceptions of NOS of science teachers at Christian schools.

This review of literature contains two main sections—worldview and NOS. The first section is devoted to worldview and focuses on defining worldview, articulating Kearney’s (1984) logico-structural model of worldview, examining worldview in science education, clarifying the concept of a Christian worldview, and discussing the assessment of worldview. The second section is devoted to NOS and focuses on defining NOS and its components, highlighting the importance of NOS, discussing research on teachers’ understanding of NOS and how these conceptions may relate to teaching practices, and describing how NOS is assessed.
Worldview

Defining Worldview

To analyze the development of the concept of a worldview requires a historical journey including stops along the way to examine works by philosophers and thinkers such as Kant, Fichte, Schelling, Darwin, Nietzsche, and others (Cobern, 1991b). In his extensive study on worldview, Naugle (2002) traces the development of the concept of worldview through various religious, philosophical, scientific, social science, and theological perspectives. This study of worldview starts at the origin of the term worldview (Weltanschauung) used by Kant. From here, this notion of a worldview that “consists of basic assumptions and images that provide a more or less coherent, though not always accurate, way of thinking about the world” (Kearney, 1984, p. 41) has undergone development and refinement through various disciplines.

Current literature available for use in studying worldviews is vast. For example, a search in education literature using the ERIC database and searching with the terms worldview, world view, and views of the world yielded over three thousand documents. Therefore, it is important to narrow the discussion of worldview to the topics of interest for this study. In addition, it is important to note there are two forms of this word: worldview and world view. Worldview is the form used in this research since this starts with the first term, weltanschauung, used by Kant and is the term used in science education research (Cobern, 1991b; Wolters, 1985).

Development of Worldview

If a worldview is a framework of basic beliefs, it is important to examine how a person's worldview develops. Wolters (1985) summarizes the concept of worldview as,
Our worldview functions as a guide to our life. A worldview, even when it is half unconscious and unarticulated, functions like a compass or a road map. It orients us in the world at large, gives us a sense of what is up and what is down, what is right and what is wrong in the confusion of events and phenomena that confronts us. Our worldview shapes, to a significant degree, the way we assess the events, issues, and structures of our civilization and our times. It allows us to “place” or “situate” the various phenomena that come into our purview. (p. 4)

Worldview encompasses and influences every aspect of our interaction with the world and people around us. Likewise, our interactions with the world and people around us exert influence on our worldview beliefs. Figure 1, adapted from Walsh & Middleton (1984), illustrates some of these reciprocal interactions. Drawing on this conceptual modeling of worldview and the interaction between components of worldview, the study more closely examines the model of worldview.

**Logico-Structural Model of Worldview**

In his book, *World View*, Kearney (1984) proposes a logico-structural model of worldview based on broad range of empirical cultural, ethnophilosophical and worldview studies. Doing this, Kearney identifies seven broad cognitive categories that shape his theoretical model of worldview: Self, Other, Relationship, Classification, Causality, Space, and Time. Kearney not only seeks to identify and define the components of a worldview, but also to examine the interrelationships between the elements of a worldview. He calls these interrelationships the logico-structural integration aspects of a worldview. Furthermore, he claims that one can analyze worldviews using these logico-structural interrelationships. Figure 2 displays the aspects of Kearney’s logico-structural model of worldview and the proposed reciprocal relationships between the various aspects of worldview. This logico-
The structural model of worldview provides a framework for the description and comparison of the worldviews of the teachers in this study.

One important attribute of this logico-structural model of worldview is that it emphasizes the tendency of worldviews to be internally consistent and logical. However, worldviews can lack internal consistency as Wolters (1985) asserts.
This is not to say that worldviews are never internally inconsistent—many are (in fact, an inconsistency may be one of the most interesting things about a worldview)—but it remains true that the more significant feature of worldviews is their tendency toward pattern and coherence; even their inconsistencies tend to fall into clearly recognizable patterns. Moreover, most people will not admit to an inconsistency in their own worldview even when it is very obvious to others. (p. 3)

Nevertheless, despite the occasional lack in internal consistency, this logico-structural model of worldview is useful for identifying and characterizing attributes of worldview. As Kearney (1984) explains his model for examining worldviews,

The basic requirement of this framework is that it be applicable to any human world view without greatly distorting it. It is in this sense analogous to the diagnostic categories of doctors. When a doctor examines patients he has in mind definite notions about human anatomy and physiology that allow him to describe the patient’s state of health. Although the doctor is confronted with a wide variety of patients, he can presumably describe the most significant medical facts about them in terms of dimensions and features that are common to all patients, e.g., blood pressure, pulse, respiration. In a similar manner we must discover a universal set of
diagnostic categories to describe world views. Other possible universal dimensions of world view can be derived or posited for various purposes, but the ones that I present here appear to me to be the minimal ones for adequately analyzing and describing a world view as a dynamic logico-structurally integrated system of knowledge. (p. 65-66)

Since this was a study in the field of science education and the natural science disciplines seek to inform students about the natural world, this study focused on two aspects of worldview for closer examination: Nature (a component of The Other or NonSelf category) and Causality.

**Nature**

One aspect of the framework for worldview that Kearney’s logico-structural model defines is the Self. As Cobern (1997) articulates, “a worldview defines the Self. It sets the boundaries of who and what I am. It also defines everything that is not me, including my relationships to the human and non-human environments” (Theoretical Framework section, ¶ 1). In defining what is Self, it also defines what is NonSelf. Three main components of this NonSelf, at least for most of Western culture, are Society, Nature, and God (Cobern, 1991b).

The aspect of NonSelf that would be of much interest in a science classroom and for science teachers is that of Nature. What is the understanding of Nature taught and learned in a science classroom? The following example from Wanatabe (1974) illustrates various stereotypical views of Nature:

Three men went to see Niagara Falls. One was an Indian from India, one was a Chinese, and one an American. On seeing the falls, the Indian, as a matter of course, thought of his god, manifested in this grandeur of nature. The Chinese simply wished to have a little hut beside the falls, where he might invite a friend or two, serve tea, and enjoy conversation. The American, however, on viewing the falls, immediately asked himself what could be done to make the most of such an enormous amount of energy. (quoted in Cobern, 1991b, p. 50)

The differences in the understandings of Nature are clearly identifiable in this example.
Cobern and Loving (2000) illustrate that a variety of perspectives and understandings of Nature could exist among science teachers. Using a case study method that involved narratives and in-depth description with the four participants in their study, they identified several perspectives and understandings of Nature that could be held by North American science teachers: The Lover of Scientific Mysteries, The Optimistic Reductionist, The Scientific Buddhist, and The Logical Scientific Pollyanna. Cobern and Loving explain that the differences in the understanding of Nature (a NonSelf worldview component) are significant and will make a difference in how a person understands the world around them and how it works. It is this image of and understanding of Nature explored in this study.

1 The Lover of Scientific Mysteries: Cobern & Loving (2000) describe this science teacher as personally committed to involvement in science and Nature, and he talks like a scientist when talking about the concepts of science. Not only does he talk about the concepts of science, he also talks about how complex Nature is and how we will never know all there is to know about nature. He often talks to students about the mysteries of Nature and how scientists attempt to solve these mysteries.

The Optimistic Reductionist: Cobern & Loving (2000) describe this science teacher as strongly positive about the virtues of science. The method of science he describes is analytical reductionism, and he explains to his students that science proceeds by “taking things apart.” He believes science is powerful and will eventually triumph over Nature since nature is understandable and humans will eventually understand all. He feels that science is valuable because it extends human control over Nature.

The Scientific Buddhist: Cobern & Loving (2000) describe this science teacher as viewing nature as very complex. He states that “nature is alive” and composed of dualities he describes as Ying-yang. He often describes the complexities of Nature to his students in terms of dualities. He feels that scientific knowledge is powerful; however, there is still a mystery associated with Nature. He feels he has an “instinctual connection to the sacredness of Nature.”

The Logical Scientific Pollyanna: Cobern and Loving (2000) describe this science teacher as identifying herself as a scientist. She explains that scientists do experiments that lead to knowledge about Nature because Nature is orderly. Therefore, we can make accurate predictions about natural phenomenon due in part to this order. She sees Nature as complex; however, since Nature is logical and orderly, it is not that difficult to understand or explain.
Causality

The second aspect of worldview examined in this study is causality. In defining causality in his logico-structural model of worldview, Kearney (1984) builds on Piaget’s psychological study of the development of causal thinking in children. As a component of the Piagetian model of moral development, a mechanical view of causality develops. Kearney summarizes this model of moral development by defining the periods through which an understanding of causality develops:

These adherences are participant, animism, artificialism, finalism, and force...in feelings of participation, there is an assumed affinity of Self with external objects...the notion of animism, which endows things with consciousness and life...in the third form, artificialism, there is the uncritical assumption that objects obey will and intention, and in doing so are organized and act for the good of men. This notion that things exist for and are organized for man is the finalistic assumption. To the extent that this notion exists, the world is seen as teleological. The fifth type of adherence is the notion of force or power, which is attributed to things such that they make efforts as do muscles. (p. 87)

This mechanical cause-and-effect understanding that has helped to define modern science, a scientifically compatible worldview, and the direction of science education in much of the Western world (Cobern, 1991b). Therefore, this study explored the understanding of causality and how this understanding compares with a scientifically compatible worldview. In order for a worldview to be classified as scientifically compatible, the Causality aspect of the worldview must include presuppositions that are compatible to scientific explanation (Cobern, 1997). That is, if a worldview demonstrates a mechanical cause-and-effect understanding of modern science, then it can be identified as a scientifically compatible worldview.
Research in science education, especially research focused on misconceptions, has shown that students do not come to the classroom with minds *tabula rasa*. Rather, they come to the classroom with a host of experiences and prior knowledge that influences their learning. These experiences and prior knowledge may be influenced by formal instruction, family experience, cultural context, religious training, and various other sources (Hills, 1989; Mintzes, Wandersee, & Novak, 2001; and others). The objective of much misconception research is, as Hills (1989) states,

> To enable us to learn more about the content of the beliefs and ideas students bring to formal instruction in the sciences. The rationale lying behind much of this work is that by coming to better understand these views we will gain more insight into certain intellectual difficulties students encounter in the course of their efforts to learn science. (p. 156)

A great deal of science education research focuses on identifying the beliefs and ideas students bring to the classroom and how to use those beliefs and ideas in science instruction.

However, although science education has stressed the importance of prior knowledge and its influence on student learning of science, there is less emphasis placed on student differences in philosophical assumptions about the world and how it works (student worldviews). As Cobern (1991b) articulates, “researchers assume that students come into elementary, secondary and college science classes with relatively homogeneous, fundamental views of the natural world capable of assimilating and valuing modern scientific understanding when science knowledge is presented in proper enquiry fashion” (p. 3). However, each student entering a science classroom brings with him or her a unique worldview and perspective on how the world works. Furthermore, “world views develop,
evolve and change. Thus, experiences such as formal science instruction have the potential for influencing world view” (Cobern, 1991b, p. 9). Figure 3 depicts how worldview, scientific knowledge, and experience may interact with each other.

Because worldview plays an important part in shaping how we see and interact with the world—including science and science education, it is important that science educators recognize the role that worldview plays in their students’ learning and understanding of science. As Young (1976) articulates,

School science separates science from pupils’ everyday lives, and in particular their non-school knowledge of the natural world. It is learnt primarily as a laboratory activity, in a room full of special rules, many of which have no real necessity except in terms of the social organization of the school. (p. 53)

As a result of a lack of explicit connection made between science and students’ everyday lives, students create their own connections between science and their everyday lives.

Students’ worldviews then help to shape these connections.

School not only separates students from their everyday lives, it also separates teachers from their everyday knowledge of the natural world. Therefore, if it is important to more closely examine the relationship between worldview and science education for students, it must also be important to examine this relationship for the teachers who are “in charge” of the students’ educational experiences. In his monograph, Cobern (1991b) provides an extensive discussion of the relationship between worldview and science education. Included in this discussion is an extensive examination of the components of a worldview and how worldview theory has influenced science education and science education research traditions. Furthermore, Cobern suggests that worldview presuppositions may be closely related to a person’s understanding of NOS ideas.

Several studies have examined specific aspects of worldviews and science education and the relationship between the two. Costa (1995) proposed a grounded-theory scheme where she categorized students according to the ease in which they moved from their cultural identity, “life-world culture,” and the culture of school science. Costa explored this negotiation of knowledge and roles in high school science classrooms by interviewing 43 high school students in order to examine the congruency between their worlds of family, friends, school, and science. In addition, she made classroom observations and examined student record data in order to get a more complete picture of each student’s perspective on school science. As a result, she proposed five categories as a part of her scheme: “Potential Scientists,” “Other Smart Kids,” “I Don’t Know’ Students,” “Outsiders,” and
“Inside Outsiders” Costa then suggests the “necessity of curriculum and school practices that facilitate the integration of the students’ worlds of family, friends, schooling, and science” (p. 331).

Aikenhead (2001) expands on Costa’s (1995) grounded-theory work by examining two additional individuals (a grade 10 student as a part of an action research project and a grade 7-9 teacher as a part of a study on teachers’ views on the connection between science and culture) and looking at Solomon and Thomas’s (1999) work involving seventeen-year-old science students in the U.K. who enrolled in an advanced level, technology-design science course. Aikenhead adds an additional category to Costa’s scheme, the “I Want to Know” student. At the conclusion of his article, Aikenhead (2001) makes several suggestions for instruction by characterizing the types of interactions between a student’s cultural identity (part of worldview) and the world of science.

2 Costa’s (1995) categories that describe the world of the student and the world of science and the patterns among those worlds and the student’s worlds of family and friends and their success in science and in school:

“Potential Scientists”: Worlds of family and friends are congruent with worlds of both school and science.

“Other Smart Kids”: Worlds of family and friends are congruent with world of school but inconsistent with world of science.

“’I Don’t Know’ Students”: Worlds of family and friends are inconsistent with worlds of both school and science.

“Outsiders”: Worlds of family and friends are discordant with worlds of both school and science.

“Inside Outsiders”: Worlds of family and friends are irreconcilable with world of school, but are potentially compatible with world of science. (p. 316)

3 “I Want to Know” Student: Aikenhead (2001) describes these students as “students who want to understand Western science, but whose success is made difficult by the diversity between their cultural identity and the culture of school science” (p. 185). Furthermore, these science does not appear to fit the lifestyle of these students; however, “they have enough self-esteem and self-perception to persevere” (p. 186).
A study conducted by Allen and Crawley (1998) involved twenty-eight Native American students of the Traditional Kickapoo Band in grades five through nine. The study used audiotapes, videotapes, field journal notes, contact summary forms, student drawings, and other documents to analyze the relationship between the worldview of Native American students of the Traditional Kickapoo Band with the “worldview of science” that was encountered in their science class. This “worldview of science” is a reflection of the ideas regarding categories of worldview such as nature, classification, and causality communicated by the science teacher. One response illustrating the worldview of one of the Kickapoo students is an answer to a question about if we should change the weather. The student responds, “No...[we shouldn’t change the weather] because we’re disturbing Mother Nature” (Allen & Crawley, 1998, p. 126). The student then goes on to explain that Mother Nature is “the earth.”

In addition, text materials were examined since “teachers depended on textbooks to structure content, and the strong positivism of the text materials was reflected in classroom instruction and curriculum materials” (Allen & Crawley, 1998, p. 119). Along with the interviews and interactions with the Kickapoo students and the researchers’ field journal notes, Kickapoo adults were also interviewed in order to triangulate the data. As the researchers coded and analyzed the data, they created categories of reported, observed, and inferred data in order to triangulate the worldview categories they were creating based on the data.

Allen and Crawley (1998) conclude that particular aspects of the students’ worldview were in conflict with the “worldview of science;” thus, these Kickapoo students were not able to become successful students in the science classroom. One of the
conclusions Allen and Crawley draw is the importance of the teachers’ understanding of the nature of science: “the way teachers understand the nature of science may have a direct impact on the content and structure of the science classroom and on student learning” (p. 130).

In a position paper, when Allchin (1999) explains the practice of science is not value-free and is influenced by worldview beliefs, he suggests that science teachers who are aware of the relationship between worldview and science will be more effective in helping students to develop understanding of NOS. It is because teachers make the relationship between worldview and science an explicit part of the educational experience in the classroom that students are able to better develop their understandings of NOS ideas through the various activities in which they engage in during their science courses (Allchin, 1999).

**Christian Worldview**

In his book, *The Universe Next Door*, Sire (2004) identifies seven questions that a worldview answers:

1. What is prime reality—the really real?
2. What is the nature of external reality, that is, the world around us?
3. What is a human being?
4. What happens to a person at death?
5. Why is it possible to know anything at all?
6. How do we know what is right and wrong?
7. What is the meaning of human history?
Following a discussion on these basic tenants of a worldview, Sire goes on to discuss eight representative worldviews including Christian Theism, Deism, Naturalism, Nihilism, Existentialism, Eastern Pantheistic Monism, The New Age, and Postmodernism. However, it is important to recognize these are representative worldviews. Therefore, for the purposes of this study, the identification of the teachers in this study as holding a Christian worldview is helpful in identifying various aspects of their worldviews. However, the logico-structural model of worldview used in this study allows for individual variation of worldview, even within a broader classification of “Christian worldview.”

Teachers in this study teach at a Christian school within a tradition of including topics such as worldview in the scholarly discourse. For example, one of the school’s recent North Central Association school improvement goals was “Reformed Perspective.” This meant that the administration and faculty at the school were specifically focused on teaching about and from a Reformed perspective (part of a Reformed Christian worldview which is explained further in the following paragraph) and helping students be able to articulate this perspective and apply it to their learning and thinking. Therefore, it may have been that teachers in this study might be better able to articulate aspects of their worldview because they have spent time and energy trying to explicitly define and develop their worldview—specifically, their worldview as it relates to their religious beliefs and their chosen content area of science. In addition, the school in which they teach articulates this Reformed Christian worldview in its philosophy of education and mission statement for education at the school.

history and description of a worldview and then outlines the basic framework of the Reformed worldview: Creation, Fall, and Redemption. This Reformed Christian worldview asserts that there is no separation between sacred and secular. Therefore, all of life (including school, science, and science education) would be viewed as influenced by a Reformed worldview that entails the constructs of Creation, Fall, and Redemption.

Several authors write about the “Christian worldview”—what it is and how to develop it (Sire, 2004; Walsh & Middleton, 1984; Wolters, 1985). In fact, when discussing worldviews, specific content of particular worldviews most likely comes to mind. For example, the worldviews that Sire (2004) articulates, Christian Theism, Deism, Naturalism, Nihilism, Existentialism, Eastern Pantheistic Monism, The New Age, and Postmodernism, have specific content associated with them. Likewise, a “Reformed Christian” worldview (a subset of the Christian Theism worldview) incorporates the ideas of Creation, Fall, and Restoration. However, the logio-structural model of worldview as proposed by Kearney (1984) provides a way to study the aspects of a worldview without talking about the specific content of a worldview.

This “Christian worldview” is not the same as the worldview concept used in this study. Rather, worldview, as defined for this study, may be more comprehensive and less constrained. That is, although many of the teachers in this study may have worldview characteristics in common and may have, and according to Walsh and Middleton (1984) a Christian worldview, they may have differences in various facets and nuances of their worldviews. Therefore, the worldview definition for this study recognizes both the possibility for themes and patterns of similarities in the worldviews of the teachers and allows these teachers to have very individual variations in worldviews.
Although participants in this study may have worldview beliefs consistent with what Walsh and Middleton (1984) and Wolters (1985) classify as a Christian worldview, there are other religious-based or influenced worldviews besides a Christian worldview: Hinduism, Buddhism, Judaism, Islam, Indigenous, Atheism, and others (Clayton, 2006). Furthermore, there are current research projects involving some of these worldviews and their influencing factors and science education (Dodick, Dayan, & Orion, 2010; Mansour, 2011; Titrek & Cobern, 2011; Yuenyong & Narjaikaew, 2009; and others). However, this study will focus on the aspects of a Christian worldview as articulated by the participants in the study.

**Assessing Worldview**

A number of studies have looked at the concepts of worldview and issues surrounding science education (Allen & Crawley, 1998; Aikenhead, 2001; Cobern, 1999, 2000a; Cobern & Loving, 2000; Cobern, Gibson, & Underwood, 1999; Costa, 1995; Medina-Jerez, 2007; Lawrenz & Gray, 1995; Liu & Lederman, 2007; and others). In those studies, several worldview assessment tools and techniques have been proposed and used. For example, Allen and Crawley (1998) use a combination of individual and group interviews, classroom observations, student drawings, field journal notes, and other documents to gather data regarding worldview for analysis. Costa (1995) used interviews in her study of 43 high school science students. Liu and Lederman (2007) used two open-ended questionnaires in conjunction with follow-up interviews in a study with 54 Taiwanese prospective science teachers. In a study of 250 science teachers from Botswana, Indonesia, Japan, Nigeria, and the Philippines, Ogunniyi, Jegede, Ogawa, Yandila, and Oladele (1995) used a pen-and-paper survey. Medina-Jerez (2007) employed semi-structured interview technique adapted from Cobern (2000a) in a study involving middle- and high-school
students from northeastern Columbia. Lawrenz and Gray (1995) used a six-item questionnaire with follow-up interviews given when student responses were difficult to interpret or ambiguous in a study involving final year science student teachers in South Africa.

In their study of clergy views of science, creation, and religion, Colburn, Henriques, and Clough (2002) created an instrument that would ascertain viewpoints regarding issues separating evolutionists and creationists as well as views about the nature of science and religion. By using an instrument like this, Colburn et al. (2002) were able to not only probe for beliefs related to worldview, but also to ideas that connected worldview with understandings of NOS.

Due to the personal and abstract nature of the concept of worldview, qualitative methods are necessary in order to gain a deep understanding of a participant’s worldview. In his monograph, Cobern (1991b) not only describes the notion of worldview and its relationship with science education, he also mentions several measurement tools used to assess worldviews: ethnographic interviews, construction of visual maps, observations, the Interview-About-Instances (IAI) technique, and the paper-and-pencil Test of Preferred Explanations (TOPE). This study used ethnographic interviews, construction of visual maps, and interviews based on items from Cobern, Gibson, and Underwood’s (1995) interviews about nature and the TOPE.

**Nature of Science (NOS)**

**Defining NOS**

A succinct and specific definition for NOS that every philosopher, historian, scholar of science, and science educator agrees on has been elusive (Bloor & Barnes, 1996; Brush,
There have been various definitions of NOS proposed and changed as science and science education have changed and developed over the past 100 years (AAAS, 1990; Lederman, 1992; NRC; 1996). As summarized by Khishfe and Abd-El-Khalick (2002),

> Given the multifaceted, complex, and dynamic nature of the scientific endeavor, it should not be surprising that philosophers, historians, and sociologists of science disagree on a specific definition for NOS and many particular issues associated with the generation of valid scientific claims. However, within a certain period of time and at a certain level of generality, there is a shared wisdom (even though no complete agreement) about NOS. (p. 555)

However, a definition of NOS that has been a standard for much recent NOS research is used for the purposes of this study (Lederman et al., 2002; Liu & Lederman, 2007; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Schwartz & Lederman, 2005, 2008). This more general definition of NOS, as articulated by Abd-El-Khalick, Bell, and Lederman (1998), states that NOS refers to the “epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge” (p. 418). As a part of this more general definition of NOS, several key components of NOS have been identified: tentative (subject to change); subjective (theory-laden); empirically based (based on and/or derived from observations of the natural world); the product of human imagination and creativity; socially and culturally embedded; the functions of and relationships between scientific theories and laws; the distinction between observation and inference; and lack of a universal recipe-like method for doing science (Lederman, 1999; Lederman et al., 2002). The following sections expand on these key components of NOS and provide further information regarding each component.
**Tentative Nature of Scientific Knowledge**

In order to understand the tentative nature of scientific knowledge, one must understand that science and scientific knowledge is subject to change. In fact, understandings of NOS are also tentative and subject to change. One can see this change by considering the works of philosophers such as Popper (1959), Kuhn (1996), Lakatos (1976), and Feyerabend (1975) and observing the tentativeness of the understanding of NOS. For example, Popper asserted that scientific knowledge is progressive and cumulative. Kuhn contended that science and scientific knowledge undergo paradigm shifts. Feyerabend stated that science and scientific knowledge was neither progressive nor cumulative. Lakatos claimed scientific knowledge may develop over time by means of a succession of alterations to the *protective belt* surrounding the *hard core* of fundamental principles.

Because, like all knowledge, the understanding of NOS is an individual understanding and varies from person to person, it might be helpful to illustrate how one of these understandings of NOS may vary. Looking at the history of the development of our current scientific understanding of genetics illustrates this tentative nature quite well. Early in the history of genetics and evolutionary thought, Lamarck presented a theory of the inheritance of acquired characteristics. That is, if an organism acquires a trait such as a male crab’s front claw becoming large from repeated use to attract mates and ward off predators, this “trait” (a large claw) will be passed to its offspring. Later, Mendel’s research using pea plants suggested there was something inherent in the plants that determined traits, and this “something” was passed on through generations. Finally, the work of researchers such as Meischner, Griffith, Avery, Pauling, Franklin, Watson, Crick, and others, reported the genetic “substance” of DNA and its structure. This process of the development
of our current scientific understanding of genetics illustrates the tentative and changing
two of our understanding of science.

Although the historical development of scientific thought shows science to be
tentative, many students believe current scientific knowledge of genetics is final. As a
student reads a typical biology textbook, he or she encounters the current state of scientific
knowledge. Therefore, it would be easy for the student to adopt an idea that this current
state of scientific knowledge is the final state of scientific knowledge. However, as scientific
knowledge increases and develops, scientists expect this current state of scientific
knowledge about genetics to change if new scientific discoveries or reinterpretation of
existing information occurs in the future. This understanding of the tentative nature of
scientific knowledge is therefore an important understanding of NOS.

**Empirically Based**

Science, both as a body of knowledge and as a process, develops through
observations of the natural world. However, scientists, students, and others do not have
direct access to most natural phenomena. Rather, their observations of nature and natural
phenomena filter through their senses and are interpreted in light of prior experiences,
expected observations, theoretical frameworks, and other assumptions. Therefore, although
science is empirically based, this does not mean that science is objective.

Chalmers (1999) explains, “observations suitable for constituting a basis for
scientific knowledge are both objective and fallible” (p. 25). Chalmers illustrates and
highlights the idea that observation and empirical evidence is essential to science with an
example from the work of Galileo. Galileo devised a way to measure and record the daily
movement of four “starlets” (moons) surrounding Jupiter. He then used these
measurements (this empirical data) to support the validity of the Copernican theory that the
earth spins on its axis while orbiting around the sun. Popper (1959) also draws on the
empirical basis of science with his falsificationism in that if something is false, it can be
shown by observation or experiment.

**Subjective and Theory-laden**

In the mid 19th century, the development of positivism stressed the idea that
science should be based on empirical observations, “facts,” rather than personal opinions or
preconceived ideas. These empirical observations, as Chalmers (1999) summarizes, are
“directly given to careful, unprejudiced observers via the senses...prior to and independent
of theory...[and] constitute a firm and reliable foundation for scientific knowledge” (p. 4).
Chalmers then goes on to describe how each of these claims faces difficulty. For example,
contrary to much popular belief, the observations that science might start from are never
neutral observations (Popper, 1992). The knowledge, experience, and expectations of the
observer influence the observations.

Various philosophers challenged this positivist philosophy of neutral observations
(Feyerabend, 1975; Kuhn, 1996; Popper, 1992; and others). They claim that scientific
observations are not neutral; rather, they are subjective and theory-laden. These subjective
observations fit into Kuhn’s (1996) notion of paradigm and paradigm shifts. Scientists work
within their paradigm making observations, choosing what types of questions to ask, and
drawing conclusions. As Chalmers (1999) states, “it would seem that the scientific revolution
involved not just a progressive transformation of scientific theory, but also a transformation
in what were considered to be the observable facts” (p. 16).
It is important to recognize there has been and continues to be ongoing debate over Kuhn’s work. For example, many philosopher of science (e.g. Feyerabend, 1975; Lakatos, 1977; Toulmin, 1972) have called into question Kuhn’s definition of paradigms, the notion of “incommensurability,” and the idea of “revolution.” Nevertheless, Kuhn’s work has played and continues to play a large role in the philosophy of science and in science education.

As Kuhn (1996) asserts, the practice of science occurs within the framework of a particular paradigm. The paradigm in which a scientist works affects the types of problems investigated, the experimental set up used to investigate the problem, the observations made from the experiment, and the conclusions drawn from those observations. Therefore, the paradigm from which a scientist works greatly affects the scientific knowledge produced. Kuhn provides several examples of how a paradigm framework can influence when he explains, “looking at a contour map, a student sees lines on paper, the cartographer a picture of a terrain. Looking at a bubble-chamber photograph, a student sees confused and broken lines, the physicist a record of familiar subnuclear events” (p. 111). This paradigm-influenced scientific knowledge goes on to influence other experiments, observations, and conclusions. As Chalmers (1999) reflects, “the point is that the knowledge that provides the categories we use to describe our observations is defective, the observation statements that presuppose those categories are similarly defective” (p. 16).

Many people have difficulty recognizing science as something that is subjective and theory-laden. Lederman (1999) illustrates this difficulty identifying the subjective nature of science with some quotes from his study looking at teacher practice and its relationship to students’ understanding of NOS: “Scientists have their own opinions about things, but the strength of science is that in the end, it is objective” and “There really is no room for
subjectivity in science. Otherwise, anyone could say whatever they want” (p. 926). As these students communicated, people often categorize science as an enterprise that is completely objective. However, because science is a human activity, practiced scientists, however well intentioned, cannot be completely objective in the process of designing experiments, collecting data, interpreting results, and drawing conclusions.

**Product of Imagination and Creativity**

Although observations and explanations of the natural world are the basis of science, science does involve some level of “invention” of explanation. There is an underdetermination of theories by evidence (Irzik & Nola, 2011; Kuhn, 1996). That is, evidence (empirical data) is limited, and sometimes more than one theory explains the same evidence equally well. Therefore, science may require choice that involves imagination and creativity. Science is a human activity that, contrary to common belief, is “not a totally lifeless, rational, and orderly activity” (Lederman, 2004). Rather, a great deal of creativity and imagination often are required for the design of scientific experiments and the explanation of observed phenomena. For example, although current scientific knowledge does not accept Lamarck’s theory of the inheritance of acquired traits, certainly one can recognize the imagination and creativity that went into the creation of such a theory.

One such example is described by Okasha (2002) with the example of Kekule, the scientist who discovered the hexagonal structure of benzene. While Kekule was struggling to determine the structure of benzene, he had a dream about a snake biting its tail. It was this circular image of the snake that led Kekule to propose the benzene ring and begin to test this model. In addition, many other scientific models and theories required imagination and
creativity to create the “stories” that are used as explanations for various physical phenomena.

**Socially and Culturally Embedded**

Because scientists who are members of a larger social and cultural community practice science, science is inextricably embedded both socially and culturally. Kuhn’s (1996) notions of paradigms are a significant example of how social and cultural milieu influence science and the practice of science. Feyerabend (1975) also supports this social and cultural embeddedness by purporting that success by scientists has traditionally involved non-scientific elements, such as inspiration from mythical or religious sources. Likewise, Toulmin (1972) explains that truth can be a relative quality that is dependent on historical and cultural contexts.

An examination of the Lysenko-based genetics of the 1930s Soviet Union provides a prime example of this inescapable intermingling of social and cultural influences and the practice of science. Because it supported the existing Nazi eugenics program and the political leanings of Stalin, Lysenko and other Soviet scientists advocated a Lamarckian approach to genetics and the inheritance of acquired characteristics, even though this was in opposition to scientific concepts accepted by Western Science. Likewise, Okasha (2002) describes how the Church sought to ban books and information describing and explaining the Copernican idea that the sun, not the earth, was at the center of the solar system.

Chalmers (1999) illustrates this idea using a sketch of a staircase such that when one looks at it, one can interpret the sketch as either a staircase viewed from above or a staircase viewed from below. If this sketch is shown to an observer familiar with staircases and two-dimensional perspective drawings, the person is likely to report seeing a staircase.
However, as Chalmers explains, if this sketch is shown to members of an African tribe who would not be accustomed to seeing three-dimensional objects depicted in a two-dimensional drawing or may have never seen a staircase, their interpretation of the image would likely be much different even though they may be viewing the same physical sketch.

**Distinction between Observations and Inferences**

Another important aspect of NOS is the awareness of the distinction between observations and inferences. Even introductory science texts highlight the importance of recognizing the differences between observations and inferences. Observations are descriptive statements about natural phenomena that are “directly” accessible to the senses. In contrast, inferences are statements about natural phenomena that are not “directly” accessible to the senses and interpretations of those observations. Prior knowledge and experience are often the basis for these interpretations. For example, when observing a white, cylinder-shaped object with a flame at the top, many people may infer this is a small white candle. However, it could be a potato cut into the shape of a small cylinder with a small piece of almond stuck in the top. This almond could be lit so that it looks like the wick of a candle.

Philosophers of science have also been interested in the concept of observation and inference. For example, Salmon (1967) explains,

> We all believe that we have knowledge of facts extending far beyond those we directly perceive. The score of our senses is severely limited in space and time...we believe, never the less, that we have some kind of indirect knowledge of such facts” (p. 5)

Salmon goes on to assert,

> [Science] embodies knowledge of matters of fact that are not open to our direct inspection. Indeed, science purports to establish general laws or
theories that apply to all parts of space and time without restriction. A “science” that consisted of no more than a mere summary of the results of direct observation would not deserve the name” (p. 5)

In his book, The Foundations of Scientific Inference, Salmon outlines the problem of induction related to observation and inference and then focuses on probability as a means by which inferences can be justified. He explains, “it is the problem of determining whether the inferences by which we attempt to make the transition from knowledge of the observed to knowledge of the unobserved are logically correct” (p. 6).

Science and scientific research relies on the important distinction between observation and inference and the relationship between them. For example, as Ellis-Christensen (2010) explains, for many years there have been drawings of what dinosaurs looked like. These drawings draw from inferences made after examining skeletal remains of dinosaurs, comparing dinosaurs with modern animals, and making guesses about how to interpret that information. However, as paleontology has advanced, the inferences scientists make about dinosaurs have changed. For example, some scientists suggest some dinosaurs had feathers, were warm-blooded, or had greater intelligence than once thought. And with claims of dinosaur DNA sampling such as Woodward, Weyand, and Bunnell (1994) published in Science, scientists may be able to infer relationships with more recent or currently living animals.

However, it can be very difficult to separate observation and inference. As Shapere (1982) explains, “we begin with sense-perception already infused with beliefs” (p. 521). Therefore, the challenge for scientists and all those conducting scientific inquiry would be to try to separate what is directly accessible to the senses from that which goes beyond the senses as much as possible. Thus, a recognition of the subjectivity tenant of NOS is also
important when attempting to distinguish between observation and inference. As Chalmers (1999) states,

One difficulty concerns the extent to which perceptions are influenced by the background and expectations of the observer, so that what appears to be an observable fact for one need not be for another. The second source of difficulty stems from the extent to which judgments about the truth of observation statements depend on what is already known or assumed, thus rendering the observable facts as fallible as the presuppositions underlying them. (p. 17)

**Relationship between Scientific Theories and Laws**

The relationship between scientific theories and laws is another important tenant of NOS. As Beverly (2002) explains, “scientific theory is the best explanation at a given time that accounts for the evidence available” (p. 5). These scientific theories are related to scientific laws; however, the relationship between theories and laws is not the hierarchical relationship that many students assume. Laws are “statements or description of discernible patterns in observable phenomena, and theories are inferred explanations for those phenomena” (Abd-El-Khalick et al., 1989, p. 425).

Laws are statements that describe the relationship between observed phenomena; they do not explain. Chalmers (1999) describes laws such as thermodynamic and conservation laws by stating, “these quite general laws have consequences for the behaviour of physical systems, and can be used to predict their behaviour, quite independently of the details of the causal processes at work” (p. 221). For example, the ideal gas law describes the relationship between the pressure, temperature, and volume of a gas. Notice this law (the description of the relationship) does not propose any type of explanation for why there is a relationship between pressure, temperature, and volume of a gas. Rather, it simply describes the relationship between these variables. Therefore, unlike
the common misconception, laws are not simply theories that have been proven repeatedly over time. Rather, laws are a description of a relationship.

In contrast to laws, theories are explanations inferred from observed phenomena. Popper (1959) asserts that scientific knowledge is progressive, and Kuhn (1996) describes paradigms, paradigm shifts, and revolutions in the theories that explain the observable phenomena in the world. For example, Kuhn states, “because it demands large-scale paradigm destruction and major shifts in the problems and techniques of normal science, the emergence of new theories is generally preceded by a period of pronounced professional insecurity” (p. 67).

Furthermore, a scientific theory is a well-supported explanation for an observed phenomena or for a problem or question that may be of interest to science. For example, the kinetic molecular theory explains the forces between molecules and the energy that these molecules possess. This kinetic molecular theory explains the “why” behind the observations that are described by the idea gas law. No matter how many times this kinetic molecular theory is accurate, it will never be called a law because it provides an explanation rather than a description. Likewise, Darwin’s theory of natural selection, one of the cornerstones of modern biology, provides for a key explanation of and mechanism of evolution of one species into another. Theories also allow scientists to make predictions regarding future observations and data obtained regarding a particular scientific problem or question. For example, Darwin’s theory of natural selection was used in the past and is currently used to make predictions regarding the types of organisms that should be found in fossil record.
The Myth of the Scientific Method

One of the most widely held misconceptions about science is the existence of a universal scientific method by which all scientific inquiry takes place. However, this notion of a universal scientific method, although still widely held by many, has been debunked by both historians and philosophers of science, the scientific community, and by science educators (AAAS, 1993; Bauer, 1992; Chalmers, 1999; Feyerabend, 1975; NRC, 1996; Shapin, 1996). Feyerabend (1975) contends that a historical and universal scientific method does not exist. Chalmers (1999) summarizes Feyerabend’s ideas as he states, “there is no scientific method, then. Scientists should follow their subjective wishes. Anything goes” (p. 157).

As Lederman (2004) asserts, the majority of pre-college students and the general public have a distorted view regarding scientific inquiry, especially in regards to “the scientific method.” Due to past science classes when memorizing the steps of “the scientific method” and reading scientific reports structured in the same manner as “the scientific method,” many people believe one “scientific method” exists and that the process of scientific inquiry follows these steps. However, the scientific and science education community recognize that the process of scientific inquiry does not proceed by the rigid stepwise, recipe-like sequence of “the scientific method.” For example, in his series of essays, Schaar (1966-68) describes a number of scientific discoveries made by sheer accident: aniline dyes, quinine, iodine, Vaseline, insulin, and more. However, as Bauer (1992) asserts,

That the scientific method is a myth, that is does not explain the success of science and that scientists in practice do not follow the method, does not mean that the method itself should not be ignored or disparaged. Rather, it
should be seen as an idea—an admittedly unattainable idea—not as a
description of actual practice. (p. 39)

This concept of scientific inquiry not proceeding by a rigid stepwise, recipe-like sequence is
also included in science education reform documents,

Scientists differ greatly in what phenomena they study and how they go
about their work. Although there is no fixed set of steps that all scientists
follow, scientific investigations usually involve the collection of relevant
evidence, the use of logical reasoning, and the application of imagination in
devising hypotheses and explanations to make sense of the collected
evidence. (AAAS, 1993, p. 12)

Therefore, students should not only to learn about the process of scientific inquiry, but also
to participate in that process of scientific inquiry (NRC, 1996).

Lawson (2009, 2005, 2003) proposes another view on the “the myth of the scientific
method”: hypothetical-deductive thinking. This is, as Lawson (2009) explains,

A theory/hypothesis driven view in which hypotheses/theories are needed
to give direction to data collection—specifically by leading deductively to
specific predictions. Once one has predictions one can then gather data to
compare with those predications and indirectly test the hypotheses/
theories in question. Sometimes the scientist may be explicitly aware of
these elements in his thinking—sometimes they may be implicit. (p. 122)

Lawson (2009) illustrates examples of this hypothetical-deductive thinking in his analysis of
the research program of Peter and Rosemary Grant and their work on Darwin’s finches. He
outlines the if/and/then nature of the hypothetical-deductive thinking process and
illustrates how the Grants’ research work employed this process. However, there have been
various critiques on Lawson’s hypothetical-deductive thinking. These critiques highlight the
idea that Lawson appears to ex post facto impose his hypothetical-deductive thinking onto
historical examples. Lawson imports a philosophical model onto the historical work of
scientists and to reconstruct the historical argument along the lines of that philosophical model (Allchin, 2003, 2006; Brush, 2004).

While one single, rigid, stepwise, recipe-like sequence that is “the scientific method” may not exist, it is important to still recognize the qualities of scientific inquiry that separate it from other disciplines: collecting evidence, logical reasoning, and applying imagination and creativity in the development of hypotheses and explanations to describe and make sense of evidence collected. That is, even without a precise definition of what compromises scientific inquiry and the methods of science, “one knows what science is when one sees it.” So, while one specific definition of the methods of science cannot be articulated such that is it inclusive of all that is deemed science yet exclusive enough to separate it from other disciplines outside of science, it is important that one still recognizes science as a distinct discipline.

The key components of NOS used in this study are widely agreed upon (Abd-El-Khalick et al., 1998; Lederman, 1999; Lederman et al., 2002; Liu & Lederman, 2007; Osborne et al., 2003; Schwartz & Lederman, 2005, 2008). However, as mentioned earlier, a succinct and specific definition for NOS that every philosopher, historian, scholar of science, and science educator agrees on has been elusive (Bloor & Barnes, 1996; Brush, 1974; Chalmers, 1999; Duschl, 1985; Grinnell, 1992; Herron, 1971; Irzik & Nola, 2011; Matthews, 1989a, 1989b; Robinson, 1998; Shapin, 1982). For example, Irzik and Nola (2011) advocate a “family resemblance” approach to NOS. This family resemblance approach to NOS seeks to identify similarities and differences among scientific disciplines. These similarities and differences, as Irzik and Nola explain, “can be classified in a systematic way in terms of the following categories that give us a structural description of NOS: (1) activities, (2) aims and values, (3)
methodologies and methodological rules, and (4) products” (p. 596). They explain, “whereas the consensus view [current view of NOS] presents a frozen picture of NOS, the family resemblance approach captures the dynamic and open-ended nature of science. It recognizes the fact that as science develops it may, and indeed often does, acquire new characteristics” (p. 602). Furthermore, Irzik and Nola state, “under the consensus view, NOS appears as fixed and timeless. It gives the students the impression that science has no history and no room for change in its nature” (p. 593).

This family resemblance approach to NOS is intriguing and may appear to better capture the essence of NOS. However, there are problems with Irzik and Nola’s (2011) characterization the consensus view. For instance, they claim that the consensus view of NOS presents a “frozen picture” of NOS where “NOS appears as fixed and timeless.” However, this interpretation of the consensus view of NOS is not advocated by those who have helped to develop this consensus view (Abd-El-Khalick et al., 1998; Lederman, 1999; Lederman et al., 2002; Liu & Lederman, 2007; Osborne et al., 2003; Schwartz & Lederman, 2005, 2008). Furthermore, when attempting to characterize and articulate a consensus view of NOS, there was careful attention paid to not call it the NOS, but rather to call it simply NOS with the recognition that there is no singular NOS or agreement on precisely what NOS means (Lederman et al., 2002). This consensus view of NOS, as Irzik and Nola label it, is the one used in this study since it is the most widely used standard for NOS research (Abd-El-Khalick et al., 1998; Allchin, 2011; Khishfe & Abd-El-Khalick, 2002; Lederman, 1999, 2007; Lederman, et al., 2002; Liu & Lederman, 2007; Osborne et al., 2003; Schwartz & Lederman, 2005, 2008).
**Importance of NOS**

In his review of research on students’ and teachers’ conceptions of NOS, Lederman (1992) shows how the development of student thinking and student and teacher understanding of NOS has been a desired outcome of science education for over a century. However, in his review of the history of science education, DeBoer (1991) asserts that a positivist view of science still pervades the thinking of many science teachers. This positivist view of science depicts science as a collection of proven facts that are universally accepted. However, this positivist view of scientific study and NOS does not accurately reflect the actual practice of science and practiced NOS. Science is a field of study that is constantly changing and transforming to the types of questions that those who practice science are asking. Nevertheless, students are still leaving their science classes without an accurate understanding of NOS.

As a result, numerous documents that call for reform in science education (AAAS, 1990; AAAS, 1993; NRC, 1996; and others) cite an understanding of NOS ideas as crucial to the development of science education so that students are being educated in such a way as to become scientifically literate. In fact, AAAS (1990) begins their *Science for All Americans* document by stressing the importance of understanding NOS ideas:

> Over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. Those ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing. (p. 1)
Just as it is important in the development of any type of educational endeavor to articulate the goals of the particular course of action, it is important that teachers identify understanding of NOS as one of their prime educational objectives. McComas, Almazroa, and Clough (1998) argue that the understanding of NOS is most important in science education and for the development of students (and members of society) who are scientifically literate. In their argument, they articulate several values of developing an understanding of NOS: to enhance the learning of science content, to enhance understanding of science, to enhance interest in science, to enhance decision-making, and to enhance instructional delivery. Following this list of “advantages” to developing understanding of NOS, they make several suggestions for instructional changes such as less dependence on textbooks and changes in the role of the teacher in the classroom.

**Teachers’ Understandings of NOS**

Previous research has shown that both preservice and in-service teachers, without explicit instruction related to NOS, do not possess adequate conceptions of NOS (Abd-El-Khalick & Lederman, 2000b; Gallagher, 1991; Lederman, 1992; Nott & Wellington, 1998; Pomeroy, 1993; and others). In addition, because teachers cannot teach what they do not understand it is important to investigate teachers’ conceptions of NOS.

Early studies of teachers’ conceptions of NOS indicated that teachers did not possess adequate conceptions of NOS. In a study of 17 preservice secondary science teachers, Carey and Stauss (1968) attempted to characterize the conceptions of NOS of these preservice teachers, examine how these NOS conceptions may be related to certain academic variables, and determine if a secondary science methods course could make a contribution to these preservice teachers’ conceptions of NOS. To do this, Carey and Stauss
examined an essay written by each of the preservice teachers responding to the prompt, “what is your concept of the nature of science?” The analysis of these essays looked for specific statements concerned with characteristics of science. Carey and Stauss also administered the Wisconsin Inventory of Science Processes (WISP) test to these preservice teachers following the completion of the essay but before the start of the secondary science methods course. The secondary science methods course implemented by Carey and Stauss was described as,

Initiated with an introduction to the nature of science by lecture, discussion, and outside reading. Thereafter, throughout the course, whether concerned with the objectives of science education, lesson planning, lesson presentation, or test construction, etc., the question placed before the group during discussion was: “Is this compatible with present philosophy concerning the nature of science?” (p. 359)

The preservice teachers completed the WISP a second time following the conclusion of the course.

The analysis of the essays of these preservice teachers indicated a minority of the preservice teachers considered “science to be consisting of a body of knowledge, methods and modes of inquiry, and a human endeavor” (p. 362). Carey and Stauss (1968) examined the WISP pretest and posttest scores and found that these preservice teachers did not possess adequate conceptions of NOS prior to the secondary science methods course. However, they found the pretest and posttest scores following the secondary scientific methods course to be significantly different (alpha level of 0.01). Therefore, Carey and Stauss concluded that a secondary science methods course could “make a significant contribution toward the gaining of an understanding of the nature of science” (p. 363). In addition, Carey and Stauss calculated correlation coefficients and found the inadequacy of
preservice secondary science teachers’ conceptions of NOS did not appear to be correlated to grade-point average, experience in science courses, or mathematics grades.

Carey and Stauss (1970) also completed a following study doing a similar analysis of the possible correlation between conceptions of NOS and various academic factors. In this study, they calculated correlation coefficients of the results of the WISP test and various academic factors (grade-point average, experience in high school and college science and mathematics courses, and years of teaching experience) for thirty-one teachers and found no correlation (Carey & Stauss, 1970). In conclusion, Carey and Stauss (1968, 1970) suggest that developing conceptions of NOS be explicitly addressed in methods courses.

Responding to criticisms inferring that science teacher preparation programs were not preparing science teachers to teach NOS, Kimball (1967-68) examined conceptions of NOS for science teachers and professional scientists. One of the main research questions asked during his study was, “Do qualified science teachers express the same view of the nature of science as do practicing scientists of similar academic background?” (p. 111). To answer this question, Kimball developed the Nature of Science Scale (NOSS), a 29 item, Likert-type scale instrument. This instrument development involved analysis by experienced science teachers, school science supervisors, science professors, and professors of science education to establish the face and content validity of the NOSS. Several pilot tests administered as a part of the NOSS development helped establish the reliability of the NOSS. Following the comparison of 712 science teachers and professional scientists in his sample population, Kimball found that both science teachers and practicing scientists “scored lower than might be hoped or expected” in regards to understandings of NOS (p. 119). In addition, Kimball found no significant differences in conceptions of NOS exist between the science
teachers and professional scientists of similar academic backgrounds. Therefore, Kimball concludes that the science teacher preparation programs are not to blame for the lack of adequate conceptions of NOS.

Further studies, such as Schwartz and Lederman (2005, 2008) have also reported that “scientists did not necessarily hold informed conceptions of all NOS and NOSI categories” (p. 42). However, Schwartz and Lederman (2005, 2008) report that the scientists in their study, “as a group, demonstrated somewhat more informed conceptions [of NOS] than has previously been reported” (p. 43). Yet, the results of this study are difficult to compare directly with previous studies (such as Kimball, 1967-68) due to great differences in methodology: a 29-item, Likert-type scale instrument in the Kimball (1967-68) study compared with two open-ended questionnaires (VNOS-Sci and VOSI-Sci) coupled with semi-structured interviews in the Schwartz and Lederman (2005, 2008) study.

Other studies (Abd-El-Khalick & Lederman, 2000a; Aikenhead, 1998; Aikenhead & Ryan, 1992) indicate that open-ended questionnaires and semi-structured interviews gauge conceptions of NOS better than Likert-type instruments. For instance, the assumption made in a Likert-type instrument is that respondents will understand the question and the language of the question in the same way the researchers understand. Furthermore, Aikenhead (1998) reported, “Likert-type responses offer only a guess at student beliefs, and the chances of an evaluator guessing accurately are very remote” and ambiguity exists around an 80% level (p. 615). However, with a semi-structured interview, as was included in the Schwartz & Lederman (2005, 2008) study, the “most lucid and accurate data” could be gleaned, and ambiguity would be only around 5% (Aikenhead, 1998, p. 625). That being said, it is important to recognize that instruments designed to gauge conceptions of NOS,
whether Likert-type scale, open-ended questionnaire, semi-structured interviews, multiple-choice questions, or others are subjective, tentative, and subject to change as much as science itself.

When discussing teachers’ conceptions of NOS, it is also important to highlight the importance of the text to the development of both students’ and teachers’ conceptions of NOS. As Gallagher (1991) notes, many secondary science textbooks devote the majority of the text to presentation and illustration of science content knowledge and very little to conceptions of NOS. In fact, what limited information a textbook may have that refers to NOS (usually found in the first few chapters) often portrays science as positivistic and runs contrary to NOS. For example, many texts present “the scientific method” as a rigid set of steps to be memorized and subsequently followed in the design and implementation of all scientific investigations.

A more recent analysis of several high school biology textbooks used in the United States (Chiappetta & Fillman, 2007) determined the emphasis given to four themes or facets of NOS in those textbooks: “(a) science as a body of knowledge, (b) science as a way of investigating, (c) science as a way of thinking, and (d) science and its interactions with technology and society” (p. 1848). At the end of their study, Chiappetta and Fillman (2007) conclude that “current biology textbook have evolved to a form that is much more representative of the many facets of the nature of science than existed 15 years ago” (p. 1863). However, the study did not specifically “address various aspects of science, such as the tentative nature of science, creativity, testing ideas, and so on” (p. 1863). In addition, since this study utilizes a different NOS framework definition, it is hard to draw conclusions from their results.
Although it appears that biology textbooks may be improving in their presentation of NOS, are teachers’ conceptions of NOS improving? Gallagher (1991) found that the 25 science teachers in his study also demonstrated inadequate conceptions of NOS. This ethnographic study of 27 secondary science teachers, involved observations of over 1000 science classes, several hundred informal conversations with teachers, and numerous formal interviews with the teachers and their administrators. Through the observations and interviews, Gallagher concluded the teachers had little knowledge of the history of science and NOS, and they often placed a great deal of focus on content and science as a body of knowledge. Gallagher cites a lack of knowledge and training in NOS as contributing to these teachers’ lack of adequate conceptions of NOS. However, it is interesting to note that Gallagher describes two teachers in his study who had received training in NOS but did not always articulate adequate conceptions of NOS.

Pomeroy (1993) surveyed a group of research scientists, secondary science teachers, and elementary teachers about their conceptions of NOS in an effort to determine the extent of any differences between the scientists’ and teachers’ conceptions of NOS. The study involved 71 research scientists and 109 teachers who completed a 50-item Likert scale survey developed by Pomeroy for the study. Pomeroy does not report information regarding the validation of the survey; in fact, she alludes to the need to further develop and refine the survey instrument. Pomeroy reports data analysis and conclusions that are somewhat interesting. One conclusion Pomeroy makes is that the scientists in the study reported more “traditional” views of science than reported by teachers. (This “traditional” view of science reflects Baconian and logicoempiricist beliefs and is inadequate in terms of NOS ideas.) In addition, the secondary teachers reported more “traditional” views of science than the
elementary teachers. As a possible explanation, Pomeroy speculates that the scientists and secondary teachers have had more exposure through their coursework to “traditional” science than the elementary teachers have had. In addition, these scientists and secondary teachers have experienced a “deep initiation into the norms of the scientific community” (p. 269) and may be more trained in the tradition of Kuhn’s (1970) “normal” science. Therefore, the secondary teachers may have adopted more of the “traditional” views of science. To help teachers develop more informed conceptions of NOS, Pomeroy advocates including NOS in science methods courses for preservice teachers.

In contrast, Nott and Wellington (1998) suggest that there may be no relationship between a teachers’ academic history and their understandings of NOS. However, as Nott and Wellington state, “teachers’ views are embedded in their talk about the practice of teaching. Their knowledge of the nature of science is illustrated by discussing and analysing examples from their classroom experience” (p. 581). Therefore, Nott and Wellington conclude that teachers’ conceptions of NOS must come from teachers’ practice of teaching, their classroom experience, and their professional experience. They then suggest that “critical incidents,” similar to the types of events that the teacher might encounter in his or her teaching which would stimulate the development of understanding of NOS, could be used to teach NOS to teachers as a part of professional development programs.

In a study of 166 undergraduate and graduate students and 15 preservice secondary science teachers, Abd-El-Khalick and Lederman (2000b) found that a history of science course did not significantly change participants’ conceptions of NOS. Through qualitative analysis of open-ended questionnaires and follow-up semi-structured interviews, Abd-El-Khalick and Lederman found that most students had inadequate conceptions of NOS both
before and after taking a history of science course. However, participants with more
informed conceptions of NOS prior to the history of science course made more
improvement in their conceptions of NOS than those students with less informed
conceptions of NOS prior to the history of science course. One suggestion made in this study
is that conceptions of NOS be made explicit in a history of science course (or any other
course) if the aim is to increase students’ conceptions of NOS.

One way to do this is to include the history and philosophy of science into science
courses. Monk and Osborne (1997) outline a constructivist rationale for why the history and
philosophy of science should incorporated into science curricula. Frequently textbooks
provide students with a “popular, contemporary, cleaned-up, and prejustified accounts of
behavior of the natural world” (p. 405). Monk and Osborne propose that the history and
philosophy of science be included as a central feature of science education. To do this, they
outline a pedagogic model with the steps of (1) presentation, (2) elicitation, (3) historical
study, (4) devising tests, (5) the scientific idea and empirical tests, and (6) review and
evaluation. However, as Rudge and Howe (2009) explain, the Monk and Osborne model has
problems because it presents an implicit approach to learning about NOS where students
“learn about nature of science issues by reflecting on deeply contextualized examples of
scientific work” (p. 563). Likewise, Abd-El-Khalick and Lederman (2000a) describe this
implicit approach as an approach that “suggests that an understanding of NOS is a learning
outcome that can be facilitated through process skill instruction, science content
coursework, and ‘doing science’. Researchers who adopted this implicit approach utilized
science process skills instruction and/or scientific inquiry activities” (p. 673).
As an alternative to this *implicit* approach, researchers such as Howe and Rudge (2005) promote an approach to science education where it is advantageous for teachers to design lessons in which students *explicitly* and *reflectively* consider how their work with the conceptual material of the lessons more generally connects to an informed understanding of aspects of the NOS” (p. 424). This *explicit* approach utilizes “elements from history and philosophy of science and/or instruction geared towards the various aspects of NOS to improve science teachers’ conceptions” (Abd-El-Khalick & Lederman, 2000a, p. 673).

One example of a study looking at the *implicit versus explicit* approach of teaching and learning NOS is Khishfe and Abd-El-Khalick (2002). Using a six-item open-ended NOS questionnaire in conjunction with individual semistructured interviews, Khishfe and Abd-El-Khalick assessed the NOS views of the 62 sixth-grade participants before and after a two-and-one-half month intervention in their science classrooms. One classroom served as the intervention group, receiving an explicit inquiry-oriented instruction. The other classroom, receiving an implicit inquiry-oriented instruction, served as the comparison group. Prior to the intervention, all 62 participants were administered the NOS questionnaire. Two science education professors and two sixth-grade English teachers reviewed the items on the NOS questionnaire for content validity and readability. The NOS questionnaire was also pilot-tested with 32 students in a nonparticipant sixth-grade section in the participant school, and six of those students participated in interviews regarding items on the NOS questionnaire. In addition, a purposeful sample of eight students from the *explicit* group and eight students from the *implicit* group participated in individual interviews aimed to further validate the NOS questionnaire. The major difference between the *implicit* and *explicit* groups was, as Khishfe and Abd-El-Khalick explain, for the *explicit* group,
A reflective NOS component followed discussions of content and science process skills. At the end of each activity, all or some of the target NOS aspects were highlighted and the explicit group participants were guided to discuss and reflect on these aspects in relation to the activity at hand. (p. 563)

Khishfe and Abd-El-Khalick found that students in the implicit inquiry-oriented instructional group did not substantially improve in their NOS understandings. However, the students in the explicit inquiry-oriented instructional group articulated more informed views on the target NOS aspects following the intervention than did the implicit inquiry-oriented group. Therefore, Khishfe and Abd-El-Khalick advocate that explicit inquiry-oriented instruction be used if students are to develop informed conceptions of NOS.

Howe and Rudge (2005) present another pedagogy that incorporates “techniques that invite students to explicitly and reflectively discuss various NOS issues” (p. 423). In their research, Howe and Rudge present a series of lessons presented to a class of 24 undergraduate students enrolled in a science course for preservice elementary teachers. Through the course of the unit, students find themselves in “an open-ended problem solving environment in which they must propose and defend theories in light of available evidence” regarding a mystery problem taken from the history of research on sickle-cell anemia (p. 425). In addition, the instructors for the course facilitated the sessions using explicit and reflective discussions incorporating the targeted aspects of NOS: nature of scientific theories, tentative NOS, distinction between theories and laws, validity of observations in science, and the subjective (theory-laden) NOS. Howe (2004) conducted a study of the efficacy of the pedagogy involving 81 students enrolled in the course incorporating the aforementioned pedagogy. Using a slightly modified version of the VNOS-C (Lederman, et al., 2002) as a pre- and post-survey along with semi-structured interviews with a subset of
the respondents \((n = 19)\), Howe’s analysis concludes that “episodes from the history of science can be used to help college students achieve improved understandings of several issues of the NOS” (p. 434).

Howe (2009) expands on the idea of using history of science in instruction as a “potential contextual approach for students to explicitly and reflectively learn NOS tenets” (p. 397). To do this, he provides an explanation of a method that classroom teachers can use to episodes from the history of science to assist their students in explicitly and reflectively learning more informed NOS conceptions. This method, illustrated with an example using the work of Henry David Thoreau and introductory concepts of ecological forest succession, involves three phases: (1) identification and research of an episode in the history of science, (2) identifying germane NOS tenets, and (3) designing instruction to have students explicitly and reflectively consider NOS using the historical episode.

**Teachers’ Understandings of NOS and Classroom Practice**

Not only is it important to measure and assess teachers’ conceptions of NOS, but it is also important to see whether teachers’ conceptions of NOS influence their classroom teaching practices. Although previously assumed that there was a relationship between teachers’ conceptions of NOS and their classroom practices, research has shown otherwise (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse, 1990; Lederman, 1992, 1999; Lederman & Druger, 1985; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; and others). As Abd-El-Khalick and Lederman (2000a) summarize, “research on the translation of teachers’ conceptions into classroom practice indicates, and rightly so, that even though teachers’ conceptions of NOS can be thought of as a necessary condition, these conceptions, nevertheless, should not be considered sufficient” (p. 670).
Using a case study methodology, Lederman and Druger (1985) studied 18 high school biology teachers and the students from one of each of those teachers’ classes (a total of 409 students). All the teachers and students completed the Nature of Scientific Knowledge Scale (NSKS) at the beginning of the semester. This NSKS instrument, a 48-item instrument with Likert scale response choices for each item, purports to objectively measure a respondent’s understanding of the nature of scientific knowledge. Lederman and Druger do not report on the contents, validity, or reliability of the NSKS; rather, they refer to an outside source (Rubba & Andersen, 1978). Following the administration of the NSKS, but before the analysis of the results of the survey, three classroom observations were made in each classroom. Twelve weeks following the administration of the NSKS pretest, all the students and teachers completed a NSKS posttest. The difference in the NSKS pretest and posttest scores served as a measure of change in students’ conceptions of NOS.

Lederman and Druger (1985) found teachers’ conceptions of NOS and students’ conceptions of NOS are not significantly related. In addition, the researchers deemed specific teacher behaviors and other classroom variables such as supportive and friendly classroom environment, frequent questions, and higher cognitive level questions are important in the development of students’ conceptions of NOS. Lederman and Druger (1985) suggest that more research to determine possible teaching techniques to encourage the development of students’ conceptions of NOS.

Brickhouse (1990) employed an in-depth, qualitative case study method to examine three teachers’ conceptions of NOS and their relationship to classroom practice. For this, she conducted a case study research project involving three precollege science teachers. The teachers participated in a series of at least 4 hour-long interviews, allowed at least 35
hours of classroom observations over a 4-month period, and provided additional data including textbook and teacher documents regarding discipline, tests, quizzes, worksheets, and laboratory activity sheets. Towards the end of the study, each teacher read and reviewed a case study written by Brickhouse (1990) about them and their classrooms. They commented on and provided feedback regarding these case studies.

The two experienced teachers in the Brickhouse (1990) study had teaching practices that were consistent with their epistemological views of science. In contrast, the novice teacher had teaching practices that were not always consistent with the conceptions of NOS that he articulated. The results suggest a reciprocal relationship between the development of teachers’ conceptions of NOS and classroom practice. That is, if a teacher spends years teaching in a system that emphasizes a “traditional” view of science (one that has an inadequate understanding of NOS), then the teacher’s conceptions of NOS are likely to be more “traditional” and inadequate. Therefore, Brickhouse (1990) suggests changes to the teaching environment such that teachers can practice from and develop adequate conceptions of NOS.

Although it might seem logical that a teachers’ understanding of epistemological ideas such as NOS would influence their classroom practice, Abd-El-Khalick et al. (1998) found that although teachers may have adequate understandings of NOS, they do not communicate these understandings through their teaching. This study focused on preservice teachers’ understandings of NOS and how these understandings influenced their instructional planning and classroom practice. Fourteen preservice science teachers enrolled in a fifth year, master of arts in teaching (MAT) program. This program places explicit emphasis on NOS during science pedagogy and methods courses. In addition, the preservice
teachers learned several aspects of NOS using activities they could employ in their future secondary science classrooms. The study used an open-ended questionnaire to assess conceptions of NOS prior to the preservice teachers’ student teaching experience. During the student teaching experience, Abd-El-Khalick et al. used lesson plan analysis, classroom videotapes, portfolios, supervisors’ weekly clinical observation notes, and semi-structured follow-up interviews on the conceptions of NOS in order to construct an accurate assessment of these preservice teachers’ understandings of NOS and their classroom practice. All three researchers analyzed the interview transcripts to validate participants’ responses to the NOS questionnaire.

Through their analysis, Abd-El-Khalick et al. (1998) found that the preservice teachers possessed understandings of NOS (following a course which explicitly addressed NOS) that were “consistent with contemporary conceptions of the scientific enterprise” (p. 423). That is, the preservice teachers demonstrated adequate understanding of empirical, tentative, subjective and creative, and observation/inference aspects of NOS. They communicated discernable difference between theories and law; however, these were not well-articulated. Furthermore, they failed to explain the role that social and cultural factors play in the construction of scientific knowledge. In addition, although the preservice teachers claimed to teach these understandings of NOS through activities, the preservice teachers made no explicit references to NOS in their curriculum planning or goals.

In a similar study, Lederman (1999) looked at the relationship between understandings of NOS and classroom practice in practicing teachers. In this study, an open-ended questionnaire (explained to be face validated in previous studies), interviews, classroom observations, examinations of instructional plans and materials, and interviews
with students created a rich description of teachers’ understandings of NOS and their teaching practices. The final semi-structured interview reviewed and discussed the responses from the open-ended questionnaire. This was an effort to ensure participants understood the questionnaire items and the researcher correctly interpreted the responses.

After analyzing the data, Lederman (1999) found that although the five teachers in his study had well-developed NOS, NOS was not usually included as an instructional goal for their teaching. In addition, he found that teachers’ intentions, goals, level of experience, and perceptions of students have an impact on classroom practice; however, teachers’ understandings of NOS did not influence their teaching practices. Although several of the teachers acknowledged the importance of NOS for their students, the teachers seemed to believe that simply modeling NOS would be enough to influence and help to shape students’ understandings of NOS. As a result, Lederman (1999) concluded that teachers need to internalize the importance of NOS and make them explicit in their teaching. He used the analogy of breathing to illustrate this need of making ideas explicit. For example, although students experience breathing throughout their lives, the personal experience with breathing does not ensure that students will understanding the physiology of breathing. Likewise, simply because students experience NOS vicariously through their teachers, it does not imply that students will internalize an understanding of NOS for themselves.

Drawing on the importance for teachers to develop conceptions of NOS and make them explicit in teaching, Bell, Lederman, and Abd-El-Khalick (2000) examined preservice teachers who had completed courses with specific objectives related to developing conceptions of NOS and how to explicitly include NOS in classroom instruction. The 13 preservice teachers involved in this study participated in a Master of Arts in Teaching (MAT)
program that had instructional components that encouraged these preservice teachers to include explicit discussions and activities related to NOS in their future classroom instruction.

The teachers completed an open-ended questionnaire regarding their conceptions of NOS and follow-up interviews to these questionnaires. In addition, a variety of other data from the preservice teachers’ internship teaching experiences were collected and analyzed. Bell et al. (2000) found that these preservice teachers had adequate conceptions of NOS for the empirical nature of science, science as tentative, creativity in the process of science, subjectivity of science, the distinction between observation and inference, and the distinction between theories and laws. However, most of the preservice teachers did not express adequate understandings that science is a social and cultural endeavor. Nevertheless, these teachers demonstrated an overall adequacy in their conceptions of NOS.

However, few teachers include NOS in their actual classroom instruction (Bell et al., 2000). Similar to the experienced teachers in the previous study (Lederman, 1999), these preservice teachers demonstrated adequate understandings of NOS and a number mentioned NOS as an important instructional goal; however, these understandings of NOS were not explicitly addressed in classroom instruction or in teacher instructional objectives. Several of these preservice teachers cited pressure to cover content, time constraints, and lack of understanding and ability to teach NOS as reasons for not addressing NOS in their classroom instruction (Bell et al., 2000).

An additional study looking at preservice teachers’ conceptions of NOS and their teaching of NOS examined the effects of several specific interventions in the preservice
teacher-training program (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). These interventions included a separate NOS course, a science research internship, a stronger encouragement for preservice teachers to develop NOS objectives and assessments in unit and daily lesson plans, and instruction on how to teach NOS. Because of these interventions, Lederman, Schwartz, Abd-El-Khalick, and Bell (2001) found that the preservice teachers in this study had increased levels of attention to NOS when planning, implementing, and assessing classroom instruction than preservice teachers in previous studies (Abd-El-Khalick et al., 1998; Bell et al., 2000).

The results also suggest that merely increasing content knowledge, NOS knowledge, or pedagogical knowledge in isolation is not enough; rather, content, NOS, and pedagogical knowledge need to be developed simultaneously and concurrent implementation encouraged (Lederman et al., 2001). In addition, as noted in Bell et al. (2000), changes need to be made to teaching environments so that beginning teachers who have developed conceptions of NOS and teaching pedagogies to incorporate NOS into their classroom practices can continue to do so when they enter a classroom situation not previously influenced by a strong science education program encouraging NOS.

Schwartz and Lederman (2002) examined more closely conceptions and knowledge of NOS and teaching practices through a case study comparison of two secondary science teachers in their learning of NOS and then explicitly addressing NOS in their classrooms. This case study comparison took place within the context of the same fifth-year MAT program as the previous studies described (Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman, 1999; Lederman et al., 2001). This case study comparison emerged out of data and results obtained as a part of an overlapping NOS study (Lederman et al., 2001). The two case
studies chosen were unique because these two secondary science teachers were successful, in varying degrees, at explicitly teaching NOS during both their student teaching and first year of teaching.

A comparative analysis of these two case studies reveal, as Schwartz and Lederman (2002) explain,

The realization of and abilities to teach about the “nature of the beast” [NOS] encompasses more than simply understanding that NOS exists and should be taught. Learning and teaching the “nature of the beast” encompasses knowledge, beliefs, intentions, and pedagogical skills for NOS that enable a teacher to address NOS within his/her everyday science instruction in a manner...that weaves NOS with other science subject matter. (p. 230)

Both subject-matter knowledge and NOS knowledge are necessary if classroom teachers are to be successful at including NOS into their classroom instruction. Furthermore, if teachers are to be successful at teaching NOS in their classrooms, they need to have pedagogical content knowledge (PCK) specific to teaching NOS. This type of PCK exists at the intersection of NOS knowledge, subject matter knowledge, and pedagogical knowledge.

Assessing Understanding of NOS

Researchers have used wide variety of instruments and methods to explore student and teachers’ views of NOS. Examples of instruments used include written tests and questionnaires, interviews, observations, lesson examination, among other techniques (Brickhouse, 1990; Lederman, 1992; Nott & Wellington, 1998). In his review of research on NOS, Lederman (2007) provides a comprehensive list of almost thirty instruments constructed and validated in the past sixty years. According to Lederman, the validity of the majority of these instruments is questionable because their primary focus is on either student ability and skill to engage in the process of science, emphasis on affective domain
(attitude toward science), and/or emphasis on science as an institution rather than the development of scientific knowledge (p. 863). However, Lederman highlights a variety of NOS instruments considered valid and reliable as measures of NOS. Table 1 contains a list of these instruments.

Responding to the desire for educators and researchers to be able to measure and assess learners’ NOS views and recognizing the shortfalls of previous instruments, Lederman and O’Malley (1990) developed and open-ended survey to assess understandings of NOS. There are numerous advantages to using an open-ended survey versus a closed or forced-item (e.g., agree/disagree, multiple-choice, Likert scale) format to assess understandings of NOS (Aikenhead, 1988; Lederman, 1992; Lederman & O’Malley, 1990; Lederman, Wade, & Bell, 1998). This survey, the Views of Nature of Science Questionnaire (VNOS), aimed to better elicit a rich description of learners’ understandings of NOS.

As a part of the development and testing of the VNOS, Lederman et al. (2002) utilized individual semi-structured interviews of participants following the completion of the VNOS questionnaire in order to validate the researchers’ interpretations of the participants’ responses to VNOS items as well as to establish face validity of the VNOS questionnaire items. Lederman et al. describe a comparison of NOS experts and non-experts that helped establish the construct validity of the VNOS. An expert group of nine individuals with doctoral degrees in science education, or history or philosophy of science and a group of nine individuals with doctoral degrees in fields such as American literature, history, and education completed the VNOS questionnaire and a subsequent follow-up interview. An analysis and comparison of the completed questionnaires and interview transcripts of the
<table>
<thead>
<tr>
<th>Date</th>
<th>Instrument</th>
<th>Author(s)</th>
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</thead>
<tbody>
<tr>
<td>1961</td>
<td>Test on Understanding Science (TOUS)</td>
<td>Cooley &amp; Klopfer</td>
</tr>
<tr>
<td>1967</td>
<td>Wisconsin Inventory of Science Processes (WISP)</td>
<td>Scientific Literacy Research</td>
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<td></td>
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<td>Center</td>
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<tr>
<td>1967</td>
<td>Science Process Inventory (SPI)</td>
<td>Welch</td>
</tr>
<tr>
<td>1968</td>
<td>Nature of Science Scale (NOSS)</td>
<td>Kimball</td>
</tr>
<tr>
<td>1975</td>
<td>Nature of Science Test (NOST)</td>
<td>Billeh &amp; Hasan</td>
</tr>
<tr>
<td>1975</td>
<td>Views of Science Test (VOST)</td>
<td>Hillis</td>
</tr>
<tr>
<td>1976</td>
<td>Nature of Scientific Knowledge Scale (NSKS)</td>
<td>Rubba</td>
</tr>
<tr>
<td>1981</td>
<td>Conceptions of Scientific Theories Test (COST)</td>
<td>Cotham &amp; Smith</td>
</tr>
<tr>
<td>1987</td>
<td>Views on Science-Technology-Society (VOSTS)</td>
<td>Aikenhead, Fleming, &amp; Ryan</td>
</tr>
<tr>
<td>1990</td>
<td>Views of Nature of Science A (VNOS-A)</td>
<td>Lederman &amp; O’Malley</td>
</tr>
<tr>
<td>1992</td>
<td>Modified Nature of Scientific Knowledge Scale (M-NSKS)</td>
<td>Meichtry</td>
</tr>
<tr>
<td>1995</td>
<td>Critical Incidents</td>
<td>Nott &amp; Wellington</td>
</tr>
<tr>
<td>2000</td>
<td>Views of Nature of Science C (VNOS-C)</td>
<td>Abd-El-Khalick &amp; Lederman</td>
</tr>
<tr>
<td>2002</td>
<td>Views of Nature of Science D (VNOS-D)</td>
<td>Lederman &amp; Khishfe</td>
</tr>
<tr>
<td>2004</td>
<td>Views of Nature of Science E (VNOS-E)</td>
<td>Lederman &amp; Ko</td>
</tr>
</tbody>
</table>

*Note. NOS instruments generally considered to be valid and reliable (Adapted from Lederman, 2007)*
two groups indicated the understandings of NOS of the expert group rated nearly three
times higher than that of the novice group. Following the development and testing of the
VNOS, the authors emphasize the vital importance of conducting follow-up interviews with
participants who have completed the VNOS to ensure that researchers are properly
interpreting participants’ responses so that the instrument remains a valid tool to use to
assess participants’ understandings of NOS.

Although widely used in science education research, the VNOS is not without
criticism. In his discussion of his Knowledge of the Nature Of Whole Science (KNOWS)
assessment, Allchin (2011) highlights a few of these problems. One problem mentioned is
the consensus list of NOS statements used to develop the VNOS is, as Allchin describes,
“declarative tenets: science is empirical; observations are theory laden; science is affected
by its social and cultural milieu; science is tentative; etc.” (p. 522). However, “NOS
understanding needs to be functional, not declarative” (Allchin, 2011, p. 523).

Furthermore, since a set of declarative statements regarding NOS make up the basis
for the VNOS, they lack context. Allchin (2011) explains,

There are other problems with using general declarative statements as benchmarks. Recently, many critics have noted that standard NOS items suffer from lack of context (Clough & Olson, 2008; Elby & Hammer, 2001; Ford, 2008; Osborne et al., 2003, pp. 712–713; Schwartz, Lederman & Crawford, 2004). That is, no qualifications are mentioned, or acknowledged as relevant in assessing student responses. (p. 528)

Allchin emphasizes this claim for lack of context in the VNOS and support for his KNOWS assessment as he articulates,

For example, VNOS-C asks, “What is an experiment?” In the context of science in personal and social decision making, this question is rather metaphysical and irrelevant. What matters instead is whether the evidence, derived through experiment or observation—or any other means— is
trustworthy. The classic concept of control (parallel observations differing by a single variable), by contrast, is fundamental, whether applied to a laboratory experiment or field study, a natural experiment, or statistical analysis of a large data set. Philosophizing about the abstract nature of experiment can be left to ... well, philosophers. (p. 523)

Likewise, he explains,

Least of all does one need to distinguish between laws and theories (see Wong & Hodson, 2009, pp. 122–123, for how scientists talk). What matters, again, is how (irrespective of labels) one ascertains the degree of confidence in a particular claim. Indeed, the best way to disarm criticism of evolution as “merely a theory” may not be by clarifying the meaning of the term “theory,” but rather by rendering the whole discussion moot by redirecting focus to the robustness of the evidence. (p. 524)

It is important to note that Allchin’s (2011) critique of the VNOS is not itself without problem and critique. Schwartz, Lederman, and Abd-El-Khalick (2011) specifically crafted a response to Allchin’s critique, and they highlight several flaws and areas of concern in Allchin’s critique. For example, Allchin claims that a set of declarative statements lacking context comprise the VNOS. However, as Schwartz et al. (2011) point out, the VNOS items are not simply agree/disagree items. In addition, Allchin provides incomplete examples of VNOS items in his critique. For example, Allchin lists four sample questions from the VNOS as a part of his claim that the VNOS items lack context. However, as Schwartz et al. note, these sample questions are misrepresented. For example, Allchin lists one of the VNOS items as, “After scientists have developed a scientific theory, does the theory ever change?” (p. 527). However, in the VNOS, the question reads,

After scientists have developed a scientific theory (e.g., atomic theory), does the theory ever change? If you believe that scientific theories do not change, explain why. Defend your answer with examples. If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples. (VNOS Questionnaire)
Therefore, in Allchin’s misrepresentation of the question, he misses the context of the question and the request for elaboration and explanation from participants.

Likewise, Allchin cites a VNOS question as reading, “What is an experiment”? (p. 527). This again, is not a complete picture of how the VNOS assesses views of experiments. Rather, the VNOS asks, more completely, “What is an experiment? Does the development of scientific knowledge require experiments? If yes, explain why. Give an example to defend your position. If no, explain why. Give an example to defend your position” (VNOS Questionnaire). In addition, as Schwartz et al. highlight, “the implication for what claims can be made from different investigative designs is critically important. Can a scientist make causal claims from correlational data? Students need to understand the difference” (p. 10).

Furthermore, Schwartz et al. go on to explain,

Allchin fails to include the follow-up question, and he fails to realize that a primary reason the “experiment” question is included has to do with the researcher’s interpretation of responses to other items. The VNOS items are not to be taken in isolation. They do not stand alone, but provide powerful insights into respondents’ conceptions when examined holistically, especially in terms of examining students’ responses across the VNOS items, contexts, and science-based scenarios. (p. 10)

Another area of concern with Allchin’s (2011) of the VNOS that Schwartz et al. (2011) articulate is Allchin’s argument against the importance of understanding the difference between theories and laws. For example, Allchin states,

Indeed, the best way to disarm criticism of evolution as “merely a theory” may not be by clarifying the meaning of the term “theory,” but rather by rendering the whole discussion moot by redirecting focus to the robustness of the evidence. (p. 524)

However, Allchin seems to forget, as Smith (2010) highlights in his review of research in teaching and learning evolution, that the misconception that evolution is “just a theory” has
been a misconception that has greatly affected science teachers and school policy. In fact, research has shown that explicitly teaching the nature of and differences between scientific theory and scientific law and other aspects of NOS can help to dispel misconceptions about evolution (Lombrozo, Thanukos, & Weisberg, 2008; Nehm & Schonfeld, 2007; Scharmann, Smith, James, & Jensen, 2005; and others).

Although a number of other researchers have critiqued the VNOS (Chen, 2006; Liang et al., 2006; Rudge & Howe, 2009; Rudge & Howe, 2011; Southerland, Johnston, Sowell, & Settlage, 2005), regardless of its criticisms, the VNOS, in some form, is currently the most widely used and influential NOS assessment tool (Allchin, 2011). Even in research outlining the development of a more recently developed NOS assessment tool to be used in a cross-cultural setting, the Student Understanding of Science and Scientific Inquiry (SUSSI), the VNOS survey with accompanying interviews is cited and identified as revealing valid and meaningful outcomes in terms of identifying participant views of aspects of NOS (Liang et al., 2006). Therefore, since the goal of this study is to gain a deep and in-depth description of participants’ understandings of various aspects of NOS, it utilized an open-ended survey along with follow-up interviews incorporating a modified form of the VNOS-C, the VNOS Questionnaire. The Methodology section contains more information regarding this instrument and its use.

Recommendations

The literature examined in this chapter highlights the importance of both worldview and conceptions of NOS in science. The discussion included several studies that examined NOS while also examining worldviews. However, one additional study which specifically examined the relationship between conceptions of NOS and worldview should be
mentioned. In a study on conceptions of NOS and worldviews of preservice elementary science teachers in Taiwan, Liu and Lederman (2007) found that an interrelationship between worldviews and conceptions of NOS existed.

Fifty-four preservice elementary teachers enrolled in a teachers’ college in central Taiwan completed two open-ended questionnaires and corresponding interviews in order to collect data regarding their worldviews and conceptions of NOS. Follow-up interviews verified interpretations of the responses and established face validity of the questionnaires. The worldview questionnaire contained five items, three of which were based on an interview protocol in Cobern, Gibson, and Underwood (1999). In order to establish face and content validity, a panel of five experts in the fields of worldview research critically reviewed each of the five worldview questionnaire items. In addition, a pilot test involving 10 elementary teachers indicated the items were “understandable and capable of eliciting a range of views” (p. 1287). The NOS questionnaire contained eight items, seven of which were from the VNOS-C (Lederman, et al., 2002). The additional item specifically addressed characteristics of Chinese culture. According to Liu and Lederman (2007), content validity for this item was established in a previous study.

Although Liu and Lederman (2007) cite literature which suggests teachers with alternative worldviews that may not be compatible with a scientific worldview were more likely to have inadequate conceptions of NOS, she found that participants with more informed conceptions of NOS were more likely to emphasize harmony with Nature (a more traditional Taiwanese worldview). In addition, participants with inadequate conceptions of NOS were more likely to emphasize materialistic views of Nature. Therefore, although Liu
and Lederman found a relationship between worldview and conceptions of NOS, this relationship was neither straightforward nor causal.

While the Liu and Lederman (2007) study seeks to examine a similar question as this study (a possible relationship between conceptions of NOS and worldview), several problems exist with the methodology of the study. One problem lies with Liu and Lederman’s adaptation of the VNOS-C Questionnaire—the Questionnaire contains 10 items; however, Liu and Lederman only include eight items in their instrument, one of which is a completely different question specifically designed to probe for characteristics of Chinese culture in reference to conceptions of NOS. No explanation is offered for why three of the VNOS-C items were omitted and other items were altered from the original VNOS-C.

In addition, Liu and Lederman (2007) claim to elicit information regarding worldview beliefs from their participants using methodology adapted from Cobern et al. (1999). However, the Cobern et al. study only briefly mentions the “guiding questions” that were used as a part of a larger worldview interview protocol. The larger protocol is included in Cobern (2000) and Cobern et al. (1995). Furthermore, the Liu and Lederman study uses a five-item, open-ended questionnaire rather than several semi-structured interviews as suggested by Cobern and Cobern et al. (1995). Therefore, although Liu and Lederman’s version of the worldview instrument was reported to be valid and reliable, it is questionable whether the responses to the five-item questionnaire would adequately capture ideas regarding worldview beliefs and whether this modification of the Cobern instrument is appropriate.

Nevertheless, it appears that worldviews and conceptions of NOS may together have an impact on the teaching and learning of science. However, few studies have explored
the relationship between teachers’ worldviews and conceptions of NOS, and no studies exist that focus on teachers at Christian schools. Therefore if the Christian school science teachers in the study are dedicated to helping their students become scientifically literate and develop understanding of NOS, it is important that these teachers be able to identify their own understandings of NOS. In addition, they need to identify how their worldviews (of particular focus and importance at this Christian school) might influence their understandings of NOS and how they teach NOS to their students.
CHAPTER III

RESEARCH METHODOLOGY

The purpose of this study was to characterize worldview and conceptions of NOS and explore the possible relationship between these two for Christian school science teachers. Various science education studies suggest there is a relationship between worldview and conceptions of NOS and issues in science education (Cobern, 1991b; Liu & Lederman, 2007). Furthermore, if science teachers are expected to teach NOS, then it would be important to ascertain whether their worldview beliefs influence their beliefs about what science is (NOS) (Liu & Lederman, 2007). However, as discussed in Chapter II, previous studies neglected to assess and examine worldview and conceptions of NOS for Christian school science teachers. Therefore, the purpose of this study is to explore worldviews and conceptions of NOS for Christian school science teachers.

As an exploratory study, the main purpose of this study was to explore and describe the worldview and conceptions of NOS held by Christian school science teachers using qualitative research methods. This type of qualitative and descriptive research, as described by Denzin and Lincoln (1998) focused on describing, characterizing, and interpreting any possible relationships between worldview and conceptions of NOS held by these teachers. The study used qualitative methods of data collection and analysis such as the use of open-ended questionnaires and interviews (Creswell, 1998). This study analyzes the qualitative data to identify patterns and themes that addresses the following research questions:
1. What conceptions of nature of science do science teachers at Christian schools hold?

2. What worldview beliefs, specifically two components of worldview, the conceptualizations of Nature and causality, do science teachers at Christian schools hold?

3. Is there a relationship between worldview and conceptions of NOS for science teachers at Christian schools?

**Research Participants**

Eight high school science teachers who teach at a particular Christian school in a metropolitan area in the midwestern United States were identified for participation in the study. This small number of participants was ideal for a study of this nature so that a rich and deep investigation was possible (Denzin & Lincoln, 1998). A purposive sampling technique, as suggested by Miles and Huberman (1994) provided for a more homogeneous population to allow for a better understanding and description of their conceptions of NOS, aspects of their worldview beliefs, and any possible relationship between these.

Therefore, the population size of the participants was kept small (less than 10), all participants taught science, and all participants taught at the same school. This is important to note that this school asks its teachers to prescribe to a particular statement of faith and to reflect that in their teaching. Furthermore, of the eight teachers completing this study, six attended the same college for their undergraduate education. This college is a liberal arts institution rooted in a reformed Christian perspective. In addition, seven of these eight teachers also attend churches whose foundations are in reformed Christian theology.
The intent of this purposive sampling was to recruit teachers who were more likely to share commonalities in worldview beliefs and views of NOS since this would facilitate the determination of any possible relationship between conceptions of NOS and worldview beliefs. If there was a relationship between conceptions of NOS and worldview beliefs, it should be able to be documented in such a homogeneous population.

The school where the participants taught was familiar to the researcher (the same school at which the researcher taught) and allowed the researcher access to its science teachers. All the science teachers at this school received a recruitment letter asking them to participate in the study, and data for the study includes responses from the eight teachers who gave informed consent and completed all surveys, questionnaires, and interviews. The recruitment letter and HSIRB form informed teachers of a small financial honorarium for participating in the study to thank them for their time and expertise. In addition, the recruitment letter and HSIRB form informed teachers that participation in the study might allow them to reflect upon aspects of their worldview, their understanding of NOS issues, and their classroom teaching practices.

Each teacher participant in the study received a pseudonym for use with data analysis and reporting. Teachers who agreed to participate in the study read and signed consent forms to indicate their agreement to include their responses as a part of the research study results. Appendix I contains a copy of this consent form.

The researcher obtained names and addresses of science teachers at this Christian school from the main office of the school. To recruit participants for the study, the researcher sent a letter explaining the study to the school principal and curriculum coordinator, and the researcher distributed the recruitment letters to the individual science
Appendix I contains copies of this cover letter and recruitment letter. A discussion of the ethical issues associated with this type of recruitment strategy is in the Limitations section of Chapter V.

Data Collection Procedures

This study incorporates a variety of methods from several methodologies of qualitative and quantitative research. Since the study examines and analyzes the attitudes and perceptions that high school science teachers have regarding worldviews and conceptions of NOS, the methods reflect the nature of the goals of the study. Included in the data collection techniques are several questionnaires and a number of interviews and follow-up interviews. Figure 4 shows a visual representation of the interview process for the study.

Questionnaires

Demographic Questionnaire

Along with the recruitment letter, participants received a copy of a short questionnaire regarding demographic information such as age, gender, subject taught, and years of teaching experience. Prior to participating in interviews regarding worldview and conceptions of NOS ideas, teachers participating in the study filled out this questionnaire and returned it along with a signed copy of the consent form. Appendix A contains a copy of this demographic questionnaire.

Religious Beliefs Survey

In addition to the consent form and demographic questionnaire, participants also received a copy of the Religious Beliefs Survey to complete and return (Appendix B). The intention of this survey was to examine the actual religious beliefs of the participants in the
Although the participants teach at a Christian school, it was helpful to obtain a simple measure of their religious beliefs in order to classify them as either holding or not holding orthodox Christian beliefs. Earlier studies on conceptions of NOS did not include a measurement of participants’ religious beliefs. Therefore, although the results from the Religious Beliefs Survey will not necessarily allow results to be generalized to the broader...
population, it helped to more clearly define the participant population and identify another possible influencing factor on these teachers’ worldview and conceptions of NOS.

This Religious Beliefs Survey is adapted from The Christian Orthodoxy Scale developed by Fullerton and Hunsberger (1989). This scale was developed and used to determine the degree to which participants accept beliefs central to Christianity. Although different Christian groups have varied views on particular aspects of beliefs, as Hill and Hood (1999) explain, the statements on this scale assess “bedrock” statements that define Christian faith. Fullerton and Hunsberger report a Cronbach’s alpha of 0.98 with mean interitem correlations between 0.57 and 0.70. Factor analysis revealed one factor accounted for a large portion of the test variance (58%-74%). Based on eight different studies conducted including samples of high school students, university students, and adults, Fullerton and Hunsberger concluded the scale was unidimensional, reliable, and valid. Participants examined the list of items in the belief scale and indicated their level of agreement on a seven point Likert scale of -3 to 3 with -3 = strongly disagree, 0 = exactly and precisely neutral, and 3 = strongly agree. Appendix B contains a copy of the Religious Beliefs Survey as presented to participants.

Two versions of the Christian Orthodoxy Scale (Hill & Hood, 1999) exist: a long version and a short version. The short version of the Christian Orthodoxy Scale (Hunsberger, 1989) maintains the high interitem consistency of the longer version with mean interitem correlations between 0.69 and 0.78. Altenmeyer and Hunsberger (1992) documented the validity and reliability of this short version. Although participants completed the longer version when completing the Religious Beliefs Survey, analysis involved only responses to the questions included in the short version. This is because the purpose of this Religious
Beliefs Survey was to establish a commonality of Christian beliefs among participants, not to
describe their religious beliefs. Table 2 contains the items from the Religious Beliefs Survey
that composed the short version of the Christian Orthodoxy Scale and thus were analyzed.

Table 2

<table>
<thead>
<tr>
<th>Item #</th>
<th>Statement</th>
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<tbody>
<tr>
<td>3</td>
<td>Jesus Christ was the divine Son of God.</td>
</tr>
<tr>
<td>4</td>
<td>The Bible is the word of God given to guide man to grace and salvation.</td>
</tr>
<tr>
<td>9</td>
<td>The concept of God is an old superstition that is no longer needed to explain things in the modern era.</td>
</tr>
<tr>
<td>15</td>
<td>Through the life, death, and resurrection of Jesus, God provided a way for the forgiveness of man’s sins.</td>
</tr>
<tr>
<td>16</td>
<td>Despite what many people believe, there is no such things as a God who is aware of Man’s actions.</td>
</tr>
<tr>
<td>17</td>
<td>Jesus was crucified, died, and was buried but on the third day He arose from the dead.</td>
</tr>
</tbody>
</table>

*Note.* These items comprise the short version of the Christian Orthodoxy Scale (Hunsberger, 1989).

*Views of Nature of Science Questionnaire*

Upon return of the completed consent form, demographic questionnaire, and the
*Religious Beliefs Survey*, participants received a copy of a questionnaire regarding their
conceptions of NOS to complete and return. This questionnaire was the *Views of Nature of
Science Questionnaire* (VNOS Questionnaire) which was a modification of the VNOS-C
(Lederman et al., 2002). The VNOS-C ascertains teachers’ conceptions of NOS: tentative
(subject to change); subjective (theory-laden); empirically based (based on and/or derived
from observations of the natural world); the product of human imagination and creativity; socially and culturally embedded; the functions of and relationships between scientific theories and laws; the distinction between observation and inference; and lack of a universal recipe-like method for doing science; (Lederman, 1999; Lederman et al., 2002).

Several prior studies have used the VNOS-C to articulate teachers’ conceptions of NOS (Abd-El-Khalick & Lederman, 2000b; Lederman et al., 2001; Schwartz, Lederman, & Crawford, 2004).

Lederman et al. (2002) report that an expert panel (including three science educators, a historian of science, and a scientist) examined the ten items on the VNOS-C and concluded the instrument contained both face and content validity. Construct validity was inferred based on the construct validity previously established for the VNOS-B (earlier VNOS Questionnaire from which the VNOS-C was derived). Eighteen individuals with doctoral degrees completed the questionnaire in order to establish construct validity for the VNOS-B. Of the eighteen individuals, nine held degrees in science education or history or philosophy of science such that they would be expected to have informed view of NOS, and nine held degrees outside of science such that they would be expected to be less likely to have spent time thinking about conceptions of NOS. In addition, a systematic contrast and comparison of the participant’s NOS profiles generated from separate analyses of the questionnaires and follow-up interview transcripts indicated that the participants’ responses to the questionnaire items were congruent to those expressed in participant follow-up interviews (Lederman et al., 2002).

It is important to note that it is problematic that establishing the face and content validity of the VNOS-C included just three science educators, one historian of science, and
one scientist. Of concern is that no experts in the philosophy of science assisted with assessing the face and content validity of the VNOS-C. In addition, no scientists were included in the group of individuals used to validate the VNOS-B (the basis for the VNOS-C). However, Schwartz and Lederman (2008) found that scientists have varied conceptions of NOS. Therefore, scientists’ conceptions of NOS are troublesome to use to validate a VNOS instrument. Regardless of the possible problematic issues regarding validation, the VNOS-C is the most frequently used instrument to elicit conceptions of NOS.

This study used a modified version of the VNOS-C, the VNOS Questionnaire. This modified version contained twelve questions: one question modified from the VNOS-C, eight questions directly from the VNOS-C, and three additional questions. One question from the original VNOS-C is absent in the VNOS Questionnaire.

One of the questions in the VNOS Questionnaire used in this study is a modification of one of the VNOS-C questions (VNOS Questionnaire #8 is a modification of VNOS-C #6).

VNOS-C #6 reads as follows:

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 the 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?

VNOS Questionnaire #8 (the modified question) reads as follows:

There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen “dark matter,” the center of the earth, or into the nucleus of an atom. Yet we have ideas and even representations of such phenomena (such as diagrams of atoms in science textbooks).

a. If scientists have never seen these things (such as details of the inside of an atom), what kind of information is this knowledge based on? [i.e. How do they know what they know about these things?]
b. How certain do you think scientists are about the structure of the atom?
c. Do you think explanations or descriptions of things scientists have not seen are scientific? Why or why not?
d. Should we, as a public, accept this type of knowledge? Why or why not?

Schwartz (2007) used this modification in the VNOS/VOSI-270 questionnaire employed in her study regarding embedding NOS in a biology course. The modified version of the question allows more opportunity to elicit information regarding participants’ conceptions of various aspects of NOS. Therefore, this study included this modification in the VNOS questionnaire participants completed (VNOS Questionnaire).

In addition, the VNOS Questionnaire contains three additional questions to the VNOS-C: VNOS Questionnaire #4, #6, and #12. The goal of including these additional questions was to provide further opportunities for participants to articulate their understandings of various aspects of NOS. One of the additional questions is VNOS Questionnaire #4:

The “scientific method” is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

- _____ YES, scientists must follow the scientific method
- _____ NO, there are many scientific methods

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
- If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

The VOSI uses this question (Schwartz, Lederman, & Lederman, 2008). It is a direct question probing the participant’s views of the “scientific method.”

Another additional question is VNOS Questionnaire #6: “Do you see a role for hypotheses in developing theories and laws? If so, what is that role? If not, why?” This question is adapted from a reflective journal prompt used by Schwartz et al. (2004) in their
study of developments in NOS conceptions during a science research internship course for preservice secondary science teachers. Responses to this question might reveal aspects of a participant’s understanding of the subjective aspect of NOS, the theories and laws aspect of NOS, and/or the scientific method aspect of NOS.

The last additional question is VNOS Questionnaire #12: “How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others of their claim?” Schwartz (2004, 2007) uses this question as part of the VOSI instrument. As Schwartz, Lederman, and Lederman (2008) explain,

This question targets views of justification. Responses often make reference to purpose of science, evidence, and the role of scientific community...Typical responses indicating more naive views suggest that with sufficient data, scientists show they have the right answer. They also suggest that the scientific method is necessary. (p. 16)

One question from the VNOS-C is absent in the VNOS Questionnaire. This VNOS-C question states,

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? (Lederman et al., 2002, p. 509)

This question is very content specific to the field of biology. However, not all participants in this study have expertise in biology. Therefore, the VNOS Questionnaire did not contain this question.

Each item of the questionnaire was on a separate page as to allow participants enough room to include their written responses. Participants also received postage-paid envelopes in which to return the completed questionnaires. However, a number of
participants opted to deliver their completed questionnaires personally to the researcher.

One of the participants, Carl used a word processing program to complete the VNOS Questionnaire, and he returned a digital copy of his completed questionnaire. A copy of this questionnaire is included in Appendix C.

**Test of Preferred Explanations**

This survey instrument elicits aspects of the participants’ worldviews particularly related to the participants’ understanding of Causality. The items included in this survey instrument are adapted from the Test of Preferred Explanations (TOPE). The basis for the TOPE is the “assumption that when a student is faced with an unfamiliar phenomenon, he or she is more likely to accept an explanation that is more consistent with his or her worldview than an explanation of the phenomenon that is less consistent” (Cobern, 1997, ¶1). The TOPE is comprised of fictional episodes followed by two explanations, one more scientifically compatible than the other, from which participants need to pick the one they feel is most acceptable. In a study describing the development and validation (construct and content) of the TOPE (Cobern, 1997), 120 first year college students and group of professional scientists completed the TOPE. The college students also completed a measure of science interest. An analysis of the results of the TOPE and measure of science interest indicated there was worldview variation in regards to causality among the college students. Those college students who favored the more scientifically compatible explanations indicated a higher level of science interest. However, even those students with a higher level of science interest were less likely to choose the more scientifically compatible explanation than were the professional scientists.
In a study involving 250 science teachers from Botswana, Indonesia, Japan, Nigeria, and the Philippines, Oggunniyi et al. (1995), used a variation of the TOPE to identify the nature of worldviews among this group of science teachers from nonwestern countries. This study found that the teachers’ responses reflected a variety of alternative worldview presuppositions in the following categories: magical, mystical, spiritism, parapsychology, rational, metaphysical, pseudoscience, and science. In addition, the TOPE successfully elicited views of causality in studies involving students, teachers, and scientists (Cobern, 1997; Cobern et al., 1995; Liu, 2003).

The following assumption, articulated by Cobern et al. (1995), is essential to this TOPE instrument, “when a student is faced with an unfamiliar phenomenon, he or she is more likely to accept an explanation that is more consistent with his or her worldview than an explanation of the phenomenon that is less consistent” (p. 29). This assumption appears logical since it likely to be more comfortable for a person to choose an explanation for a phenomenon that fits into or is already a part of his or her conceptual framework for how things work. Therefore, the participants supposedly chose explanations that were amenable to their worldviews. A copy of the TOPE is included in Appendix F.

**Interviews**

This study involved interviews conducted in two rounds. The first round of interviews included interviews regarding worldview aspects of the conceptions of nature. All the interviews were recorded and transcribed for later analysis (see Data Analysis section for more information regarding the analysis process). This analysis created a set of assertions regarding worldview and conceptions of NOS. Following the analysis, the teachers participated in a second round of interviews. These interviews included several facets
including clarification of the intended meaning of previous interview responses and questions that asked participants to confirm, deny, or modify assertions made during the first tier questionnaire and interview analysis.

Although there was a prepared structured set of questions for the various interviews as Fontana and Frey (2000) and Creswell (1998) suggest, as the interview progressed, teachers and the researcher explored lines of thoughts and questioning that arose. As Creswell suggests, careful design of the logistics of the interviews occurred before the interviews began. As the interviews were conducted, they were audiotaped for transcription and analysis. In addition, the interviews were conducted in a location of the teachers’ choosing (i.e., in their classrooms, in the staff lounge, at their home). Furthermore, before the interviews began, the researcher reminded each participant of the informed consent document he or she signed. This reminder referenced the participant’s right to discontinue the interview at any time, how his or her participation in the interview will in no way affect his or her employment status, and about the possibility his or her responses will be included in a research report in a confidential fashion using pseudonyms. A copy of the consent letter is included in Appendix I.

**Round One Interviews: NOS and Worldview—Nature**

**NOS Interview.** Following the completion of the demographic questionnaire, Religious Beliefs Survey, and VNOS Questionnaire, the interview stage of the study began. The initial interviews conducted during the first round of interviews were the NOS Follow-Up Interviews. Although there were two different interviews conducted during this first round of interviews (NOS and Worldview—Nature), the NOS interviews were conducted first since participants had already completed the VNOS Questionnaire. The hope was that
participants would be better able to remember the reasoning to their responses, elaborate on, and explain them at this interview. As Lederman et al. (2002) and Schwartz and Lederman (2005, 2008) suggest, it is extremely important that the administration of the VNOS Questionnaire be coupled with follow-up interviews to not only validate participants’ responses to questionnaire items but also to elicit additional information from participants regarding their conceptions of NOS.

For these interviews, prompts included the same questions participants answered as a part of the VNOS Questionnaire. This repetition of questions allowed participants to expand on their original responses to the VNOS Questionnaire (their original responses were made available to them), to clarify aspects of their original responses, or, in some instances, to significantly change their original VNOS responses. These NOS Follow-Up Interview questions included questions developed by Abd-El-Khalick et al. (1998) specifically for NOS follow-up interview protocol to probe participants’ conceptions of NOS. These questions guided the interview, several questions employed by Schwartz (2007) from the VNOS and Views of Scientific Inquiry (VOSI) surveys (Lederman et al., 2002; Schwartz et al., 2008), and questions emerging from various themes identified during the initial analysis of the VNOS Questionnaires guided the interviews. Most of the questioning focused on allowing participants to clarify any discrepancies and expand upon the answers they provided when completing the questionnaire on their own. Furthermore, participants added additional information to their answers. Appendix D contains a copy of interview protocol that guided these follow-up interviews.

The following paragraphs identify the questions included in NOS Follow-Up Interview protocol that were not a part of the VNOS Questionnaire participants completed.
The sources of the additional questions are identified along with a rationale for the inclusion of the question in the NOS Follow-Up Interview. The first NOS Follow-Up Interview item not included in VNOS Questionnaire is the opening question of the interview. This question, from Abd-El-Khalick and Lederman (1998) states, “What do you think are the most important things to emphasize in your teaching?” This question sets stage for the interview and allows teachers to start to think about their own teaching. It helps to frame the interview and hopefully allows teachers to begin thinking about teaching and learning as they begin the interview.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #5 (as found in Appendix D). This question, from Schwartz (2007) reads:

A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

a. Do you consider this person’s investigation to be an experiment? Please explain why or why not.

b. Do you consider this person’s investigation to be scientific? Please explain why or why not by describing what it means to do something “scientifically.”

This question probes into participants understanding and definition of an experiment. Several questions in the VNOS Questionnaire and NOS Follow-Up Interview ask about experiments and observations. Therefore, responses to this question may further help define a participants’ understanding of both experiment and observation. Furthermore, the second part of the question which probes as to the qualifications for something to be “scientific” might elicit information related to a participants’ notion of scientific method.
The next NOS Follow-Up Interview items not included in VNOS Questionnaire are questions #8 and #11 (as found in Appendix D). These questions, generated by the researcher for this study, ask, “How does a scientific theory develop/come to be? When can theories change?” and “How do scientific laws develop? How do scientific theories develop?” These questions followed similar questions from the VNOS-C regarding theories and laws. Responses to these questions helped to further define a participants’ understanding of the nature of theories and laws and the similarities and differences between the two.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #13 (as found in Appendix D). This question, also generated by the researcher for this study, asks, “What is ‘indirect evidence’?” Six of eight participants mentioned indirect evidence in their responses to the VNOS question regarding the specific evidence they thought scientists used to determine what an atom looked like (VNOS Questionnaire #8). This question from the VNOS would be expected to elicit information regarding the differences between observation and inferences. Therefore, this question asked participants to further define and expand on their understanding and meaning of the phrase indirect evidence. If needed, more probing questions were asked of participants to define and distinguish any difference between inference and indirect evidence.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #14 (as found in Appendix D). This question, from Schwartz (2007), states, “In science, do you think there is a difference between data and evidence? Explain your answer.” This question asks participants to define and differentiate between data and evidence. Data are observations, and evidence is the interpretation of data. Some of the
other VNOS Questionnaire and NOS Follow-Up Interview questions ask participants about data. Therefore, the response to this question might shed light on those other responses.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #15 (as found in Appendix D). This question, adapted from a question from the VNOS-D found in Lederman (2008), states,

We often hear that scientists have learned something more about dinosaurs, but we don’t have any dinosaurs alive today. Scientists have never actually seen a live dinosaur.
- How do scientists know that dinosaurs really existed?
- How certain are scientists about the way dinosaurs looked?
- How certain are scientists about the way dinosaurs moved?
- What kind of information do you think scientists use to figure out how dinosaurs looked and moved? Do they use the same kind of information or different? Why?

This series of questions probes into the participants’ understandings of NOS related to the empirical basis of scientific knowledge and the observation and inference aspect of NOS.

Participants with informed views would integrate their understanding of the empirical NOS with observations of physical evidence of dinosaurs with the observation and inference aspect of NOS of how scientists interpret and apply those observations.

The next NOS Follow-Up Interview items not included in VNOS Questionnaire are questions #17 and #18 (as found in Appendix D). These questions state,

If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions? Explain why or why not.
If several scientists, working separately, ask the same question and follow different procedures to collect data, do you think they will come to the same conclusions? Explain why or why not.

These question probes into the participants’ understanding of NOS related to the subjectivity of science. Participants with an informed view of the subjective NOS would be
expected to respond such that scientists could come to the same conclusions or different conclusions since data is interpreted in order to reach conclusions. In addition, this question might also probe into the scientific method aspect of NOS since participants’ responses may stress that the procedure, the scientific method, is the key. For example, participant responses to the question indicating different procedures were used to collect data could indicate that there was something wrong with the procedure such that the scientists did not follow the correct method.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #21 (as found in Appendix D). This question, generated by the researcher for this study, states, “Are creativity and imagination ever used in experimenting, data collection, and data analysis? Is it ever appropriate?” All eight participants stated that creativity and imagination are used in experimenting, data collection, and data analysis (VNOS Questionnaire #11). However, many participants simply explained how creativity and imagination could be used in experimental design and did not comment on whether or not they felt that creativity and imagination could be used in other aspects indicated in the question such as data collection or data analysis. Therefore, this question asked participants to further define and expand on their understanding of how creativity and imagination could be used and if that use was or was not appropriate.

The next NOS Follow-Up Interview item not included in VNOS Questionnaire is question #23 (as found in Appendix D). This question, an adaptation of a question from the VNOS-D found in Lederman (2008), states

You learn and teach science and about science in school and in everyday life outside of school. That information (scientific knowledge) comes from scientists. Do you think the scientific knowledge we have today (such as that
in a textbook) may change in the future? Explain why or why not and give an example if you can.

This question probes into the participants’ understanding of the tentative and subjective aspect of NOS. An informed response would integrate understanding of how new observations and reinterpretations of observations continually provide for the tentativeness of scientific knowledge. In addition, the reinterpretation of data through the filters of changing theories also provide for the subjective NOS.

The next NOS Follow-Up Interview items not included in VNOS Questionnaire are questions #24 and #25 (as found in Appendix D). These questions, from Abd-El-Khalick and Lederman (1998), state,

Do you think that teaching the Nature of Science ideas is important? Why? (Or why not?)
Do you teach Nature of Science ideas? If yes, how? Why do you teach Nature of Science ideas in that particular way? (If not, why?)

These questions help to wrap-up the interview and provided an opportunity for participants to add any additional thoughts or ideas to their previous responses.

The final NOS Follow-Up Interview item not included in VNOS Questionnaire is question #26 (as found in Appendix D). This question, generated by the researcher for this study, states, “Do you think there are special implications for Christian school teachers in their teaching of Nature of Science ideas?” This question specifically related to the research questions for this project. One of the research questions was what conceptions of NOS do these science teachers at a Christian school hold? In addition, they study investigated the possible relationships between worldview and NOS for these teachers. Therefore, this question allowed the participants to reflect on whether or not they thought there were special NOS implications specific for a Christian school teacher. As mentioned earlier,
Appendix D contains a copy of interview protocol that guided these NOS Follow-Up Interviews.

**Worldview—Nature Interview.** Approximately two weeks following the NOS Follow-Up Interviews, participants completed the interview regarding worldview conceptions of nature and the natural world, the Worldview—Nature Interview. The interview protocol used was the one employed by Cobern (1997, 2000a), Cobern et al. (1995, 1997), and Cobern & Loving (2000) to obtain an understanding of teachers’ worldview conceptions of the Non-Self/Nature aspects of Kearney’s (1984) worldview model. A description of the interview protocol is included in the following paragraphs. The interview protocol is included in Appendix E.

The Worldview—Nature Interview elicits aspects of the participants’ worldviews particularly related to the participants’ understanding of Nature, a sub-category of Kearney’s (1984) non-self category of the logico-structural model of worldview. For each participant, this interview began, as Cobern et al. (1995) suggest, with a focusing event structured by participants viewing a set of photographs depicting nature at micro and macroscopic levels. The key question of the interview emerges shortly thereafter: “How would you define Nature or the Natural world?” Following this key question, participants completed Task One, a word sorting task. The participants received a stack of 3x5 cards with thirty-three different words printed on these cards. The words for Task One and the phrases for Task Two were picked and, as Cobern (1991a) explains,

> The elicitation devices were structurally informed in that they were based on the view that conceptualizations of nature are rooted in the worldview category NonSelf, and that in western culture there are a limited number of ways in which nature is conceptualized. (p. 14)
In addition, these words fall into categories of epistemological, ontological, emotional, and status. However, the interview or in the interview analysis do not mention these categories. Rather, as Cobern et al. (1995) explain, the categories simply help ensure a wide variety of words. The words and their descriptive categorizations are in Table 3.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task One Terms</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Epistemological Description: (Reference to knowing about the natural world.)</th>
<th>confusing</th>
<th>orderly</th>
<th>mysterious</th>
<th>understandable</th>
<th>predictable</th>
<th>changeable</th>
<th>unpredictable</th>
<th>unchangeable</th>
<th>knowable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontological Description: (Reference to what the Natural world is like.)</td>
<td>material</td>
<td>matter</td>
<td>living</td>
<td>complex</td>
<td>beautiful</td>
<td>dangerous</td>
<td>chaotic</td>
<td>diverse</td>
<td>powerful</td>
</tr>
<tr>
<td>Emotional Description: (Reference to how one feels about the natural world.)</td>
<td>peaceful</td>
<td>frightening</td>
<td>exciting</td>
<td>“just there”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Status Description: (Reference to what the Natural world is like now.)</td>
<td>“full of resources”</td>
<td>endangered</td>
<td>exploited</td>
<td>polluted</td>
<td>doomed</td>
<td>restorable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Terms adapted from Cobern et al. (1995).*

The participants sorted the cards into piles of “Nature is” and “Nature is not” and explained their choices of categorization. To assist them with this sorting task, participants laid six cards numbered one through six across the top of the table. An additional card labeled “Nature Is...” was placed above the card labeled “1,” and an additional card labeled “Nature is Not...” was placed above the card labeled “6.” Participants sorted the Task One words into piles according to how much they felt the term reflected what “nature is” or
“nature is not.” The following questions, provided by Cobern (2000a) served as the tacit guide to questioning throughout the interviews:

1. Can one know things about Nature?
2. If so, what sorts of things can one know about Nature and how do these things become known?
3. Who finds out these things that can be known about Nature?
4. Why do they (or anyone) seek to know such things about Nature?

Although there is no set of specific questions for this interview, these questions served as a guide during the interviews.

After sorting the Task One terms into piles according to how strongly they felt the term reflected what “nature is” or “nature is not,” participants reviewed their cards and explained various groups and relationships they saw with various cards. Finally, participants created one pile of cards. This pile had cards ranked such that the top card was the card they felt most strongly that “Nature is” and the bottom card they felt most strongly that “nature is not.” During the earlier sorting task and this ranking task, participants were asked to “think aloud” so that the researcher could capture a glimpse and record what types of thoughts and thought processes these participants were undergoing during this process.

Following the completion of Task One, participants continued with the discussion on nature using a variety of statements relating to nature instead of single words as in Task One. These statements are somewhat redundant with the terms of Task One. However, as Cobern (2000a) explains,

> The sentences are more suggestive than the words in Task One...the sentences of Task Two give the informant the opportunity to bring more focus to issues concerning epistemology, ontology, emotion vis-à-vis
Nature, and perceptions of the status of Nature. An informant can further develop ideas because there is sustained engagement with the topics. The statement devise also provides specific prompts in some areas. This is done because some concepts cannot always be adequately represented by single words. (p. 23)

The statements used in Task Two are in Table 4. Participants completed a similar sorting and ranking activity for the statements in Task Two as they did for the terms in Task One. Again, throughout the interview, participants were encouraged to use a think aloud procedure to explain their justification for sorting and ranking statements. Following the completion of all sorting and ranking tasks, participants responded again to a key question: “what is nature and the natural world?” Basic interview protocols for these interviews are included in Appendix E.

**Round Two Interviews: Assertions Regarding NOS and Worldview**

Following the analysis of the VNOS Questionnaire responses, TOPE responses, NOS Follow-Up Interview, and Worldview—Nature Interview, each participant participated in a final follow-up interview. (See Data Analysis section for a description of the analysis procedures for the first round of interviews.) During these interviews, participants reviewed the personal interpretive narrative constructed from their responses to the VNOS Questionnaire, TOPE, NOS Follow-Up Interview, and Worldview—Nature Interview. Participants provided clarification and elaboration regarding their conceptions of NOS and worldview beliefs regarding nature and causality.

**Data Analysis**

Analysis of the data collected as a part of this study incorporated a variety of techniques in order to look for trends, patterns, significance, and correlations in the data.
<table>
<thead>
<tr>
<th>Epistemological Description: (Reference to knowing about the natural world.)</th>
<th>(a) Knowable:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nature is something that should be studied so that we can learn more about it.</td>
<td></td>
</tr>
<tr>
<td>2. It is important to understand how things work in Nature.</td>
<td></td>
</tr>
<tr>
<td>(b) Unknowable:</td>
<td></td>
</tr>
<tr>
<td>3. Nature is difficult to understand.</td>
<td></td>
</tr>
<tr>
<td>4. To me Nature is mysterious.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Ontological Description: (Reference to what the Natural world is like.)</th>
<th>(a) Supernaturalistic:</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. I see in Nature the work of God.</td>
<td></td>
</tr>
<tr>
<td>7. Nature is the result of purpose, and things happen in Nature because of purpose.</td>
<td></td>
</tr>
<tr>
<td>(b) Naturalistic:</td>
<td></td>
</tr>
<tr>
<td>8. I view Nature as something solid, substantial and reliable.</td>
<td></td>
</tr>
<tr>
<td>9. Nature is the material, concrete world around us.</td>
<td></td>
</tr>
<tr>
<td>10. The Natural world is all there is, all there ever was, all there ever will be.</td>
<td></td>
</tr>
<tr>
<td>11. The material world of Nature is the only real world there is.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emotional Description: (Reference to how one feels about the natural world.)</th>
<th>(a) Positive:</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. I see beauty in Nature.</td>
<td></td>
</tr>
<tr>
<td>13. I have a pleasant emotional response to Nature.</td>
<td></td>
</tr>
<tr>
<td>(b) Neutral:</td>
<td></td>
</tr>
<tr>
<td>14. Nature is an everyday part of life that I generally do not think much about.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status Description: (Reference to what the Natural world is like now.)</th>
<th>(a) Resource Orientation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. Nature is a very important resource: water, energy, food, materials for making things.</td>
<td></td>
</tr>
<tr>
<td>16. Without the things that we get from Nature, we could not enjoy the lifestyle we have today.</td>
<td></td>
</tr>
<tr>
<td>(b) Conservationist Orientation:</td>
<td></td>
</tr>
<tr>
<td>17. I believe Nature needs to be protected.</td>
<td></td>
</tr>
<tr>
<td>18. I am concerned about pollution and the damage it does to Nature.</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Statements adapted from Cobern et al. (1995)
The data analysis process included the formation of assertions and evaluation of these assertions throughout the analysis process as suggested by Cobern et al. (1995). Since data collection occurred in several stages, the data analysis also occurred at several different stages. The small sample size and qualitative and exploratory nature of the study all but eliminated the use of statistical analysis.

Several of the data collected were appropriate for quantitative analysis procedures. For example, simple quantitative analysis procedures such as frequency counts, simple means, and standard deviations could analyze the participant responses to the demographic information questionnaire and the Religious Beliefs Survey. However, because of the small number of participants in the study, the quantitative analysis did not yield the most insightful information. Therefore, the analysis was extensively qualitative.

The qualitative analysis process occurred throughout the study; however, two separate points in the study required more focused analysis. The first stage of analysis followed the first round of questionnaires (Religious Beliefs Survey, VNOS Questionnaire, and TOPE) and interviews—NOS interviews and worldview interviews on conceptualizations of nature. After completing the first stage of data analysis, protocols for the second round of interviews developed. These protocols, individualized for each participant, drew upon the assertions made from the first stage of data analysis. Following this second round of interviews, the researcher again used qualitative data analysis procedures with data. The following sections explain the process of the data analysis in more detail.

**Transcription and Coding**

Before any analysis occurred, the researched transcribed all the questionnaire and interview data. Dragon NaturallySpeaking speech recognition software assisted the
interview transcription. This first stage of the data analysis also involved the organization of the data. As Glanz (1998) suggests, this included a gathering and review of all data collected as a part of the project. The researcher noted items and themes that appear to be significant or unusual. Becoming familiar with the data in order to identify major themes and sub-themes was the main goal in this stage of data analysis.

For the analysis of the worldview interviews, as Cobern et al. (1995) suggest, the researcher assigned code words to chunks of information in the transcript. Some of these code words for the worldview interviews were Task One prompt words and others from the transcripts themselves. Various coding categories for this study were developed and applied in this stage of data analysis. Table 5 contains a portion of the coding scheme used in analyzing the Worldview—Nature Interviews. Due to the personal and individual attributes of a person’s conceptions of nature, these codes were flexible, developed, and changed according to the responses provided by the participants in this study.

*Visual Maps and Analysis Tables*

The second main category of data analysis Glanz (1998) suggests is generating categories, themes, and patterns. After completing transcription and coding of the questionnaire and interview responses, the researcher used these coded responses to create various visual maps and analysis tables. The coded worldview interview data was loaded into a computer program, The Ethnograph, that organized the data by code words to further analyze the data and assist in developing theoretical connections between the coded concepts as Berg (2004) suggests. As Cobern et al. (1995) explain, The Ethnograph can be used to provide a “computer printout for text associated with each code...lists codes in which the searched for code/text is embedded and codes embedded within the searched for
The sections of text and associated codes were used to construct visual maps that represent the participants’ conceptualizations of worldview aspects of nature. These visual maps are in Appendix H.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Sample Code Words for Worldview—Nature Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowable</td>
<td>Confusing</td>
</tr>
<tr>
<td></td>
<td>Explainable</td>
</tr>
<tr>
<td></td>
<td>Knowable</td>
</tr>
<tr>
<td></td>
<td>Learn</td>
</tr>
<tr>
<td></td>
<td>Mysterious</td>
</tr>
<tr>
<td></td>
<td>Predict</td>
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<td></td>
<td>Study</td>
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<tr>
<td></td>
<td>Understand</td>
</tr>
<tr>
<td></td>
<td>Unexplainable</td>
</tr>
<tr>
<td></td>
<td>Unpredictable</td>
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<tr>
<td>Material</td>
<td>Material</td>
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<tr>
<td></td>
<td>Resource</td>
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<tr>
<td></td>
<td>Tangible</td>
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<tr>
<td>Order</td>
<td>Changeable</td>
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<tr>
<td></td>
<td>Diverse</td>
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<tr>
<td></td>
<td>Order</td>
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<tr>
<td></td>
<td>Pattern</td>
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<tr>
<td></td>
<td>Reliable</td>
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<tr>
<td>Unchangeable</td>
<td>Unpredictable</td>
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</table>
In addition to the creation of the visual maps for the Worldview—Nature Interviews, the researcher also created analysis tables from the VNOS Questionnaire and NOS Follow-Up Interview responses and TOPE responses. The analysis of the VNOS Questionnaires and NOS Follow-Up Interviews involved making notes in sections of participant responses and organizing these notes and direct participant quotes into an organizing chart. Participant responses and researcher notes were placed under the appropriate aspect of NOS. Table 6 shows how this NOS analysis table was constructed.

Following the organization of notes and participant responses, a VNOS continuum score was assigned to each aspect of NOS according to criteria used in previous studies (Schwartz & Lederman, 2002; Schwartz et al., 2004). That is, each aspect of NOS was scored

Table 6
NOS Analysis Table

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>NOS Continuum Score</th>
<th>Notes</th>
<th>Participant Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative</td>
<td></td>
<td></td>
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<tr>
<td>Subjective</td>
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<tr>
<td>Empirical</td>
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<td></td>
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<tr>
<td>Creative</td>
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<td></td>
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<tr>
<td>Social and Cultural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theories and Laws</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Observation and Inference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific Method</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
with a “-” to indicate the participant had a naïve understanding of NOS, a “(+)” to indicate the participant had an emerging understanding of NOS, a “+” to indicate the participant had an informed understanding of NOS, a “++” to indicate the participant had an informed understanding of NOS and articulated this understanding in his/her own words, and a “+++” to indicate the participant had an informed understanding of NOS and articulated this understanding in his/her own worlds and provided examples in this articulation. Each VNOS continuum score then was translated into a numerical scores which can be correlated with continuum scores such that 0 = naïve, “-”; 1 = emerging, “+”; 2 = informed, “+”; 3 = informed and articulated in participant’s own words, “++”; and 4 = informed and articulated in participant’s own words with examples provided, “+++”. It is important to note that this VNOS continuum score is not an absolute score. Rather, it is purely a nominal classificatory label which serves as a rating or indication of each participant’s understandings of the aspects of NOS on a relative scale and does not imply any quantitative property. Assigning each participant a VNOS continuum score rather than a marking on a VNOS continuum line facilitated analysis and assisted with comparisons between participants.

Finally, analysis tables for TOPE responses included participant TOPE explanation choices, participant responses to their explanation choices, and researcher notes. Table 7 shows the formatting of the TOPE analysis tables. These analysis tables not only organized the data, but also indicate any areas and ideas that need to clarification by individual participants.

**Participant Narratives**

Using the data taken from the VNOS Questionnaire responses, interview transcripts and visual maps, a first person narrative was constructed for each participant. Cobern et al.
(1995) suggest this narrative be created by using as much of the participants’ language as possible as all the code words in the visual map are used to create the narrative. This narrative included a summary of the participants’ conceptions of NOS and worldview beliefs in regards to their conceptualization of nature and the natural world and causality. Participants read through, edited, and commented on the content of the narratives with the researcher during the second round of interviews to ensure that the narratives accurately reflected their thinking.

**Assertions**

As Cobern et al. (1995) suggest, as the data analysis process was ongoing, the researcher noted tentative assertions for later use. Following the completion of the visual maps, tables, and narratives, the researcher sorted, compared, and crosschecked the data to find consistencies and differences for individual participants and among all participants. This process was similar to a second coding process where the researcher identified larger themes and patterns in the data and crosschecked this with the other data. These

<table>
<thead>
<tr>
<th>Table 7</th>
<th>TOPE Analysis Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPE Item</td>
<td>Participant Response</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

*Note. +/- indicates if the explanation choice of the participant was the more scientific choice (+) or less scientific choice (-).*
comparisons allowed for the formation of further assertions. The researcher placed these assertions into logical groups and crosschecked to confirm or disconfirm any data.

After the researcher created these assertions, participants completed the second round of interviews. During these interviews, participants reviewed their responses and summaries of their NOS responses, their TOPE responses, and their worldview—nature narratives. Participants commented, edited, and elaborated on the worldview and NOS summaries created by the researcher. Following this second round of interviews, the researcher transcribed all the participant second round interviews and sorted the interviews into logical sections relating to aspects of NOS and the worldview conceptualizations of nature and causality. The researcher used this new data to reflect new information and insights, to alter prior assertions, and/or create new assertions.

**Validity**

Several techniques used, as suggested by Cobern et al. (1995), ensured that the interpretations and data analysis had validity. First, an outside researcher reviewed the VNOS Questionnaire responses and follow-up NOS interview transcripts in order to assign each participant with a VNOS continuum score. Recall this VNOS continuum score is not an absolute score; rather, it is a rating or indication of each participant’s understandings of the aspects of NOS on a relative scale. This VNOS continuum score was compared to the scores assigned by the researcher to ensure valid VNOS continuum scores. When discrepancies were found, the researcher and the outside researcher re-examined and analyzed both the VNOS Questionnaire responses and the follow-up NOS interview transcripts and discussed the discrepancies until a common VNOS continuum score and analysis was agreed on by both the researcher and the outside researcher.
Second, when coding the Worldview—Nature Interviews, a code was not used until the meaning of the chunk or line of text was taken in light of the entire text and matches the definition of the code in the lexicon. In addition, the process of coding one text after another proceeded iteratively. Therefore, the lexicon grew with the addition of new codes, and code definitions were refined.

In addition, the researcher crosschecked assertions against each case to confirm or disconfirm data. Also, an outside researcher crosschecked the assertions and discussions against the concept maps and interpretive narratives. Finally, participants read through, edited, and commented on the content of the narrative constructed from their questionnaire and interview responses during the second round of interviews and following the final analysis of the data in order to crosscheck the narratives. These steps helped ensure the interpretations of the results of this study were valid.

**The Researcher’s Views**

**The Nature of Science**

Science is the study of the natural world—what it is, how it behaves, why it behaves as it does. The foundation of observations and evidence is what makes science is different from other disciplines of inquiry. Other disciplines, like philosophy, places emphasis almost exclusively on mental processes of logic and thinking. But science examines tangible things, physical things, and requires physical evidence—empirical evidence—along with those mental processes.

Scientific knowledge and understanding develops and changes. Although various physical phenomena may stay constant (or they may change), our understanding of these phenomena develops. Development of new, powerful, advanced technology, cooperation
and collaboration with other scientists, and further observation and experimentation leads to this changing knowledge.

Although science develops through observations of the natural world, direct access to most natural phenomena is not possible. Therefore, observations of the natural world filter through the senses and are interpreted in light of the prior experiences, expected observations, theoretical frameworks, and other assumptions of the people “doing” the science. Therefore, although science is empirically based, it is not necessarily objective. Science is a human activity.

Because humans “do” science, scientists use their creativity and imagination in all stages of scientific inquiry and investigation. The types of questions that they choose to ask, how they plan and design an experiment, and how they interpret and use the data all require a great deal of creativity and imagination.

Not only does science reflect the creativity and imagination, it also reflects social and cultural values. Social norms and the cultural milieu influence the types of questions asked, the types of data collected, the conclusions drawn, and the implications of the results. Even a cursory examination of science conducted by World War II Nazis, modern Western scientists, indigenous people groups, and others illustrates the social and cultural embeddedness of science.

Experimentation can be an important part of science inquiry. An experiment is something that someone (a scientist) does to test an idea or a hypothesis. Usually there is a careful attempt to control all the variables in the situation except for one. Of course, not all variables are always known or evident. But scientists do their best to control all variables but one so that the changes noticed are due to the experimental variable.
However, the development of scientific knowledge does not always require experiments in the way that many people may think of experiments. In an experiment, scientists try to carefully control and/or alter certain variables and make careful observations of the changes that occur. However, ecologists and others who study the environment, animal behavior, and so forth, cannot do carefully controlled experiments. Rather, they make a large number of observations about the system/situation, and then draw conclusions based on those observations. These conclusions are scientific knowledge. For instance, there is “scientific knowledge” about what happens in regards to environmental changes (carrying capacity, succession, etc...), but these ecosystems did not undergo controlled experimentation.

There is a difference between a scientific theory and a scientific law. It is a widely held misconception that there exists a hierarchical relationship between scientific theories and laws—that theories turn into laws when proven repeatedly. However, theories and laws actually serve separate but related purposes. The purpose of a scientific law is to describe phenomena and patterns in the natural world. For example, the law of gravity describes the observation of objects falling to the earth when dropped. However, this law does not attempt to explain why these objects fall to the earth. This is where scientific theories come into play. A scientific theory attempts to explain why a phenomenon occurs. Theories not only help to explain, but they can also help scientists make predictions.

**Worldview—Nature and the Natural World**

Nature and the natural world are very complex and diverse. The natural world is a physical and material world of matter that consists of both living and non-living things. Nature and the natural world is very orderly. In addition, nature is knowable. This allows us
to study and learn about nature and the natural world. Not only can we learn about what
has happened and is currently happening in nature and the natural world, we can also make
predictions about what will happen in the future. God created nature and the natural world
and all the physical laws and forces that are at work in nature.

Sometimes, we do not understand what is happening in nature and the natural
world. This can cause feelings of confusion, danger, unpredictability, chaos, and fear.
However, we continually need to strive to learn more about nature and the natural world.
Doing this can allow us to not only learn more about the natural world, but also allow us to
learn more about God.

Experiencing nature and the natural world can evoke a variety of emotions. This
interaction with nature can be exciting and peaceful. In addition, interacting with and
experiencing nature and the natural world can evoke a spiritual experience. God created
nature and the natural world. Therefore, many of the characteristics of nature are
reflections of God: His orderliness, power, beauty, holiness, mysteriousness, complexity, and
sacredness. Nature itself is not sacred. However, God created nature and the natural world
and calls us to be caretakers and stewards of His creation.

Unfortunately, we have not always been good caretakers of nature and the natural
world. We have viewed the natural world as simply a source of resources for our use. There
are many resources in the natural world that we can use; however, we have exploited parts
of nature and the natural world. Therefore, some of the living and non-living aspects of
nature and the natural world are endangered. However, nature and the natural world are
not doomed. Rather, we need to work for the restoration of creation. We need to carefully
examine how our lives and needs interact with nature and the natural world. Then we can try to live in a sustainable fashion.

**Worldview—Causality**

Science is a study of the physical, natural, and tangible world around us. Therefore, a mechanical cause-and-effect understanding of events in the natural world can explain and predict such events. However, I do believe that God, who created nature and the natural world, can work, if he chooses, outside of those mechanical cause-and-effect restrictions. Nevertheless, situations where God works outside of natural cause-and-effect mechanisms are rare (hence, they are called miracles). Therefore, when attempting to provide an explanation for causality of any particular event or phenomenon, the mechanical cause-and-effect explanation is the best explanation.
CHAPTER IV

RESULTS

This chapter presents a qualitative analysis of participants’ conceptions of NOS and worldview beliefs as revealed in written questionnaires and personal interviews. A seven-point Likert-type scale instrument (Appendix B) assessed the degree to which participants held to various points of Christian religious orthodoxy. An open-ended questionnaire (Appendix C) used as the primary instrument to capture participants’ conceptions of NOS addressed the following aspects of NOS: (1) tentative and subject to change, (2) subjective and theory-laden, (3) empirical, (4) product of human imagination and creativity, (5) social and culturally embedded, (6) relationship between theories and laws, (7) distinction between observation and inference, and (8) the myth of the scientific method. The questionnaire and follow-up interviews addressed each of these aspects of NOS. A semi-structured interview (Appendix H) used as the primary instrument to elicit participants’ ideas and beliefs regarding nature and the natural world asked participants to “think aloud” while they sorted cards and sentences containing terms and statements regarding nature and the natural world. A questionnaire (Appendix F) used as the primary instrument to capture participants’ ideas regarding causality asked participants to choose between two explanations of an event (one explanation being more scientific than the other). Participants picked one explanation and explained why they made that particular choice.

This chapter has six main sections. The first section, “Religious Beliefs Survey Analysis,” analyzes participants commitment to basis tenants of the Christian faith. The
second section, “VNOS Analysis,” analyzes participants’ views of NOS. The third section, “Worldview—Nature Interview Analysis,” summarizes participants’ worldview beliefs as elicited during the Worldview—Nature Interview and follow-up interview. The fourth section, “TOPE Analysis,” analyzes participants’ beliefs regarding causality as indicated on the TOPE. Responses to these items are analyzed in the light of individual participants’ conceptions of NOS and responses on the Religious Beliefs survey. The fifth section, “Participant Case Studies,” presents a case study for each participant that summarizes each participants’ conceptions of NOS and worldview beliefs regarding nature and causality. The sixth section, “Summary,” concludes this chapter.

**Religious Beliefs Survey Analysis**

Each participant completed a Religious Beliefs Survey (Appendix B). As mentioned earlier, the intention of this survey is to examine the actual religious beliefs of the participants in the study. Although the participants teach at a Christian school, it was helpful to obtain a simple measure of their religious beliefs. A purposive sampling technique, as suggested by Miles and Huberman (1994) intended to provide a more homogeneous population to allow for a better understanding and description of their conceptions of NOS, aspects of their worldview beliefs, and any possible relationship between these. However, although participants taught at the same Christian school, that does not guarantee they all hold identical religious beliefs. Therefore, the intent of using the survey was to more clearly define the participant population and identify other possible influencing factors on these teachers’ worldviews and conceptions of NOS.

Participants examined the list of items in the belief scale and indicated their level of agreement on a seven point Likert scale of -3 to 3 with -3 = *strongly disagree*, 0 = exactly and
precisely neutral, and 3 = strongly agree. Appendix B contains a copy of the Religious Beliefs Survey as presented to participants. Although this Religious Beliefs Survey participants completed was the longer version of the Christian Orthodoxy Scale (Hill & Hood, 1999), only responses to items composing the short version (Hunsberger, 1999) constituted items analyzed. This is due to the fact that the purpose of this Religious Beliefs Survey was to establish a commonality of Christian beliefs among participants, not to describe their religious beliefs. Keys (2004) describes a similar use of this short version of the Christian Orthodoxy Scale. For the six items, all participant responses were identical. Table 8 shows the items from the Christian Orthodoxy short scale from the Religious Beliefs Survey along with participant responses.

Since participant responses were identical on all six items of this short versions of the Christian Orthodoxy scale, this gives support to the notion that this was a quite homogeneous group of individuals concerning their basic religious beliefs. This homogeneousness of religious beliefs allows for (but does not guarantee) the possibility of more similar worldview beliefs since religious beliefs are one facet of a person’s worldview. Therefore, if relationships exist between worldview and conceptions of NOS, then the more homogeneous the worldview beliefs (as illustrated with these responses) and conceptions of NOS, the more possible relationships between the two might be illuminated.

**VNOS Analysis**

**Overall NOS Analysis**

Each participant completed a VNOS Questionnaire (Appendix C) and a NOS Follow-Up Interview (Appendix D). The questionnaire and interview elicited ideas from the participants regarding their conceptions of various aspects of NOS: tentative, subjective,
empirical, creative, social and cultural, theories and laws, observation and inference, and scientific method. Each participant received a score on a VNOS continuum scale based on his or her responses to the VNOS Questionnaire and NOS Follow-Up Interview. It is important to note that this VNOS continuum score is not an absolute score. Rather, it is a rating or indication of each participant’s understandings of the aspects of NOS on a relative scale (Schwartz & Lederman, 2002; Schwartz et al., 2004). Assigning each participant a VNOS continuum score rather than a marking on a VNOS continuum line facilitated analysis and assisted with comparisons between participants. Table 9 shows participant VNOS continuum scores for each aspect of NOS and average VNOS continuum score for each aspect of NOS. Table 10 shows the participant VNOS continuum scores distributed by aspect of NOS. The

<table>
<thead>
<tr>
<th>Item #</th>
<th>Statement</th>
<th>Participants’ Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Jesus Christ was the divine Son of God.</td>
<td>3 = strongly agree</td>
</tr>
<tr>
<td>4</td>
<td>The Bible is the word of God given to guide man to grace and salvation.</td>
<td>3 = strongly agree</td>
</tr>
<tr>
<td>9</td>
<td>The concept of God is an old superstition that is no longer needed to explain things in the modern era.</td>
<td>-3 = strongly disagree</td>
</tr>
<tr>
<td>15</td>
<td>Through the life, death, and resurrection of Jesus, God provided a way for the forgiveness of man’s sins.</td>
<td>3 = strongly agree</td>
</tr>
<tr>
<td>16</td>
<td>Despite what many people believe, there is no such things as a God who is aware of Man’s actions.</td>
<td>-3 = strongly disagree</td>
</tr>
<tr>
<td>17</td>
<td>Jesus was crucified, died, and was buried but on the third day He arose from the dead.</td>
<td>3 = strongly agree</td>
</tr>
</tbody>
</table>

*Note. These items comprise the short version of the Christian Orthodoxy Scale (Hunsberger, 1989).*
individual responses varied from naïve to informed; however, as a group, the majority of responses of the participants appeared to be emerging to informed on most aspects of NOS.

This is consistent with previous research findings (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick et al., 1998; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson, Abd-El-Khalick, & Lederman, 2004; Bell et al., 2000; Lederman, 1999; Nott & Wellington, 1998).

### Table 9
VNOS Continuum Scores for Each Participant with Average NOS Scores for Each Participant and Each Aspect of NOS

<table>
<thead>
<tr>
<th></th>
<th>Allen</th>
<th>Betty</th>
<th>Carl</th>
<th>Damon</th>
<th>Elizabeth</th>
<th>Frank</th>
<th>Grace</th>
<th>Ian</th>
<th>NOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td>Subjective</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>Empirical</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Creative</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>2.1</td>
</tr>
<tr>
<td>Social &amp; Cultural</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Theories &amp; Laws</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>2.8</td>
</tr>
<tr>
<td>Observation &amp; Inference</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Scientific Method</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Note.* Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
In order to understand the tentative nature of scientific knowledge, one must understand that science and scientific knowledge is subject to change (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the tentative aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up...
Interview responses, if a participant response indicated that everything in science was subject to change as scientists discovered new evidence and interpreted that evidence or reinterpreted that evidence, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated that the scientific community becomes more and more sure of particular results or theory since the same result is obtained repeatedly or science has “right and wrong” answers or is absolute or certain, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

One participant, Allen, demonstrated an emerging view of the tentative aspect of NOS. Seven of the eight participants demonstrated an informed view of the tentative aspect of NOS and were able to articulate the tentative aspect of NOS in their own words (“++” VNOS continuum score). Carl, Damon, Elizabeth, Frank, Grace, and Ian articulated in informed view of the tentative aspect of NOS in their own words and were also able to provide supporting examples (“+++” VNOS continuum score). Figure 5 shows the participants’ VNOS continuum scores for the tentative aspect of NOS.

Allen was the one participant who articulated an emerging view of the tentative aspect of NOS. He seemed to understand that science is subject to change with new observations and reinterpretation of observations. Furthermore, he incorporated an example into his explanation of the changing nature of scientific theories and knowledge:

Yes, Theories do change. That is because as more evidence is gained, theories are restructured or tweaked. As an example, when Rutherford did his gold foil experiment he hypothesized (from Thomson’s model) that most alpha particles that were sent would go straight through the gold foil. But his actual results showed that some alpha particles were greatly deflected. These results changed this atomic model to include the nucleus. (Allen VNOS Questionnaire)
Nevertheless, Allen still appeared to hold onto the notion that there still are some absolutes in science—right and wrong answers. For example, Allen explains, “there are some things that you may be able to prove—there are some absolutes” (Allen NOS Follow-Up Interview).

In addition, while he is explaining his views on the difference between theories and laws, Allen explains, “a theory is an idea based on the evidence that you have at the time. They are just not sure that it is totally proven” (Allen NOS Follow-Up Interview). This mixture of an informed view of how scientific knowledge developed and continues to develop and a lingering notion that some absolutes exist in science led to the categorization of Allen’s VNOS continuum score for the tentative aspect of NOS as emerging.

Figure 5. Participant’s VNOS continuum scores for the tentative aspect of NOS. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
Betty was one of the participants who articulated an informed view of the tentative aspect of NOS and was able to describe her view in her own words which gave her a “++” on the VNOS continuum. For example, Betty explains,

A theory can change as new evidence is developed...as new knowledge comes on the scene that would help. I think of a theory as something that explains how something works and why it does what it does. If new knowledge comes on the scene that wasn't used in the development of the theory, then using that knowledge to redesign the theory would lead to a different theory. I would say they usually build on each other. I’m thinking of examples like the atomic theory. Where new knowledge comes to light and changes how you look at the theory. (Betty NOS Follow-Up Interview)

Although Betty does mention the atomic theory, she does not explain how the atomic theory exemplifies the tentative and changing nature of scientific knowledge.

The other six participants articulated informed views of the tentative aspect of NOS in their own words and provided supporting examples (“++” VNOS continuum score). For example, Carl explains,

Scientific theories definitely can and do change over time...One example of theories changing relates to the flat earth theory. Scientists observed that it appeared that the earth came to an end at a certain distance but after further experimentation the theory was changed to explain that the earth is in fact a sphere with no end or beginning and that it was merely that light travels in straight lines that explain why the earth appeared to end. Thus the explanation/theory of why the earth seemed to end was changed from a flat earth to the fact that light waves travel in straight lines. We still continue to use and learn theories because they are usually very well supported, and they are useful in making predictions for future experiments. Just because theories can change...does not mean that they are useless or undependable...students can learn a great deal from looking at different theories even if they might change twenty years from now. (Carl VNOS Questionnaire)

Likewise, several participants gave examples of how scientific knowledge changes, specifically mentioning the atomic theory. For example, Grace states,
Theories change because of new evidence that is brought out by new experiments that often come because new technology allows us to do experiments that we didn’t have access to before. But the atom, the atom was a philosophical idea back in the Greek times. And then John Dalton, 2000 years later, came up with the basic, rudimentary experiments that proved there were little particles. But he had no idea of the structure inside of them. And then over time, more and more evidence came about—the cathode-ray tube, Rutherford's experiments, and Bohr’s work with the atom—to give us a more intricate view of what’s going on. But we still don’t know every little detail. I would imagine 20 years from now, we will know even more about it because of more technology and people that keep working on it. (Grace NOS Follow-Up Interview)

Using the same example, Elizabeth explains,

Dalton believed that the atom was indivisible (the smallest particle of matter). When J.J. Thomson experimented, however, the behavior of the gases indicated that there as something smaller and that the atom was divisible. From these experiments, the atom was changed to be made up of (--) particles: the Plum Pudding Model. Rutherford and Bohr and Chadwick followed with additional experiments and the model kept changing because of how matter behaved. New theories continue as we learn more and new advances can be made as we understand more. It is important to learn the theories so we understand what is known (or believed) and so we can advance or go beyond where we are now. (Elizabeth VNOS Questionnaire)

These participants articulate the tentative aspect of NOS as they describe the changing nature of scientific knowledge with new observations and reinterpretations of observations.

Subjective

In order to understand the subjective nature of scientific knowledge, one must understand that “science is influenced and driven by the presently accepted scientific theories and laws” (Schwartz et al., 2004). This includes not only the development of questions, design of experiments, and collection of data, but also the interpretations and applications of data. Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naive or a more informed view of the subjective aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up
Interview responses, if a participant response that indicated that different scientists could develop different interpretations of the same data based in part on the differences in their backgrounds and education, their prior knowledge, and the different ways that they think and learn, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated that scientists are, need to be, and can be strictly objective while solving problems using a set of procedures, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

One participant, Grace, articulated a naïve view of the subjective aspect of NOS, and four participants, Allen, Betty, Damon, and Ian, articulated an emerging view. Three participants, Carl, Elizabeth, and Frank, articulated an informed view of the subjective aspect of NOS in their own words (“++” VNOS continuum score). Carl also provided supporting examples to illustrate his understanding of the subjective aspect of NOS (“+++” VNOS continuum score). Figure 6 shows the participants’ VNOS continuum scores for the subjective aspect of NOS.

One participant, Grace, articulated a naïve view of the subjective aspect of NOS that data and data interpretation can be free from subjectivity. For example, in her response to the question, “If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions?,“ Grace explained,

They should come to the same conclusions if they do not make mistakes. If they have the same set up, and the same working environment, and the same “x, y, and z,” in science you count on them to come to the same conclusion. If they don’t, then you know that something is wrong somewhere. You have to go back and find out why. (Grace NOS Follow-Up Interview)
It is this idea that scientists should, given the same data and barring mistakes, come to the same conclusions. Furthermore, experiments and data should and can be free of bias and subjectivity that categorizes Grace’s ideas regarding the subjective aspect of NOS as naïve.

Four participants, Allen, Betty, Damon, and Ian articulated an emerging view of the subjective aspect of NOS. For each of these participants, various responses to the VNOS Questionnaire and the NOS Follow-Up Interview reflect an informed understanding while other responses reflect a more naïve understanding. For example, Betty explains, “when designing an experiment, even as objective as we want to be, there is some subjectivity to it. And there is some subjectivity that we are probably not even aware of” (Betty NOS Follow-Up Interview). However, at times, she seems to talk about science as “systematic, objective,
measurable” (Betty NOS Follow-Up Interview). In contrast, at other times, she appears to recognize the subjective aspect of NOS such as when she explains,

Subjective means, to me, it has more to do with your opinions and your inferences are what you see, or think, or feel. Is there room for it? I think yes. We have to make inferences because we can't, even in science, you can’t always repeat things that have happened in the past. So trying to think about how everything came into being, or to think about what a black hole is. All of those things require little subjectivity because we can't go out there and physically hold them, weigh them, and measure them. (Betty NOS Follow-Up Interview)

Therefore, given her mixed responses, her view of the subjective aspect of NOS is emerging.

Similar to Betty, Allen’s responses regarding the subjective aspect of NOS also appear mixed. At one point, in response to a question regarding how different scientists could get different conclusions if they are looking at the same data, Allen explains that he thinks eventually the scientists could agree, “if they become more well-versed in how the Earth works…I think they will get more information as people do more and more experiments. This will help them come to a better conclusion” (Allen NOS Follow-Up Interview).

Likewise, in response to whether scientists working separately with the same questions and same data collection procedures will come to the same conclusions, Allen explains, “I would hope the come to the same conclusion” (Allen NOS Follow-Up Interview). Allen goes on to further describe this as he explains, “I don’t think that anything is concrete and in stone. At least we are not that far in our science yet” (Allen NOS Follow-Up Interview). These responses seem to reflect a belief that science and scientists are subjective only because they do not have all the possible data available to them. That is, if
scientists had access to enough data, they would be able to remove the subjective aspect of NOS from their work.

Although several of Allen’s responses reflect a naïve view of the subjective aspect of NOS, he did articulate a more informed view in several of his responses. For example, Allen explains,

That is why you have different scientists doing the same experiment the same way. That is why the scientific method is so important because it give you the format to do it all the same. I think they will come to the same conclusions, but sometimes they don’t. They do not interpret or analyze the data the same way. I just think of my own students. I give them a set of data about a pendulum experiment, and they come up with all kinds of different explanations. (Allen NOS Follow-Up Interview)

In addition, when responding to the question about how difference scientists using the same set of data reach difference explanations, Allen responded, “I am sure both have evidence to support their claims” (Allen VNOS Questionnaire). This reflects an informed view of the subjective aspect of NOS since it recognizes that different conclusions based on the same data are possible since the background, education, and other beliefs of scientists may affect the development of their explanations. Therefore, since Allen provided responses that demonstrate a naïve view but also responses that reflected a more informed view of the subjective aspect of NOS, Allen articulated an emerging view of the subjective aspect of NOS.

Frank was one of the participants articulating an informed view of the subjective aspect of NOS in his own words (“++” VNOS continuum score). In response to being asked, “If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions?,” Frank illustrates his informed view of the subjective aspect of NOS when he states,
It's the same thing as being humans and thinking differently. I think that they might have different biases coming in, different backgrounds, and other things...even if you assume they had the same data, I don't think you can say for sure that they would come to the same conclusions. Especially this way. If they have a different bias or a different background, the data collected might even be different. (Frank NOS Follow-Up Interview)

Likewise, Elizabeth explains,

I don't know that they would still come to the same conclusion just because there may be more than one explanation that could be offered for the data that they get. I think that you see that happening many times. People read the results of somebody and say, "I don't think this is what it means." I think that you will not always have them come to the same conclusions. (Elizabeth NOS Follow-Up Interview)

Carl was the participant articulating an informed view of the subjective aspect of NOS in his own words and providing an example (“+++” VNOS continuum score). When Carl responds to the question asking how scientists could arrive at different explanations while using the same set of data, Carl states,

In this case the evidence would seem to support the notion of a catastrophic event that dramatically changed the climate of the earth but the cause of this catastrophe is unknown. From here scientists look at the data and make the best educated guess as possible. Each group looks at the data but interprets it differently. It is like people watching an accident, there are probably at least three different explanations for why the accident happened because each person has their own point of view. It is clear that there was an accident but one person may say it was due to ice, while another may say that the driver in front braked too hard or the person in back was too close. It could also be like seeing the score of a football game being 6-0. Seeing this score I might guess that one team has kicked two field goals but another might guess that the team scored a touchdown but missed the extra point. Now as time goes on and new data comes to light one of the extinction theories might be supported more than the other. (Carl VNOS Questionnaire)

Furthermore, Carl explains, “it is this proposed explanation that makes theories somewhat subjective because two different scientists looking at the same data/results can and often
times interpret the results quite differently” (Carl VNOS Questionnaire). Likewise, he also states,

I think inherently with people involved, I think there is going to be some form of subjectivity. Especially since theories are when you are trying to explain why something happened. I think that is just impossible for you to try to explain something and why it happened for it to be totally objective. (Carl NOS Follow-Up Interview)

Carl recognizes science is influenced by an unavoidable element of subjectivity which scientists bring with them as they engage in scientific inquiry.

**Empirical**

In order to understand the empirical nature of scientific knowledge, one must understand that science and scientific knowledge are based on observations of the natural world (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the empirical aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated much of the development of scientific knowledge depends on observations of the natural world, the participant received a VNOS continuum score that indicated a more informed view of NOS. In addition, if participants talked about science as something more than just observable facts, they received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated that science is simply a collection of facts, very straightforward, and void of personal opinion or bias related to observations, the participant received a VNOS continuum score that indicated a more naïve view of NOS.
All the participants demonstrated an informed view of the empirical aspect of NOS. Two participants, Frank and Grace, also articulated the empirical aspect of NOS in their own words (“++” VNOS continuum score). In addition, three participants, Carl, Damon, and Ian, also provided supporting examples (“+++” VNOS continuum score). Figure 7 shows the participants’ VNOS continuum scores for the empirical aspect of NOS.

Three participants, Allen, Betty, and Elizabeth, simply articulated an informed view of NOS that states that science and scientific knowledge is based on (or derived from) observations of the natural world (“+” VNOS continuum score). For example, in response to the question, “What makes science different from other disciplines of knowledge?,” Betty explains,

**Figure 7.** Participant’s VNOS continuum scores for the empirical aspect of NOS. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
It’s more systematic. It’s based more on material, objective things. Where philosophy and theology and those types of subjects—a lot of it is just in people’s heads: what they think and what they believe. Whereas science is more measurable...measurable, tangible, physical, material things. (Betty NOS Follow-Up Interview)

Furthermore, in her response to how scientists know dinosaurs existed, Betty responds,

I know they found fossils of skeletons. They found bones and skeletons, and they have been able to build what they think the rest of the animal would look like around those bones. They have also found fossils of prints, portions, and even maybe eggs and babies or embryos of dinosaurs. (Betty NOS Follow-Up Interview)

Betty recognizes the dependence that the development of scientific knowledge has on observation and the empirical aspect of NOS.

Frank and Grace articulated an informed view of the empirical aspect of NOS in their own words (“++” VNOS continuum score). Frank explains, “science usually deals with studying the material world. Although science can be more abstract, often it deals with more concrete evidence that can be explored, investigated, tested, etc... Science provides a unique opportunity to discover new knowledge” (Frank VNOS Questionnaire). Likewise, Frank states,

I think that part of it is, at least aspects of science are more testable than the other disciplines. Obviously we have theories and things like that in biology and other areas that have not been proven, but to a large extent, you can go and investigate, see, and set up an experiment. You can look at things under microscopes and telescopes...in science you actually go out and explore and investigate a little bit more. (Frank NOS Follow-Up Interview)

Throughout his responses, Frank demonstrates an informed view of the empirical aspect of NOS—he explains that scientific knowledge and experiments based on and using that knowledge are based on and derived from observations of the natural world.
Carl, Damon, and Ian articulated an informed view of the empirical aspect of NOS and were able to articulate this understanding in their own words and provided supporting examples ("+++") VNOS continuum score. For instance, in his VNOS Questionnaire response, Ian states,

What makes science different from other disciplines is that science deals with *measureable quantities*. Unless something is measurable, science has no way of dealing with it in a meaningful way. That's not to say that things which aren’t measureable aren’t real. For example, love and justice (and God) are real but they do not have a length you can measure, no mass, no volume. Thus, love and justice (and God) are not topics you will find in a physics textbook. (Ian VNOS Questionnaire)

In this response, Ian not only describes, in his own words, how science is empirical, but also illustrates this idea with the example of love and justice being real but not measurable and therefore not included as a part of science.

**Creative**

In order to understand the creative nature of scientific knowledge, one must understand that the process of science and the generation of scientific knowledge involve creativity and imagination. This creativity and imagination is based on and incorporated with observations and inferences made regarding the natural world (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the creative aspect of NOS.

For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated creativity and imagination, along with logic, are essential to the process of science, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated that scientists only use creativity and imagination in the designing phase of
experiments or only when collecting data but not after data collection since the scientist needed to be more objective at that point, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

Two participants, Betty and Frank, articulated a naïve view of the creative aspect of NOS, and two participants, Allen and Elizabeth, articulated an emerging view. Carl articulated an informed view of the creative aspect of NOS in his own words (“++” VNOS continuum score). Three participants, Damon, Grace, and Ian, demonstrated an informed view of the creative aspect of NOS, articulated that in their own words, and provided supporting examples (“+++” VNOS continuum score). Figure 8 shows participants’ VNOS continuum scores for the creative aspect of NOS.

Two participants, Betty and Frank, articulated a naïve view of the creative aspect of NOS. For example, Betty states,

Yes, creativity and imagination are useful in some of the steps of scientific investigation. In planning and design, creativity helps scientists develop tests, control unwanted variables, consider many valid hypotheses (before selecting one to test). After this step, objectivity must rule. Carrying out the experiment, collecting data, and analyzing data are not facilitated by creativity, and may be negatively affected by it. (Betty VNOS Questionnaire)

This idea that the scientific process needs to be very objective (as opposed to creative, in this case) and that creativity and imagination could negatively affect the scientific process is why Betty’s view of the creative aspect of NOS is naïve. Likewise, in his NOS Follow-Up Interview, Frank states,

Although creativity is good in these areas, I think that creativity can be dangerous when it comes to analyzing the data. I believe that most of the time, the data obtained should clearly either confirm or refute the hypothesis. I don’t see why creativity would be needed to manipulate this data. In fact, the only time this creativity may be useful is in advertising
where a company needs to spin the data in a way that supports their product or service. (Frank NOS Follow-Up Interview)

Not only does Frank feel that creativity can be dangerous when analyzing data, he feels that using creativity during data analysis can lead to the unethical use of data.

Two participants, Allen and Elizabeth, articulated an emerging view of the creative aspect of NOS. For example, Elizabeth states,

I think scientists used creativity and imagination during their investigations. Scientists who think "outside the box" are more likely to discover more things. I think creativity and imagination are used in all parts of investigations. Think of the discovery of penicillin. It was an accident. Fleming could have recoded it as a mistake, and thrown it away. But he didn’t. So many advances occur because the scientists could see the possibilities rather than just follow a set method. Using creativity and imagination makes data deeper and richer. Scientists use creativity and
imagination because they can get more than just the expected results. The sky’s the limit. (Elizabeth VNOS Questionnaire)

However, she also goes on to explain,

I think they do use creativity and imagination during their investigations. I think their creativity can come in with how they planned and design an experiment. I don’t know if it would come in so much with the collection of data. Although, I suppose they could be, well no. Well, different people might collect different data, but it’s probably pretty set depending on what your hypothesis is. But I think that you can be very creative and imaginative when you’re designing an experiment...I think that they might use creativity and imagination their experimental design. But I would think that most of the time they are not being terribly imaginative when they make their conclusions or analysis. (Elizabeth NOS Follow-Up Interview)

Furthermore, she goes on to explain that using creativity and imagination in data analysis is “probably not appropriate. I think that if they did, people would say, ‘they are just being fanciful’ or something like that. Maybe there are places for it, I guess, but most of the time they don’t” (Elizabeth NOS Follow-Up Interview). Since Elizabeth hesitates but does not completely dismiss use of creativity and imagination in aspects of scientific inquiry following data collection, her views regarding the creativity and imagination aspect of NOS are emerging rather than naïve.

Carl articulated an informed view of the creative aspect of NOS in his own words (“++” VNOS continuum score). Carl provides examples of creativity and imagination used in scientific processes as he explains,

I would definitely say yes, scientists use creativity and imagination. If you are dealing with very difficult, not problems, but if you are trying to explain something that is very difficult. You are going to have to think of a very ingenious way to look at it. There is some experiment with a guy trying to detect radiation content in space. And he filled up this massive tank with water, and he measured some type of radioactive isotopes and how they changed over time with radiation came from space. Some sort of odd experiment. But that’s crazy. Or even someone finding the mass of the Earth by looking through a keyhole to two rooms over or figuring out the speed of
light by looking at light between two different mountains. All those examples are of ingenious planning and design to try to explain something. (Carl NOS Follow-Up Interview)

When asked if scientists use creativity and imagination during data collection or data analysis, Carl responds, “they might be creative in trying to find a relationship that maybe you would not think of. Or creative ways to measure something” (Carl NOS Follow-Up Interview). Therefore, even though Carl does provide numerous examples of scientists using creativity and imagination during the processes of planning and design, he does not elaborate much on the use of creativity during interpretation of results or while drawing conclusions. As a result, “++” is his VNOS continuum score for the creative aspect of NOS.

Three participants, Damon, Grace, and Ian, articulated an informed view of the creative aspect of NOS in their own words and provided supporting examples (“+++” VNOS continuum score). For example, in his VNOS Questionnaire, Damon states,

I think creativity is essential at all three of the states you describe [planning and design, data collection, and after data collection]. Creatively deciding how best to isolate the variables to be studies and design instruments to measure the results. Creativity to decide what data to collect and how best to measure it. Even creativity in putting the data together in new ways as Bohr did putting the data about the hydrogen spectrum together with the atomic model of his day. (Damon VNOS Questionnaire)

Likewise, in her NOS Follow-Up Interview, Grace explains,

Yes, for sure scientists use creativity and imagination during their investigations. I think that they use it in every stage. It varies depending on the experiment. So you have imagination and creativity when you come up a question that you’re going to research. You need to be creative in planning how you are going to get your information and design your experiment. Some things are not easy to do and some data is not easy to get. You ask, I want to get this data, how am I going to get it? And even data collection can be a challenge. I think that when things are not easy and obvious, you need to be creative. So if there is data that is hard to collect... I’m sure was hard for people to figure out how much gasses weigh way back then. They had to be creative in figuring that out. And then to interpret the data. Going back
to the example I used before with Rutherford getting the bounce backs from his gold foil experiment, he had to imagine what was going on there. He could not see it and say "oh, I just saw them crash." There is a lot of imagination and creativity. And it's in every part. (Grace NOS Follow-Up Interview)

This recognition of the role that creativity and imagination play in every part of scientific inquiry, not just design and planning, is why these participants received a “+++” VNOS continuum score for the creative aspect of NOS.

**Social and Cultural**

In order to understand the social and cultural nature of scientific knowledge, one must understand that science is human enterprise which is influenced by the culture and society in which it is practiced (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the social and cultural aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated that culture and all factors in human society do influence the ideas of science, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated since science is all about the facts, it cannot and should not be influenced by cultures and societies, and that scientific knowledge is universal and does not change from place to place, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

One participant, Carl, articulated a naïve view of the social and cultural aspect of NOS. Four participants, Allen, Betty, Elizabeth, and Ian, articulated an emerging view of the social and cultural aspect of NOS. Three participants, Damon, Frank, and Grace, demonstrated an informed view of the social and cultural aspect of NOS in their own words.
and provided supporting examples (“+++” VNOS continuum score). Figure 9 shows the participants’ VNOS continuum scores for the social and cultural aspect of NOS.

One participant, Carl, demonstrated a naïve view of the social and cultural aspect of NOS. For example, in his VNOS Questionnaire, he states,

I believe that science is universal and that scientists may do the best job of disconnecting themselves from the social and political values of their time. From my point of view, scientists are concerned with the facts and with the results of their experiments. (Carl VNOS Questionnaire)

Carl then continues to provide an example to illustrate how he feels that science is universal and void of social and cultural influences as he explains,

One example that shows [scientists’] disconnection from the social and political values is the collaborations that spring up between scientists in

![Figure 9. Participant’s VNOS continuum scores for the social and cultural aspect of NOS. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.](image-url)
different countries. This seems to show that the scientists are not concerned with the different norms of each culture but with making discoveries. Another example can be found by looking at the number of foreign graduate students who come to the United States for their Masters and Ph.D. work. If cultural norms dictated what they worked on they most likely would not be and would find it extremely difficult to work with American professors. (Carl VNOS Questionnaire)

Four participants demonstrated an emerging view of the social and cultural aspect of NOS. For example, Betty states, “I think that it is impossible to transcend the social and cultural values, even in science. I believe that science makes every effort to be totally objective and not influenced, but still probably is influenced” (Betty VNOS Questionnaire). In addition, in his VNOS Questionnaire, Allen states, “I believe science is universal because water is H\textsubscript{2}O no matter where you go” (Allen VNOS Questionnaire). However, in his NOS Follow-Up Interview, Allen states,

I think that science is affected by social, political, and philosophical values. If you go to certain countries that are theocracy, I'm sure they have much of their science based on what their beliefs are. Which in many cases may be just like taking the Bible and saying that it is a science textbook, which it is not. I think that, depending on where you are, it really does reflect some of the social and cultural values. Good scientists try to do science without all of those things. Science does reflect the social and cultural values. (Allen NOS Follow-Up Interview)

It appears that Allen is developing his understanding of the social and cultural aspect of NOS as he processes ideas about science as “both a collection of facts and a process” (Allen NOS Follow-Up Interview).

Three participants, Damon, Frank, and Grace, demonstrated an informed view of the social and cultural aspect of NOS in their own words and provided supporting examples (“+++” VNOS continuum score). For example, Damon speaks to the influence of social and cultural aspects in the application of science. He explains,
Science reflects social and cultural values. There are some groups of people who use science to prove things. You can look at it and twist it around and use it to prove whatever you want. There are some topics that are so charged right now that you can hardly talk about them without people yelling at each other because it has become a social issue. It is hard to separate the scientific data and observations from what that is going to mean in terms of cost to society, government regulation of this or that, individual freedoms, or something like that. (Damon NOS Follow-Up Interview)

Likewise, Damon is able to articulate how social and cultural aspects can influence both what and how science is conducted. For example, he states,

Part of the problem today is that people in the general population have, in my view, to broad a definition of science. Science is more limited in what it can discuss than many people would like to think. I also think that values might influences how I go about investigating a certain topic but that doesn’t make the topic good or bad; valuable or not. I could investigate the action of disease-causing bacteria in the genetics lab on mice or I could infect the population of a small town with it. The idea of how the bacteria work is not evil or good. How much I value mice or people will affect how I go about my investigation. (Damon VNOS Questionnaire)

Similarly, in his VNOS Questionnaire, Frank states,

I believe that science does reflect social and cultural values. I think that most scientists try to make science universal but I don’t think that it is really possible to complete extract our biases from our science. The biggest issue is that we are often not aware of the biases that we hold. If we do not recognize them, then how can we avoid allowing them to affect our experimentation and analysis of the data? (Frank VNOS Questionnaire)

These participants assert that because science is a human endeavor, even if scientists are trying to be “universal,” it is impossible to have scientific knowledge and scientific inquiry devoid of social and cultural influences.

**Theories and Laws**

In order to understand the theories and laws nature of scientific knowledge, one must understand that theories and laws are different types of knowledge. Laws describe
relationships and phenomena in the natural world; theories are explanations for those relationships and phenomena. No hierarchical relationship exists between theories and laws (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the theories and laws aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated that laws simply described relationships between phenomena and theories proposed an explanation for the relationship between the phenomena, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated a hierarchical relationship exists between theories and laws such that theories can become laws if proven repeatedly or that laws are irrefutably true where theories can change, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

Two participants, Allen and Ian, articulated a naïve view of the theories and laws aspect of NOS. For example, Allen states,

A theory is an idea based on the evidence that you have at the time. They are just not sure that it is totally proven. Or there is some room for movement there. Like the Big Bang theory: there is some evidence out there for it, but I think that it is not absolute at this time. A scientific law describes much of what happens. For example, Charles’s Law: When you increase the
temperature, you increase the volume of the gas. At this point, almost everyone agrees that it is true. And so to me, if you compare the two, the law is the stronger one as compared to a theory. (Allen NOS Follow-Up Interview)

Allen highlights his belief in the hierarchical relationship between theories and laws and how laws are “stronger” and more proven than theories. Likewise, in his NOS Follow-Up Interview, Ian explains,

They always say a law has been around for a long time. A theory is generally accepted, but a law has been around. There's more credence given to a law than to a theory. A theory is a step up from a hypothesis. But a law is a step up from theory. Like the law of gravitation. Some people describe that as Newton's theory of gravitation. I'm not saying that the theory has to be around for 50 years, and then in the 51st year we will call it a law. I think that the theory and the law are kind of loosely switched one for the other. But a scientific law is something that is generally considered to be true by

![Figure 10. Participant’s VNOS continuum scores for the theories and laws aspect of NOS. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.](image-url)
virtually the whole scientific world. It's a matter of more time. A law has been around longer. There is less argument about laws. I don't know if they would consider something like evolution, well there are different kind of evolution, the evolution of animals or something like that. There is more controversy with that, so they call it the theory of evolution. But some people consider that to be a law, I guess. So the laws the highest you can get. (Ian NOS Follow-Up Interview)

Not only does Ian explain his idea of how a theory can become a law over time, he also supports his beliefs with the examples.

It is worth noting that Allen and Ian are the oldest participants in this study who received their training at least one decade prior to any of the other participants. Some of the development of the usage of the terms law and theory in the literature on NOS has been more clearly delineated in recent years. Therefore, it may be that Allen and Ian actually understand the difference between empirically derived laws (e.g. Boyle’s Law) with minimal theoretical underpinnings and a theory that has broad explanatory power (e.g. kinetic theory of gasses). However, based on their responses to the VNOS Questionnaire and NOS Follow-Up Interview, Allen’s and Ian’s responses reflect a naïve understanding of the theories and laws aspect of NOS as understood today.

Elizabeth and Frank articulated an informed view of the theories and laws aspect of NOS in their own words which categorized their views as “++” on the VNOS continuum. Elizabeth explains,

There is supposed to be a difference between a scientific theory and a scientific law. A scientific theory is the explanation. And the scientific law is a description. A theory explains, but a law is just the statement. That's how I would say the difference is. That would be the definition, even though it doesn't always comes through that way. When we talk about the law of gravity, we say, “this is what it is.” We don't say why. We don't say why this is what happens. We just say that if you let something go, it will fall. And that's the law. And the theory would be, “why does that happen?” (Elizabeth NOS Follow-Up Interview)
Likewise, in his NOS Follow-Up Interview, Frank used an analogy to explain his understanding of theories and laws aspect of NOS,

One of the examples that I like to use with my students is about sports and box scores. You read the paper today to see what happened with the Tigers and you get a play-by-play of if they lost or not. You get a play-by-play on what happened: “They gave up a lot of runs, because the shortstop missed a ball. They gave up a grand slam, and this happened, and this happened, etc...” Whereas a law is just like the box score. It just says: Tigers: 0, Twins: 11. So I guess I see the difference as that of the theory explains, and a law just describes. (Frank NOS Follow-Up Interview)

Both Elizabeth and Frank differentiate between the functional difference of laws and theories: laws describing relationships observed in the natural world and theories providing the explanations for those relationships.

Betty, Carl, Damon, and Grace’s articulations of the theories and laws aspect received “+++” on the VNOS continuum since they articulated the theories and laws aspect of NOS in their own words and provided supporting examples. For example, Grace states,

As I understand it, a theory is something that explains the world around us, how things work. And the law is not something that explains how, it just tells you what it does. So there is a difference. There is the atomic theory of the atom, which kind of explains how the atom works. Whereas there is the law of gravity. That does not explain how gravity works, it just tells you, “there is gravity, things fall down.” (Grace NOS Follow-Up Interview)

Likewise, in his NOS Follow-Up Interview, Damon explains,

I've always been taught, and it makes sense to me that the theory tries to go over the law and explain why it works. The laws are, "when I drop something it accelerates at 9.81 m/s per second." It happened here, it happens in Florida, it happens everywhere, and it works. You can predict how things will happen. The theory tries to get into what it is about the thing that you dropped in the Earth that make them do that. This is the more subtle question. It's misunderstood often. Most students think that theories are things that you haven't quite figured out yet, and laws are set in stone like the 10 Commandments. The theory tries to... the theory is deeper, I think, than the law. Gravity would be a good example. The law of
gravity: there are tons of equations you can use, and constants, and things that let me throw something, and I can predict pretty much when and where it will lay out. They sent people to the Moon based on the law of gravity, and it worked fine. But the theory of gravity...why do they do that? What is it about massive objects that make them attractive to each other and not repel? We do the same thing with magnetism and electromagnetism. We can understand the wavelength and frequency and how that works, but why do they fluctuate like that? (Damon NOS Follow-Up Interview)

In these examples, both Grace and Damon illustrate the functional difference between theories and laws by incorporating the example of the gravity. It is interesting to note that as a group, these participants had more informed conceptions of the theories and laws aspect of NOS than teachers in previous studies (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). This is examined in more detail in the Discussion and Implications section.

**Observation and Inference**

In order to understand the observation and inference nature of scientific knowledge, one must understand the distinction between observations gathered using the senses and inferences which are interpretations of those observations. Both observation and inference are important to the development of scientific knowledge (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the observation and inference aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated that observations and evidence can be indirect, can relate to things that we don’t see directly, and that there can be multiple interpretations of data, the participant received a VNOS
continuum score that indicated a more informed view of NOS. However, if a participant indicated that scientists only use observations when studying the natural world and that you need to be able to observe something in order to be sure of it, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

Overall, scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough information regarding participants’ views of the observation and inference aspect of NOS. Given the data obtained, however limited, five participants, Allen, Betty, Carl, Frank, Grace, and Ian articulated an emerging view. One participant, Elizabeth articulated a naïve view of the observation and inference aspect of NOS; and two participants, Damon and Grace, demonstrated informed views of the observation and inference aspect of NOS (“+” VNOS continuum score). Figure 11 shows the participants’ VNOS continuum scores for the observation and inference aspect of NOS.

One participant, Elizabeth, demonstrated a naïve view of the observation and inference aspect of NOS. When asked to explain her understanding of indirect evidence, she states,

Indirect evidence is evidence that you get without being able to see or touch something. You might do something and see what happens as a result of what you do. And that allows you to draw some conclusions about what you think is happening inside. (Elizabeth NOS Follow-Up Interview)

When asked if this notion of indirect evidence is the same as inference, Elizabeth explains, “I guess that an inference, in my opinion, is something that you make without having as much evidence for. You just have an inference about something—it is not as strongly supported” (Elizabeth NOS Follow-Up Interview). This explanation does not really reflect an informed
understanding of inference as an interpretation of observation. Rather, it seems to set up a hierarchical notion where inference might be some type of observation for which you simply have less evidence. Therefore, her view of the observation and inference aspect of NOS is considered naïve.

Six participants, Allen, Betty, Carl, Frank, Grace, and Ian demonstrated an emerging view of the observation and inference aspect of NOS. For example, as Betty explains her understanding of the difference between indirect evidence and inference, she states,

I think inference is when you have physical evidence or something that you have observed, and you apply what you know. So, I do not think that indirect evidence and inference are the same thing. The fall color of the trees, if you look at the map of the United States and at the peak time of leaf color change, you can look for patterns. Just say what you see is the
pattern would be an observation. Saying that the peak time of the earlier, the farther north you go in latitude would be an observation. The inference than that would be based in what you know, that the temperature affects when photosynthesis begins the start of the season. The northern latitudes would have the cooler temperatures; therefore, the leaves will change color earlier there. That would be an inference. That's not really the same as indirect evidence. (Betty NOS Follow-Up Interview)

Betty recognizes the difference between observation and inference; however, there is not sufficient information to classify her view as informed. Therefore, her views regarding the observation and inference aspect of NOS are emerging.

Damon and Grace articulated an informed view of the observation and inference aspect of NOS (“+” VNOS continuum score). When asked about the role of observation versus inference, Damon explains,

> The observation is the thing that you thought you could explain. You look at the surface of the earth, and you notice that the continents move around. You say there must be something causing that, so you try to figure out what's going on. Or you look at how galaxies are held together, and you see that there's not enough gravity to hold it all together. So you look at the laws that you have. If there's something that's unexplainable, you have to look at your observations and make inferences either for new observations, where you would develop a new instrument to see what you couldn't see before, or you have to make an educated guess. I keep thinking of astronomy because I just read about it this summer. They watched Mars go this way and then they watched it go backwards. And so they had all these goofy circles because they couldn't see what was actually happening. It was probably not true, but it was inference made on an observation. (Damon NOS Follow-Up Interview)

Damon recognizes the difference between observation and inference, he explains it in his own words, and he provides an example referring to the inferred path of the movement of Mars. However, this is the only time during both the VNOS Questionnaire and the NOS Follow-Up Interview where Damon mentions inferences. Therefore, due to the lack of more
data, “+” is Damon’s VNOS continuum score for the observation and inference aspect of NOS.

**Scientific Method**

In order to understand the scientific method nature of scientific knowledge, one must understand that a universal step-wise method that guarantees the generation of accurate and valid knowledge does not exist (Lederman et al., 2002; Schwartz et al., 2004). Lederman et al. (2002) provide examples of responses to various VNOS items that illustrate a naïve or a more informed view of the scientific method aspect of NOS. For instance, when analyzing the participants’ VNOS Questionnaire and NOS Follow-Up Interview responses, if a participant response indicated that the step-wise procedure often referred to as the scientific method may be a good way for scientists to communicate their findings, but that is not really how scientists actually work, the participant received a VNOS continuum score that indicated a more informed view of NOS. However, if a participant indicated that scientists use an exact, step-wise method in order to ensure they obtain accurate results, the participant received a VNOS continuum score that indicated a more naïve view of NOS.

Two participants, Allen and Ian, articulated a naïve view of the scientific method aspect of NOS. Four participants, Betty, Damon, Frank, and Grace, articulated an emerging view. Elizabeth articulated an informed view (“+” VNOS continuum score), and Carl, articulated the scientific method aspect of NOS in his own words and provided supporting examples. Figure 12 shows the participants’ VNOS continuum scores for the scientific method aspect of NOS.

Allen and Ian demonstrated a naïve view of the scientific method aspect of NOS. For example, in his VNOS Questionnaire, Allen states, “to me, because of how I think, it seems
only logical to use [the scientific method]. To me there must be standards and procedures so others can replicate and verify what one has done” (Allen VNOS Questionnaire). In addition, in his NOS Follow-Up Interview, Allen explains,

> Really generalized, to me, it [the scientific method] is just problem-solving. It is a structure or a rubric basically to try to figure out answers to some questions that they don’t know. That, to me, is what the scientific method is. That’s where I get to concrete and the abstract. Although the abstract is also solved that way as well. If you didn’t have an experiment, you wouldn’t be able to figure out things like pills. You know, like whether or not it will work. So you set up an experiment so that it helps prove or disprove your hypothesis. (Allen NOS Follow-Up Interview)

Allen refers to specific steps and step-wise procedures several other times during his VNOS Questionnaire responses and NOS Follow-Up Interview.

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**Figure 12.** Participant’s VNOS continuum scores for the scientific method aspect of NOS. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
Ian was another other participant who articulated a naïve view of the scientific method aspect of NOS. For example, when asked about the “scientific method” being described as involving the steps of making a hypothesis, identifying variables (dependent and independent), designing an experiment, collecting data, reporting results, Ian explains,

I think scientists must follow the scientific method. That's a definite no-brainer—yes. They must follow the scientific method because it's a scientific method. If you are going to be a scientist, that is the method that you follow in order to qualify as a scientist. The scientific method is a method followed by scientists to discover knowledge: observation, explanation, experimentation. Or as you put it in a more complicated fashion here: Hypothesis, identifying variables, designing experiments, collecting data, and reporting results. I prefer this: A scientist has to observe something. And then they say, "hey, look at that." Then they make an explanation where they say "I bet I know why that happened." That sort of their hypothesis. But then they do more than that. They check it out. They check it out covers the “identifying variables, designing an experiment, collecting data, reporting results.” So when I have the three steps: observation, explanation, experimentation, I am actually including the observation which you have neglected. Even though you have more steps, yours is incomplete. And mine with three steps, is complete. (Ian NOS Follow-Up Interview)

Repeatedly throughout his VNOS Questionnaire and NOS Follow-Up Interview, Ian referred to the scientific method as a specific series of steps to follow when doing science. Even as he defines science in his VNOS Questionnaire, he explains that science is both a body of knowledge and a way of attaining knowledge that “refers to the method and activity of science which is also called The Scientific Method” (Ian VNOS Questionnaire).

Betty is one of the participants who articulated an emerging view of the scientific method aspect of NOS. For example, she explains,

I think the steps of the scientific method are basically the same in all good science, but they might not always be in the same order or look exactly the same to an outsider. For an experiment to be credible and the results to be considered valid, certain steps must be followed. If the results of an experiment are to be useful to the scientific community, then there must be
a consistent overall process that all scientists agree on and use. (Betty VNOS Questionnaire)

This response appears to reflect the naïve view that science has a particular, step-wise method that must be followed. However, in her NOS Follow-Up Interview as she reviews and comments on this response, she explains,

But here I said yes, but I was thinking more of experiments. I guess, if the doing of science is making observations of the natural world, trying to find correlations, coming up with theories about laws, I don't think it necessarily has to be in the form of an experiment (which would mean the scientific method). But I think that it still needs to be done scientifically. So you don't necessarily have to be the scientific method. I don't think that you need to do everything in that specific order. It's more of a process. You might get to a point that you realize that you have to change the experiment because something isn't working. And then it becomes more of a cycle than actually a step by step linear thing. It would usually, I guess, lead to further experiments or tweaking to test something a little differently. (Betty NOS Follow-Up Interview)

Her views of the processes of science and the scientific method aspect of NOS appear to be emerging. She seems to be trying to hold on to some type of procedure to use scientific experiments. However, she does seem to recognize the need for other types of ways to do science. Therefore, her overall view of the scientific method aspect of NOS is emerging.

Elizabeth articulated an informed view of the scientific method aspect of NOS (“+” VNOS continuum score). She explains,

I don't know if I want to say "the" scientific method. I am tending to say there may be many scientific methods. Traditionally, they look at that and they even order the steps. I don't think they have to be in that order. A lot of times you don't start there. I do think though that there should be some kind of steps that a scientist would follow in terms of trying to come up with some sort of results... I think that you need some sort of process usually. I think that it should be logical. Things happen by mistake, and discoveries are made that happen by mistake and not through a specific process. I still think they were doing science, whether it was through an accident or not. If you are creative person, for example, and not as logical, you might do something that other people would think is kind of strange to do. But you
might do that because of your creativity. I would not want to say that there is “a” scientific method, but there usually is some sort of process they go through. (Elizabeth NOS Follow-Up Questionnaire)

Although Elizabeth believes that science does often, but not always, progress through some sort of process, she is careful to point out that there is not one particular method by which science must progress. This reflects an informed view of the scientific method aspect of NOS.

Carl was the only participant who articulated an informed view, in his own words, supported with an example (“+++” VNOS continuum score). For example, Carl explains,

I believe that to do good science, scientists do not always have to follow the scientific method. There are, in fact, many scientific methods that work. I do think that the standard scientific method taught in schools is a good model, but there is no reason to think that it is the only way to do science. Often times, major discoveries come by surprise and were unexpected. Sticky notes are a good example of a scientist performing an experiment at 3M with the intent of making a very adhesive material; but in the end he made an adhesive that was quite weak. Also, there are times when a scientist does not start with an observation or problem but simply begins with a hypothesis or an idea. In essence, I believe there are numerous types of scientific methods that differ in their starting point or even in their order. (Carl VNOS Questionnaire)

Carl recognizes that the step-wise process of the scientific method is not how scientists actually go about doing science.

Worldview—Nature Interview Analysis

Each participant participated in a Worldview—Nature Interview (Appendix E) in order to articulate his or her worldview beliefs regarding nature and the natural world. Participants discussed nature and the natural world in terms of their religious beliefs, content areas, personal experiences, and aesthetics. During the discussion these participants articulated, incorporated, and melded religious and scientific understandings.
For these participants, faith did not appear to interfere with their ability to think scientifically in regards to their worldview beliefs regarding nature and the natural world. Rather, faith was incorporated into a scientifically compatible worldview regarding nature and the natural world.

**Scientific Understanding and Content Area**

The participants tended to describe nature and the natural world in a scientific way. For example, Ian explains

> The natural world is something that is tangible, touchable, and seeable. You can work with it. You can do experiments with it. You can find orderly processes involved with it. It is possible for human beings to write equations and come up with theories on how things work. It’s tangible. It’s measurable. That’s an even better word! Nature involves things that are measurable. (Ian Worldview—Nature Interview)

The content areas in which the participants were familiar appeared to influence the participants’ views of nature. For example, in his Worldview—Nature Interview, Ian provided a number of examples regarding astronomy, one of the courses he taught during his career. He states,

> I think looking at the Hubble telescope pictures that have been taken is exciting. I got the Sky and telescope magazine a few days ago, and it has a DVD of pictures from Mars from the rover. I think it’s exciting to see that. (Ian Worldview—Nature Interview).

Likewise, Frank, who has a background in biology and life sciences, states,

> Full of resources. Since it is in the terms of nature, I would start to think of things like fossil fuels, water, and having the resources to use things like hydroelectric power. I guess ecology comes to mind and food chains pop into my mind. (Frank Worldview—Nature Interview).

Many of the examples that participants provided reflected the specific content area in which they teach. For example Carl, who teaches chemistry, explained his thoughts
regarding if nature was pure by explaining, “Pure. Made of one thing. Like maybe an atom or molecule, depending on it you’re talking about an element or compound” (Carl Worldview—Nature Interview). Betty, who teaches biology, talks about patterns in nature and states, “Like, looking at a beehive. It might look totally chaotic to us, but there’s something very, very patterned going on” (Betty Worldview—Nature Interview). Likewise, Allen, who also teaches biology, explains,

It’s very complex…Food webs are an example. Complexity of DNA and genes. In the complexity of how living and non living things work. If you take out a certain community or ecosystem, the effects it has. And so the interrelationships between all of them is very complex. Even within, I mean, climate. Even within certain biomes, and things like that. (Allen Worldview—Nature Interview)

**Personal Experiences**

Participant descriptions of nature and the natural world also reflected their own personal experiences. For example, when talking about whether or not nature and the natural world could be frightening, Ian states,

Nature could be frightening. Have you even see Quimet Canyon? Going around Lake Superior? The place where you can pull off, it’s called Quimet Canyon. There are not any fences up around there, at least not the last time we were there. There is a sign that says, “Parents hold on to your children.” You go up there, and it’s huge, straight down drop. And in that sense, it’s frightening. So nature can be frightening. (Ian Worldview—Nature Interview).

Likewise, Grace explains,

We were in a tent camping once when straight-line winds came through. The trees were falling around us and crashing on trucks. We couldn’t drive home the next morning because there were too many roads closed. That was frightening. And that’s part of nature. But that doesn’t happen very often. I am not often frightened of nature. (Grace Worldview—Nature Interview)
When Elizabeth explains how she does not think that Nature is “unchangeable,” she states, “we were at Pictured Rocks last summer, and it wasn’t the way I remembered it being as a little kid because the top of one of those things is gone” (Elizabeth Worldview—Nature Interview). Similarly, Betty talks about her personal experiences when she explains,

I have a pleasant emotional response to nature. I do. I even noticed in Kentucky this weekend. I was talking a walk in this really cool park. Kentucky summers feel different, smell different, and sound different than Michigan. They feel different because it’s so humid, you can feel the water in the air. This now, I can’t describe this now. Every not and then, if I’m in a place that is real woodsy, and it’s hot and humid, and there’s been some cut grass of something. Something that’s kind of decaying. I’ll get a whiff of it here, but it’s not often. And I think, oh, that smells like Kentucky. And the bugs are so loud. It’s bugs, bugs, bugs. So the crickets, and bugs and cicadas and everything. It’s interesting. (Betty Worldview—Nature Interview)

Allen explains that his personal experiences in nature are peaceful. He explains, “If I want to get away, that’s where I go. That is why I camp. A sense and feeling of calmness that puts over me. And it does give me good peace” (Allen Worldview—Nature Interview).

Religious Beliefs

In their description of nature and the natural world, all the participants, at some point, referred to their religious beliefs. For example, in his Worldview—Nature Interview, Damon explains,

I think that nature is spiritual at a certain point. Nature itself it spiritual, but it is a revelation of the Creator, which is a spiritual act...God provides for us through nature a lot more than we think He does. (Damon Worldview—Nature Interview)

Likewise, Ian refers to his faith when he explains, “I see in nature the work of God. That’s for sure...try to explain the universe and the millions of galaxies without God. That’s a no-brainer” (Ian Worldview—Nature Interview).
A number of participants talked about the relationship between their religious beliefs and nature and the natural world by referring to the spiritual experiences they feel when interacting with nature. For example, referring to her thoughts about the spirituality of nature, Elizabeth states, “I can remember one summer when I was in Europe. I stood there in the Alps, and there was hardly anyone around. All I could think of was ‘My God, How Great Thou Art,’ that song” (Elizabeth Worldview—Nature Interview). Likewise, Frank states,

I think that sometimes it’s hard to look at beautiful things, whether it is forests, oceans, sunsets, and things like that and not just get a sense of how this can’t just be a random thing. There has to be a Creator. I think that is seen in Scripture too in general revelation and things like that. (Frank Worldview—Nature Interview)

Allen also communicates this idea of a spiritual experience with nature when he explains,

Powerful, it is a very powerful thing. Obviously. Exciting, dangerous, powerful. The wow factor. When I look at exciting, it’s the wow of nature. I mean, “wow!” I don’t know about you but when I go out and I look at it, I think “oh my!” This is incredible. Beautiful. It strengthens my faith. That God put this here for us to enjoy and to also use. (Allen Worldview—Nature Interview)

**Aesthetics**

In addition, participants often referred to aesthetics while articulating their views of nature and the natural world. For example, Frank states, “I definitely see beauty in nature. All the different aspects of nature. All the different places you can go and visit: oceans, forests, mountains, and things like that. I don’t know how you can’t see beauty in nature” (Frank Worldview—Nature Interview). Likewise, Grace explains, “I think that it is beautiful. With all the colors, the variety of textures, shapes, etc...definitely with the variety of senses that you get” (Grace Worldview—Nature Interview).
Several participants noted that even though they typically thought of nature as beautiful, there were parts of nature that were not always aesthetically pleasing. For example, Betty explains, “I think nature is beautiful. Even the things that are not aesthetically beautiful are beautiful as they are natural” (Betty Worldview—Nature Interview). Likewise, Grace states, “There are a lot of things in nature that I don’t think are beautiful too. I think there are certain plants and animals that are ugly. You just look at them and think, ‘oh no, you are not pretty’” (Grace Worldview—Nature Interview).

**Interest in Nature and the Natural World**

As a part of the Worldview—Nature responses, many participants expressed their own personal interest in nature and the natural world. For example, Grace states,

Nature is exciting. Yes. If you think about how complicated it is and all these other words that we are talking about. Some people don’t get excited about it. I don’t know why. But I think that understanding and learning about it and seeing the great variety makes it exciting. (Grace Worldview—Nature Interview)

Frank explains, “Nature is something that can be studied so that we can learn more about it. I think we should study it because I think we should always try to learn more about it” (Frank Worldview—Nature Interview). Allen talked about his personal interest by explaining,

It’s very exciting. I know that it excites me a lot more than a lot of other people. Because my wife, I get directions all the time from her: “Don’t be identifying trees, and finding bugs, etc...” So for me, it’s very, very exciting. (Allen Worldview—Nature Interview)

Additionally, later in his interview, Allen explains,

I’ve always felt this way, in terms of education as well, knowledge and the knowledge of nature is a gift that God has given us. And so for me, to me, there is an answer out there. And an exciting part of the process is to find out about it. And that’s why I do think that nature is explainable. (Allen Worldview—Nature Interview)
Concern for the Care of the Natural World

In their Worldview—Nature Interviews, many of the participants expressed a concern for the care of nature and the natural world. For example, Frank explains,

I believe nature needs to be protected. I would say for the most part that’s true. I just think of all the places that we are losing nature and resources. And trying to protect trees, and trying to control pollution, and keeping our water pure, and things like that. At the very least, set aside areas that can’t be developed. (Frank Worldview—Nature Interview)

Likewise, Betty states, “Doomed, I don’t think so. I think there are enough people who are wanting to make amends for what we’ve done wrong.

Several participants integrated both their religious beliefs and their concern for the care of nature and the natural world. For example, Grace states, “Because it is a product of God’s work, it is something that should be taken care of and held in high esteem and not abused” (Grace Worldview—Nature Interview). Likewise, Allen explains, “God put this here for us to enjoy and to also use. To use it in a way that is, obviously, a benefit to use without destroying nature” (Allen Worldview—Nature Interview).

Overall, participants discussed nature and the natural world in terms of their religious beliefs, scientific understanding, content areas, personal experiences, aesthetics, interest, and concern for care of the natural world.

Worldview—Causality: TOPE Analysis

Overall TOPE Results

Each participant completed a TOPE questionnaire (Appendix F). This instrument used to assess the preferences of participants for the causal explanation for various scenarios presented asks participants to pick the explanation they most prefer and to explain their choice. Table 11 shows participant choices for each individual TOPE item and
Table 11  
Participant TOPE Scores by TOPE Item

| Tope Item Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | Overall TOPE Score |
|------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|-------------------|
| Allen            | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 11               |
| Betty            | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 0  | 0  | 1  | 0  | 12               |
| Carl             | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 12               |
| Damon            | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 12               |
| Elizabeth        | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0  | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 10               |
| Frank            | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 13               |
| Grace            | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 12               |
| Ian              | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 0  | 12               |
| Median           | 1 | 1 | 1 | 1 | 0 | 1 | .5| 0 | 1 | 1  | 1  | 1  | .5 | 0  | 1  | 1  | 0  |                  |

*Note. A score of 1 denotes participant chose more scientific explanation. A score of 0 denotes participant chose less scientific explanation.*
an overall score. The number of more scientific explanations picked by each participant
determined his or her overall TOPE score.

As a group, the participants picked the more scientific explanation more often than
the less scientific explanation. Out of 17 items, the average number of more scientific
explanations picked was 11.75 with a high score of 13 and low score of 10. Figure 13 shows
a summary of overall TOPE scores for the participants.

**Individual TOPE Item Analysis**

The overall TOPE scores did not show much variation (scores from 10-13). In fact,
there were five TOPE items (#3, 4, 6, 11, and 12) where all participants picked the more
scientific explanation. Furthermore, there were an additional four TOPE items (#1, 2, 15, and
16) where all but one participant picked the more scientific explanation, and two TOPE

![Figure 13. Overall TOPE scores for participants. (M = 11.75)](image)
items (#9 and 10) where all but two participants picked the more scientific explanation. Therefore, there were eleven TOPE items where most participants (either all or all but one or two) picked the more scientific explanation. In contrast, there were four TOPE items (#5, 8, 14, and 17) where all but one or two participants picked the less scientific explanation. Finally, there were two TOPE items (#7 and 13) for which responses were evenly divided between the more scientific explanation and less scientific explanation. This section will analyze the responses to the TOPE items and attempt to determine if any connections can be made between participant responses to those TOPE items and participant conceptions of NOS, responses to the Religious Beliefs survey, or beliefs revealed during the Worldview—Nature Interview.

**TOPE Item 1**

For this TOPE item, seven of the eight participants picked the more scientific explanation. This TOPE item states,

Reports from a recent space flight indicate a new material has been identified in outer space. Although insensitive to the presence of ordinary matter, when approached by a human being it glows brightly in a variety of colors.

1. The new material is composed of atoms which are sensitive to the heat radiation emitted from human beings. This radiation excites the planetary electrons of the material’s atoms. When these electrons return to their ground state they emit light radiation which is determined by the distance between one atom and the heat.

2. It has long been suspected from other evidence that human beings give rise to psychic emanations, but the main difficulty has always been the development of a suitable detector for this influence. This new material appears to be an ideal detector for it is sensitive to human proximity as well as operating over a wide range of personality types.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.
In their explanations for their choice of the more scientific explanation, most of the participants stated that they picked that explanation because it sounded more scientific. For example, Allen explains, “there is more scientific evidence to support explanation #1” (Allen TOPE Item #1). This scientific reasoning, including the idea of being testable, is echoed in Frank’s response, “I think that this is because it seems like it is an explanation that could easily be tested. #2 is a bit ‘out there’ and it would be hard to prove these psychic emanations scientifically” (Frank TOPE Item #1).

Ian was the only participant to choose the less scientific explanation. However, as he is explaining his choice, he states that his choice might be the less scientific choice. For example, he explains,

> Based on the information I’d pick explanation #2 although it sounds “less scientific”. I dislike explanation #1 because if explanation #1 is correct then heat could also be given off by objects that are not human of the same temperature and these objects should cause the material to glow also. There is no information given that this is the case and, in fact, the opposite is implied. One thing I’m wondering about in #2 is what is the “other evidence”? Further, was the “other evidence” gathered in a scientific way? So, I’m reluctant to accept #1 but at the same time have questions about #2. (Ian TOPE Item #1)

It appears that even though Ian chooses the less scientific explanation, he is aware that it is the less scientific explanation. Furthermore, he uses scientific reasoning to explain why he feels that the more scientific choice in this TOPE item is still not very scientific. At the end of his response, he clarifies that he has questions about both explanations. Therefore, it appears that all participants, including Ian, demonstrate a scientific way of thinking about the world as reflected in their explanation choice for this TOPE item.
TOPE Item 2

For this TOPE item, seven of the eight participants picked the more scientific explanation. This TOPE item states,

Recently astronomers have observed an increase in radio wave activity of particular frequency from a particular sector in the sky. This observation has caused a stir and a great deal of speculation as to its explanations. So far there are two explanations that the astronomers are arguing most about:

1. Man has often doubted that he was alone in this vast universe. These radio waves might well be radio signals from some far civilization upon which we have stumbled or indeed they may even be meant for us.
2. There are many physical bodies in the heavens which emit radio waves. These emissions fluctuate and chances are these new emissions will be found to fall within the regular patterns of chance fluctuation.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

In their justifications for their choice of the more scientific explanation, most of the participants stated that that they picked that explanation because it sounded more scientific. For example, Frank states,

I would choose #2. I feel that my reasoning is similar to item 1 in that explanation #1 seems less scientific. I think that it may be hard to prove either of the explanations but since there isn’t too much other evidence to support other civilizations, #2 seems more likely. (Frank TOPE Item #2)

Likewise, Grace explains,

I cannot say that there are no other living things out there that could produce radio waves, but I think there is such a low likelihood that #2 is the best choice. I tend to go with the rational explanation that is backed up by experience. Humans know that radio waves can be produced in a variety of ways and this could just be a new manifestation of radio waves. (Grace TOPE Item #2)

Ian also refers to “natural processes” in his explanation of the more scientific choice,

I’d prefer #2. The information given does not indicate the increased radio wave activity has any indications of “intelligence” behind them. For example, intelligence would be indicated if the radio signals came in a
bursts of 1/sec, 2/second, 3/sec (indicating counting) or in bursts of 3,1,4,1,6 per second (indicating $\pi = 3.1416$ which is the ratio of circumference to diameter for a circle). We do know that many things are happening and continue to happen by natural processes in the universe and if a study is made of this section of the sky there might be an object found which is responsible for the increased radio signal activity. (Ian TOPE Item #2)

Several participants referred to their religious beliefs as a part of the explanation for their choice. For example, Elizabeth explains, “I believe God created this world, and I’m not convinced that there are other civilizations out there. It is easier for me to believe that some other physical bodies exist which would affect the radio wave activity” (Elizabeth TOPE Item #2). Here, she acknowledges her belief in God, but then proceeds to pick the more scientific explanation.

Allen was the one participant who picked the less scientific explanation for this TOPE item. In his response, he explains, “although it is true that many physical bodies emit radio waves (all the suns do), there is a possibility there is a far off civilization. To say no would limit what God is capable of doing” (Allen TOPE Item #2). Like Elizabeth, he references his belief in God and appears to cite God’s power as the reason for choosing the less scientific explanation.

**TOPE Item 3**

For this TOPE item, all participants picked the more scientific explanation. This TOPE item states:

Some people were observing a demonstration that involved a miniature red train car, a bit of track, and a tunnel. When the demonstrator pushed the train car into the tunnel a blue car came out the opposite side. When the blue car was pushed back into the tunnel the red car reappeared out the other side. People suspected that there were really two cars, originally the blue one being hidden by the tunnel.
To test this idea they listened carefully when the red car was pushed into the tunnel feeling sure that they would hear it knocking the blue car out the opposite side. Try as they might, they could hear no sound of a collision. The people then fell into two groups over the matter:

1. Some people found the demonstration intriguing and amusing. They considered the demonstrator to be a kind of magician who was proving that the hand really is quicker than the eye.

2. Other people recalled that like-poles of magnets repel each other. So perhaps there were two cars each with a magnet. Like poles faced each other so that one car entering the tunnel drove the other out without ever touching.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

A number of the participants refer to their choice as being more scientific (versus magic) in their responses. For example, Allen explains, “It is a matter of science vs. magic. I do not believe in magic. Number 2 is somewhat plausible” (Allen TOPE Item #3). Likewise, Frank explains, “definitely #2. #1 doesn’t really even list an explanation while #2 lists a very plausible explanation and one that could easily be tested by anyone with a few magnets! Magicians and science usually don’t mix too well” (Frank TOPE Item #3). Furthermore, Ian cites the need for a “natural explanation” for the event as he explains, “I’d be more willing to accept #2. A natural explanation is to be preferred than to think so “magic” is being done. Actually, the “magic” the magician does in #1 might be explained by #2” (Ian TOPE Item #3).

TOPE Item 4

For this TOPE item, all participants picked the more scientific explanation. This TOPE item states:

There once was a woman who to put it mildly drank a great deal. Every day after work she would begin going from bar to bar until late in the night. Hardly a day would pass that she did not end in a state of intoxication. People said that this was not even the worst of her moral degeneracy, but
that she was as well a cruel and spiteful woman. She seemed to delight in unkindness. One morning she did not come to work and later it was learned that she died the night before of a heart attack. Her colleagues at work spent much time that day discussing her fate.

1. As the doctors said she died of a heart attack. She undoubtedly put too much physical strain on her system and her heart finally gave way.
2. She was a young woman who should have had many years ahead of her. She was however decadent and mean, and an untimely death was the consequence.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

A number of participants refer to the need for empirical and tangible evidence in their responses. For example, Allen explains, “scientific evidence has shown that heavy consumption of alcohol does physical damage to one’s body” (Allen TOPE Item #4).

Likewise, Frank explains, “I don’t really believe that God struck her dead as a consequence for her actions! Again, this is not something that could be proven to any degree while explanation #1 could at least show evidence of heart failure” (Frank TOPE Item #4). Grace echoes those same ideas as she states, “I do not believe that you die of meanness, although it may have physical consequences on your body because of the stress it creates. Most likely she died due to the chemicals she poisoned her body with. I say #1” (Grace TOPE Item #4).

TOPE Item 5

For this TOPE item, six of the eight participants picked the less scientific explanation, and only two participants picked the more scientific explanation. This TOPE item states,

Occasionally when entering a room for the first time one gets the distinct impression that he has been there before. This impression can be very strong and disturbing, and all the more because one is sure that he has not ever seen the room before. There seems to be two reasonable explanations for this phenomenon:

1. This is an example of déjà vu which is something almost all of us experience from time to time. It is remembering a place you had never been to before or an object or person you have never seen before. This
phenomenon is a reminder of the vast complexity of the human mind, a complexity of which we understand very little. What we understand least is the capacity of the mind to perceive things outside the range of our basic physical senses.

2. The human brain is a complex electro-chemical computer. Although for the most part it functions faultlessly there are occasional lapses. The above is such a case. After the first glimpse of the room there is an instantaneous functional lapse and recovery. The lapse causes the initial glimpse to be separated from the current perception of the room. The result is that the initial glimpse becomes like a memory. One is deceived into thinking that he has seen the room before.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

Two of the eight participants, Damon and Ian, picked the more scientific explanation. Damon explains that although we (the general public and scientific community) do not always have a clear understanding about how memories are made and stored, he still feels explanation #2 is the one he most likely would accept. He then explains,

We are finding that more and more of the problems associated with the brain are due to injuries or chemistry or imbalances—I don’t see why déjà vu might not be explained in a similar way someday—when we look in the right place in the right way. (Damon TOPE Item #5)

Likewise, Ian explained that he felt that explanation #2 was more scientific,

Remembering a place you have not been to before is impossible. “Remembering” implies a previous action which is then remembered. Explanation #2 sounds more scientific. #2 would give an explanation for what is happening. There actually is a previous action which is then remembered. (Ian TOPE Item #5)

The participants who picked the less scientific explanation as the one they would be more willing to accept seemed to explain that the brain and human mind were just too complex and complicated ever to understand fully. Therefore, they felt more comfortable with a choice that communicated that complexity. In addition, Carl stated, “I don’t buy into
the brain being like a computer. I think there are many differences between the two” (Carl TOPE Item #5). Interestingly, Frank explains,

#2 is interesting and seems a bit more scientific but I am going with #1 on this one. Mostly because #2 seems way too complex (although that is not a very good reason). I think that our brain is very complicated and that we will never fully understand how it functions. Therefore, I like #1. (Frank TOPE Item #5)

It appears that although Frank picked the less scientific explanation, he seemed to recognize that his choice was less scientific. However, he seems to get caught up in the complexity of the more scientific choice and, therefore, picks the less scientific explanation.

Several other participants also echo this same idea that they recognize that they are not choosing the explanation that is more scientific, that they do not completely agree with either explanation, or that they had difficulty picking which explanation they preferred. For example, Carl states, “Tough choice but #1 is the slight winner” (Carl TOPE Item #5).

Likewise, Elizabeth explains,

This one was difficult for me. I have experienced this “déjà vu” and it is very strange. I can’t explain why it happens and I feel I just don’t have enough information to say why it occurs. (If someone had scientific proof for #2, I would probably accept that explanation.) (Elizabeth TOPE Item #5).

This item deals with the human body and its functioning—specifically the functioning of the nervous system. The less scientific explanation talks about the vast complexity of the brain and how we will never be able to fully comprehend its workings. In their Worldview—Nature Interviews, all the participants talked about how nature and the natural world are very complex. So, one can assume that all the participants possibly agreed with the less scientific explanation. However, six of the eight participants picked this explanation, and this was not the more scientific explanation.
The aspect of NOS that most closely relates to TOPE Item #5 and the possible explanations given is the empirical basis of science. Both Damon and Ian alluded to this empirical nature of science in their responses. Damon talked about scientists finding that “more and more of the problems associated with the brain are due to injuries or chemistry or imbalances” (Damon TOPE Item #5). Ian stressed the need for actually having observations and empirical data on which to base your explanations:

“Remembering” implies a previous action which is then remembered. Explanation #2 sounds more scientific. #2 would give an explanation for what is happening. There actually is a previous action which is then remembered. (Ian TOPE Item #5)

The VNOS continuum scores indicate that both Damon and Ian scored a “+++” on the continuum indicating they had an informed view of the empirical NOS and illustrated that with an example during their VNOS Questionnaire and/or NOS Follow-Up Interview. Damon and Ian were two of the three participants that scored a “+++” on this aspect of NOS. Therefore, it might appear that participants with a high understanding of the empirical NOS might also pick the more scientifically compatible explanation for causality for this TOPE item.

However, it is important to note that all participants articulated an informed conception of the empirical aspect of NOS. Therefore, articulating an informed conception of the empirical aspect of NOS is not necessarily related to choosing a more scientifically compatible explanation for causality for this TOPE item. Rather, the participants in this study appeared to be more comfortable choosing the explanation stressing the complexity of the human brain. However, several participants were able to recognize and justify their reason for choosing the less scientific explanation.
**TOPE Item 6**

For this TOPE item, all participants picked the more scientific explanation. This TOPE item states,

Two men became tired of working for their living so they decided to rob a bank to make themselves rich. They took guns, went to a local bank and demanded all the money. An alert policeman saw what was happening and intervened. The robbers fearing capture fired their guns. In the confusion they managed to escape in a stolen car leaving behind several injured and dying people. By this time the robbers were panic stricken and raced down the road at a very high speed. On a curve the driver lost control of the car and both of them died in a ghastly accident. Amongst the people who read about this incident in the newspapers there seemed to be two feelings about why these robbers died:

1. **Why did these men die?** We may be glad that they did die being so evil. The "how" however is more simple. Their evil deed was poorly planned. Had they carefully thought it all out ahead of time they either would have abandoned the idea or would have developed a much less reckless plan.

2. **Sometimes we look around and see the evil that people get away with, and we think to ourselves, "There is no justice." But often there is justice and here is a good example. These men willfully decided to do evil. Why did these two die?** It was the just price of their evil.

Which explanation do you find more acceptable? Explain.

The more scientific explanation for this item is choice #1.

In their responses, several participants specifically refer to scientifically compatible explanations, involving natural phenomenon, for the scenario presented. For example, Allen states, “they died because their car physically ran off the road” (Allen TOPE Item #6).

Likewise, Damon explains, “the men died because the friction between the tires and the road was insufficient to keep the inertia of the car from taking it in a straight line path off the road” (Damon TOPE Item #6). Similarly, Betty refers to natural causes when she explains,

Again, I don’t believe that people are punished for their evil deeds except by natural consequences. The men died as a result of the consequences of
their actions – a poorly planned robbery and a panic response that led to the crash. (Betty TOPE Item #6)

Most participants also referred to the idea that although they believed that the men in the scenario were evil, that was not an explanation they found sufficient. In addition, they refer to their religious beliefs as they explain their choice. For example, Damon explains,

Driving fast on curvy roads kills good people and bad people. I think careless or reckless might be a better word to describe why these men died rather than evil. God doesn’t kill people, or allow them to be killed, simply because they commit acts of evil. People choose what they are going to do, these men chose to put themselves in this situation and were reckless from the beginning – it seems that if they’d planned better they would have robbed a bank from which they could more easily escape. If God repaid people for their evil, there would be no one left. (Damon TOPE Item #6)

Likewise, Elizabeth explains,

Although justice may have been served in this case, I don’t think that is ‘why’ these men died. Their plan was hastily formed and bad things happened – things that they may have regretted had they lived. (Even if they had had a well-thought out plan, things could have gone wrong.) Although in the Bible God punished people for their wrong doing, I guess I don’t think that we can conclude that when something bad happens, God is meting out justice. (Elizabeth TOPE Item #6)

As seen, participants are able to incorporate various religious beliefs with their reasoning for choosing the more scientific explanation for this TOPE item.

**TOPE Item 7**

For this TOPE item, four of the eight participants picked the more scientific explanation, and the other four participants picked the less scientific explanation. This TOPE item states,

In the past when a man’s heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man’s heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about
the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is, the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.

2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

Responses were mixed on this item. Betty, Carl, Frank, and Ian were the four participants who picked the more scientific explanation. In his explanation of this choice, Carl said, “while #2 might be plausible, it is unable to be tested. Explanation #1 provides a path to explain what is happening that is very believable and more backed by scientific explanations.” Here, Carl points to the empirical and testable nature of science. Somewhat along the same lines, Frank states,

I would be more willing to accept #1. I think that declaring someone dead when their heart stopped is just a simplification. There are still parts/structures that are alive for a bit longer. Therefore it seems very reasonable that these visions are actually dreams. #2 is a bit too philosophical for me and I have trouble seeing where science fits in to this. (Frank TOPE Item #7)

While four of the participants did choose the more scientific explanation, they also explained that they would be willing to accept the other choice. For example, Betty states,

Although I do believe that a man’s spirit doesn’t die, I don’t think these near death experiences are actually what one might call “heaven.” I think the
explanation that the brain doesn’t immediately stop when the heart stops is a better explanation. (Betty TOPE Item #7)

Like Betty, the other three participants indicated that they have religious beliefs that would allow them to accept the less scientific explanation as an explanation; however, they went on to say that the explanation that they were most willing to accept was the more scientific explanation.

Two of the participants who picked the less scientific explanation for this TOPE item mentioned they thought that the more scientific explanation was scientific. For example, Grace stated that “the first explanation makes sense, and maybe this explanation scientifically explains what is happening, but I still believe #2” (Grace TOPE Item #7).

Likewise, Damon states,

I would have been more inclined to pick number 1 until the guy came and spoke in chapel a couple years ago about his own experience with exactly this situation. I know that there is life after death both for our spirit and our body. I know that we have no idea what happens “in between”. I don’t know if I agree with the use of the phrase “first empirical evidence” because the data cannot be repeated by other experimenters—it’s not scientific. However, it seems that people describing personal experiences in these situations have some similarities to their accounts. I’m not sure – I’ve never had one myself but it is plausible to me that #2 might be the truth. (Damon TOPE Item #7)

It is interesting to note that Damon was one of the participants who scored highest in the empirical nature of science on the VNOS Questionnaire. He does allude to this strong sense that science is based on empirical evidence. Nevertheless, as he discusses his choice of the less scientific explanation, he does identify it as “not scientific.”

This item deals with the human body and its functioning—specifically the functioning of the brain and the nervous system. In addition, the less scientific explanation evokes the idea of a spiritual world and religion by using talking about an afterlife and the
“spirit of a man.” In their Worldview—Nature Interviews, all participants expressed they believed that nature is created by God. In addition, all participants teach at a private, parochial school which states, as a part of its statement of faith,

> We believe in one God, the Father, Son and Holy Spirit, who has revealed himself in the Holy Bible. This God is present today and controls both humankind and history. We believe and confess that: God shows himself through all he has made—for God has made everything. (Grand Rapids Christian Schools, 2010)

The four participants who chose the less scientific explanation all used their religious beliefs as a part of their explanation for their choice. For example, Allen states that “I know that the Holy Spirit can live in us but what happens when our body dies is still a mystery to me. I do know that I will have ‘eternal life’” (Allen TOPE Item 7). Likewise, Elizabeth states

> I would say the man’s soul, rather than his spirit is alive. As a Christian, I believe that a person’s physical body will die but that his soul will live on—either going to heaven or hell. I don’t know what these places will be like, but I believe they exist. Part of me likes to think that people who have ‘died’ and come back to life have had an experience with the afterlife—with God. (Elizabeth TOPE Item 7)

However, no pattern was found with any aspect of NOS and responses to this TOPE item.

**TOPE Item 8**

For this TOPE item, six of the eight participants picked the less scientific explanation, and only two participants picked the more scientific explanation. This TOPE item states,

> In many areas of the world today the health of the people is looked after by traditional and herbal medicine practitioners. These traditional physicians practice a healing art based on generations of accumulated knowledge. In spite of this, the modern study of medicine does not include any areas of this traditional knowledge. Recently doctors concerned about this issue have divided into pro and con groups:

> 1. The study of modern medicine is the study of western medicine. This should tip us off to the real reason behind the resistance to the
scientific study of traditional herbal medicine. It is pure and simply western chauvinism. From the scientific point of view there is no reason for not carefully researching well-documented traditional cures. The findings would benefit all of mankind; and in addition there would be a greater appreciation of the traditions of non-western peoples.

2. Modern experimental medicine has been successful largely because it is directed by rational theory. The theoretical structure of a science tells the investigator which avenues of experiments are most likely to be profitable, thus avoiding many dead ends. Since there is no such structure in traditional medicine a researcher would be left to follow dozens, even hundreds of nebulous accounts of "cures that work." Such ad hoc experimenting is wasteful and inefficient. It is for this same reason that "home cures" that so many families use are not pursued by researchers.

Which position would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

Two of the eight participants, Damon and Frank, picked the more scientific explanation. Frank explains,

I am not sure I really accept either because I feel that both western and eastern techniques can be good. However, if I must choose... I pick #2. I do agree that it is very hard to test or prove that these traditional techniques are actually working because it is hard to follow an approach like the scientific method when conducting these “experiments”. With western medicine, we can test one single variable by setting up controlled experiments. (Frank TOPE Item #8)

Likewise, Damon states,

While there is western chauvinism in many areas, presumably medicine also, I think that enough herbal or traditional medicines have been found to have physiological truth. Also, I don’t think you can discount the ability of a person’s belief that a “cure” will work. The placebo effect is also documented. I guess that #2 is somewhat callous in its money drives all research approach, but it’s true that without sufficient funds, no research gets done. If something looks like it might work or have a basis that can be used and produced on a large scale – that’s when the industrial machine will take over. I don’t know, but I’d bet that many pharmaceutical R & D departments have many, many more dead-ends than successful treatments. I’d also guess that many of the home remedies have indeed been researched but we have just not heard about any of the results that came out negative because what R & D team is going to put in the newspapers
that chicken soup has no benefit or that drinking sugar water upside down will not cure anything. (Damon TOPE Item #8)

In contrast to Damon and Frank’s responses, most of the participants pick the less scientific explanation. However, two participants noted in their explanations that they liked part of the more scientific explanation. For example, Elizabeth states,

#1 (but with part of 2!) I agree that modern medicine is western medicine and there are those who simply won’t accept traditional herbal medicine. I also think that there needs to be a way to research cures. We shouldn’t accept traditional cures to make non-western people feel appreciated, but there has to be a way to research their cures that seem to work to find out why they work. The western way is not always the only way. (Elizabeth TOPE Item #8)

Similarly, Betty states,

I would be more likely to accept #1, even though it doesn’t line up with my normal, objective thinking. I think that traditional and herbal medical practices are often based on natural ingredients that have an underlying medical benefit. Many current medicines are based on components of plants and fungi, so why wouldn’t “natural” medicines also be valid? There are ways that these traditions could be studied scientifically by researchers. (Betty TOPE Item #8)

In addition, all of the participants, regardless of whether they picked the more scientific explanation or the less scientific explanation, indicated they thought there are traditional and herbal medicine practices that may indeed “work.”

This TOPE item appears to be related most closely to the social and cultural aspect of NOS, the subjective and theory-laden NOS, and the understanding of the idea of the scientific method. However, there are no clear connections between participant responses and these aspects of NOS. The two participants that picked the more scientific explanation, Damon and Frank, talked about the importance of following an approach like the scientific method and using controlled experiments when evaluating traditional and herbal medicine
practices. However, there is nothing in their VNOS responses or Worldview—Nature Interview responses that would indicate a connection between either of those and this TOPE response.

One interesting note is that the validation studies for the TOPE were conducted more than twenty years ago (Cobern, 1988a). Since then, the interest, among both the general population and the scientific medical community, in alternative, indigenous, and non-Western health practices has been growing (Aratani, 2009; National Institutes of Health, 2011). In fact, the National Institutes of Health has a specific division devoted to investigating complementary and alternative medicine: The National Center for Complementary and Alternative Medicine. Therefore, it is possible that this TOPE item is no longer a valid question for distinguishing between more and less scientific explanations.

**TOPE Item 9**

For this TOPE item, six of the eight participants picked the more scientific explanation. This TOPE item states,

A startling discovery has recently been made amongst a pre-modern group of people in a remote region of the Amazon Basin. An anthropologist living with these people for a year noted that the council of elders had a perfect record on predicting rainy days. Out of 365 days there were 109 days on which rain began to fall. All of these days were correctly predicted two to four days in advance. For the same period of time the government meteorological forecasts were much less accurate. The elders based their predictions upon the pattern made by dried chicken bones which they would cast a specific number of times each day. The scientist was impressed with the accuracy but skeptical that the bones had much to do with it. He got the elders to cooperate in a number of experiments by which he hoped to determine the real nature of their predictions. None of his hypotheses were confirmed, all were rejected. In the end he was convinced that the predictions must indeed rest upon the chicken bones. Later the anthropologist reported his findings at the symposium; and although his peers agreed with his conclusions they disagreed in their reasons:
1. Pre-modern people although pre-modern are still clever. They skillfully put to use the collective observations and knowledge of their ancestors, as in this case. Modern people are surprised by their achievements only because they think of the pre-modern man as naïve and unintelligent.

2. First of all the anthropologist's studies were rationally designed and carefully conducted. Secondly, his findings are corroborated by the work of other anthropologists amongst other types of people. Thirdly, chemists have recently found that dry bones absorb moisture from the air and that the amount of "bounciness" in the bone depends on how much moisture has been absorbed.

Which side do you find more acceptable? Explain.

The more scientific explanation for this item is choice #2.

In their justifications for their choice of the more scientific explanation, most of the participants stated that they picked that explanation because it sounded more scientific. For example, Allen states,

"It is hard for me to believe that pre-modern people were 100% correct in their forecasting. What was not stated was what observation of the bones did the pre-modern people use. The second one is somewhat more scientific in its approach (Allen TOPE Item #9)."

Likewise, Carl explains, “explanation #2 seems to provide a scientific explanation for the results of the experiment while #1 merely states that pre-modern men are intelligent. Explanation #2 makes no attempt to explain why the chicken bones might predict rain” (Carl TOPE Item #9). Ian also refers to idea that the second explanation is more scientific as he explains, “I like #2. There is in #2 a “scientific flavor” when the dry bones’ water absorption vs. bounciness is mentioned” (Ian TOPE Item #9). Elizabeth states,

"I guess I’m thinking like a scientist on this one and want there to be a scientific explanation for why the bouncing chicken bones work. It’s not that I think pre-modern man is naïve and unintelligent but that there is a reason for why watching the bones work. (Elizabeth TOPE Item #9)"
The two participants who picked the less scientific explanation, Damon and Frank, still referred to various types of observations in their justification of their choice of explanation.

For example, Frank explains,

However, I think it is very possible that these elders have paid attention to various signs and feelings and used these as their clues. It seems like a lot of older folks can “feel” when rain is coming due to changes in pressure. Maybe this is what the elders were using while pretending it was chicken! (Frank TOPE Item #9).

Likewise, Damon explains, “I’d have a harder time believing that the chicken bone and the weather were connected than that the people had learned to read the sky/wind/animals/etc... around them” (Damon TOPE Item #9). Therefore, even though these two participants picked the less scientific explanation, they still allude to the empirical aspect of NOS in their justifications.

**TOPE Item 10**

For this TOPE item, six of the eight participants picked the more scientific explanation. This TOPE item states,

Pea seeds when passed through a magnetic field germinate faster than seeds which are not passed through a magnetic field. There appears to be two logical explanations for this:

1. The magnetic field has an effect on the pea seed chromosomes. This results in faster cell division due to the pre-alignment of the chromosomes by the magnetic field. The seeds therefore germinate quicker.
2. After fertilization there is a principle of life which begins to drive the growth process. At an early stage that principle can be stimulated and quickened by many outside forces such as a magnetic field. Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

In their justifications for their choice of the more scientific explanation, most of the participants stated that they picked that explanation because it was, in fact, more scientific.
For example, Carl explains, “explanation #1 is based on scientific fact that apparently has been observed in the lab while explanation #2, while it may be true, has no means of proof or justification” (Carl TOPE Item #10). Likewise, Ian states, “I like #1 better. It is more specific with the cause-effect relationship” (Ian TOPE Item #10). Frank also explains,

I would accept #1 because it seems more scientific and therefore more testable. #2 is way too vague in what these forces and principles are. It seems like #1 could be tested by using this approach on other seeds to see if their germination times increase as well. (Frank TOPE Item #10)

The participants who picked the less scientific explanation seem to have perhaps forgotten that the TOPE items are fictitious, and that they simply needed to pick the explanation they found more acceptable. For example, in his response, Allen states,

“basically I have never heard of chromosomes being passed through magnetic fields. I have no reasonable explanation to give” (Allen TOPE Item #10). Likewise, Elizabeth explains, “I don’t think the magnetic field could cause chromosomes to line up. I could accept that a magnetic field could stimulate a change in the seed so it could germinate more quickly” (Elizabeth TOPE Item #10). Her response indicates that she is focusing on the actual content in the question rather than the question of causality. Consequently, these responses are not good indicators of these two participants actual beliefs regarding causality for this scenario. Therefore, the participants demonstrate a scientific worldview in terms of causality in that their explanations include reference to the natural world, empirical observations, and the testability aspect of science.

**TOPE Item 11**

For this TOPE item, all participants picked the more scientific explanation. This TOPE item states,
When plant seeds are grown in small pots it is possible to quicken their growth rate by periodically shaking the pots. This "shaking effect" is poorly understood but there are two schools of thought on the matter:

1. The roots of plants use up first the nutrients in the soil which are closest. The result is that the amount of soil nutrients increases with distance from the roots. Shaking stirs up the soil and helps bring richer but distant soil into contact with the roots.

2. All living things benefit from an occasional but gentle stirring up of their environment, and even of themselves. It gets the juices, fluids and chemicals moving and flowing. It provides fresh air and removes the stale. It encourages, one might say, the processes of life.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

In their responses, a number of participants specifically state that they picked the first explanation because they felt it was more scientific. For example, Allen states, “because it provides more scientific evidence” as his reason for his choice (Allen TOPE Item #11).

Likewise, Betty explains, “#1 makes more sense to me. It relies more on objective reasoning: the use of nutrients in the soil. #2 sounds good, but it is not based on any reasonable evidence” (Betty TOPE Item #11). Carl explains, “explanation #1 is a specific hypothesis for what is happening and it can be scientifically tested. Explanation #2 is a broad statement that is more about feelings than about facts” (Carl TOPE Item #11). Likewise, Grace states, “the second explanation seems more a philosophy than a scientific explanation” (Grace TOPE Item #11). As illustrated by their responses, the participants prefer the more scientific explanation precisely because it is more scientific as it is testable, natural, and empirical.

**TOPE Item 12**

For this TOPE item, all participants picked the more scientific explanation. This TOPE item states,

Bird migrations are an interesting phenomenon. For instance some geese can fly thousands and thousands of kilometers from one point on the earth
to another never getting lost. This remarkable feat of navigation is of great interest to biologists and also controversial. There are two much debated explanations:

1. Some biologists view bird navigation as a kind of natural movement. For instance, humans, can both walk and crawl; but they always walk because that is what is natural for them to do. It is possible for geese to fly in the wrong direction but that would be like humans crawling. They do not do it because it is unnatural.

2. Some biologists are quite convinced that wind currents act like Coriolis forces on the birds. The geese are sensitive to very slight variations in wind force and direction. By instinct they react to these variations and thus maintain their course.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

In their responses, several participants refer to scientific characteristics such as being empirical, experimental, natural, logic, and more scientific. For example, Allen explains, “#2 provides more concrete rather than abstract scientific evidence” (Allen TOPE #12). Betty states, “#2 is a more logical explanation. Once again, it is based on objective, testable ideas. #1 is too vague and not testable. How would we know what “feels wrong” to a bird??” (Betty TOPE Item #12). Carl refers to the experimental aspect of science when he explains, “Explanation #1 is not testable. Explanation #2 could be tested using birds and a huge environment where wind forces and directions can be changed” (Carl TOPE Item #12).

Likewise, Frank states,

I’ll go with #2 again because it seems more scientific. #1 just seems kind of weird and a very weak explanation – it still doesn’t really explain how they know what the correct direction is. #2 is at least a decent explanation but I do think it would be pretty hard to test/prove. (Frank TOPE Item #12)

Ian refers to the natural characteristic of science as he states, “Number 2 would be the preferred choice. This gives a natural explanation which I prefer” (Ian TOPE Item #12). As
demonstrated by their responses and justifications for this TOPE item, these participants articulate a worldview with a scientifically compatible notion of causality.

**TOPE Item 13**

For this TOPE item, four of the eight participants picked the more scientific explanation, and the other four participants picked the less scientific explanation. This TOPE item states,

Is it logically possible for a system to explain itself? It appears to be a tautological dilemma since to explain itself a system can only explain the system in terms of itself. For instance is it possible to know how the brain really works since any theory put forward is a product of the human brain? The dilemma seems very discouraging yet scientists are undeterred.

1. The key to understanding any system, no matter how complicated, is in its parts which are necessarily less complicated than the whole. By examining and experimenting with the parts we eventually will learn enough about the whole brain to enable us to restore all neurological disorders.

2. Science has enjoyed great progress in understanding natural phenomena and scientists as a result have come to take progress as a scientific right. They have lost sight of the fact that all human endeavors including progress are limited and unending progress is not to be expected. If neuro-scientists were to remember that then their present viewpoint on the human brain would certainly be more humble.

Which of the above positions would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

Responses were mixed on this item. Allen, Betty, Grace, and Ian were four participants who picked the more scientific explanation. These four participants agreed with the idea that science and scientific knowledge progresses and grows. For example, Allen explains “we also must understand how the parts are interrelated. I believe we will always progress through scientific inquiry. It is a gift from God to preserve knowledge” (Allen TOPE Item #13). Likewise, Betty explains, “I think we already have learned a lot about the human
brain, and will continue to do so as scientists systematically study different components” (Betty TOPE Item #13).

Although the four participants who picked the more scientific explanation tended to focus on the idea that science and scientific knowledge progresses, two of the participants, Grace and Ian, pointed out that, although science does progress, there are limits to this advancement. For example, Grace explains,

I believe that as long as there are things to study and learn about, we will always make progress. The problem is that there will always be something else that is failing apart or changing at the same time, making ultimate perfection impossible to achieve. (Grace TOPE Item #13)

Similarly, Ian explains, “#1 is like a “divide and conquer” idea...although I don’t think it will give the ultimate “Why does it exist?” explanation which I think gets into a more religious/philosophical realm” (Ian TOPE Item #13).

The participants who picked the less scientific explanation on this item explained their choices by pointing out the limits of science. For example, Carl states,

I do believe human progress is limited because there are just some things that cannot be tested for and testing devices are going to have error that will limit their range and scope. I also would argue that sometimes the parts are more complicated than the system. (Carl TOPE Item #13)

Along that same line of reasoning, Elizabeth explains,

I don’t think scientists will fully understand the working of the human brain (at least not in this life!) God, as the great designer, is more complex than we and I just don’t think we have the ability to figure everything out. I think we can continue to progress and learn thinks, but we will never know it all. (Elizabeth TOPE Item #13)

One important note to make here is that although these participants picked the less scientific explanation for this TOPE item, in their justification of their response they
articulate a scientifically-compatible explanation. That is, they talk about the tentative aspect of NOS and the idea that there are limits to scientific knowledge.

This item deals with the concept of systems thinking and theory and the idea of the connections between the individual parts of a system and the whole system itself. The less scientific explanation, #2, talks about the progress that scientists have made in regards to understanding natural phenomena; yet, it highlights the ideas that human endeavors are limited and unending progress should not be expected because it is not possible. As mentioned previously, in their Worldview—Nature Interviews, all the participants talked about how nature and the natural world are very complex. However, not all participants agreed about whether or not nature and the natural world were explainable and understandable.

In fact, participants who, in their Worldview—Nature Interviews, stated that nature and the natural world were not fully understandable or explainable were the same participants who picked the less scientific explanation for this TOPE item: Carl, Damon, Elizabeth, and Frank. For example, Frank chose the less scientific explanation on this TOPE item stated in his Worldview—Nature Interview,

I think overall, with all the different aspects of nature and the natural world, ranging from things like mountains down to what we consider more biology type things like molecules, our nature. It is very complex. And that’s one reason why we will never fully understand it...I don’t know if we really explain things correctly or not. That is the key. I think that definitely some of it will be unexplainable, it’s just too complex for us to be able to really imagine how some of those things work. But I think that we have proven that some of it is very explainable. (Frank Worldview—Nature Interview)

Likewise, Carl states, “I think you can know things about nature, not everything is knowable, but you can know something. You are not going to know all of it” (Carl Worldview—Nature
There is an idea that parts of nature and the natural world are understandable; however, there is some point where nature and the natural world are just too complex for humans to be able to understand. Elizabeth communicates this when she says, “I think that there are certain things that we can know about nature and can explain. But I also think that there are things that we don’t always know. And I’m not sure that we will” (Elizabeth Worldview—Nature Interview).

In contrast, participants who picked the more scientific explanation on this TOPE item, Allen, Betty, Grace, and Ian, were also the participants who stated in their Worldview—Nature Interview that humans can seek to learn about and explain nature and the natural world, even if it might seem confusing or difficult to understand. For example, Betty states,

> There are things that happen in the natural world that are very confusing. Things that don’t make sense like in the past when astronomers studied Mars, and it looks like it was going backwards in its orbit. But it turns out it wasn’t. So there are times when nature is confusing. Although usually those kinds of things can be figured out...We don’t fully understand nature. But is it understandable? Maybe someday. (Betty Worldview—Nature Interview)

Likewise, Grace states, “I think of it [nature] as having enough structure and enough orderliness that we have faith that it will be the same the next time we see it. It’s not going to change on you” (Grace Worldview—Nature Interview). In addition, Ian stated,

> Nature is not unexplainable. But, there are a lot of things that we don’t understand. I guess I will have to agree and disagree. That assumes that you’re given enough time, and that you are smart enough people that you could possible explain everything. If you’re in science, you assume that nature is explainable. So I will say that nature is not unexplainable. (Ian Worldview—Nature Interview)

An analysis of the VNOS results and the Religious Belief Survey results did not show any specific connections or patterns between those responses and responses for this TOPE
item. Therefore, it seems that this TOPE item might serve to corroborate findings from other areas of this research—conceptions of NOS and worldview beliefs related to nature and the natural world.

**TOPE Item 14**

For this TOPE item, seven of the eight participants picked the less scientific explanation, and only one participant picked the more scientific explanation. This TOPE item states,

People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

It is interesting to note that most of the participants include some type of religious reference in their explanation of their choice of explanation for this TOPE item. For example, Betty states, “I do believe that man is separated from the other animals, being made in God’s likeness” (Betty TOPE Item #14). Likewise, Elizabeth states, “Our ‘humanity’ makes us different from all the other of God’s creations, including chimpanzees. We are created in God’s image and we are His special creation” (Elizabeth TOPE Item #14). In her justification, Grace explains,
God created people as a special entity. Perhaps we can explain thoughts and emotions in scientific terms, but the depth of what a human experiences goes way beyond what a chimp would. We do have a great capacity for speech and language that sets us above all other animals and it will remain so. (Grace TOPE Item #14)

Here she explains that, although there may be a natural and scientific explanation for thoughts and emotions, she rejects a naturalism philosophy. So, in choosing the less scientific explanation, she has a clearly articulated reason why she makes that choice.

Likewise, in his justification Ian states,

The thing I like about #2 is that in #2 there is the feel of something “special” (indicated by the word “humanity”) about human beings. Taken one step further, the idea of where the “humanity” comes from can lead to the idea of God and other religious ideas (example—“image-bearers of God”) which I would endorse. Explanation #1 is a completely naturalistic explanation which I feel falls short of explaining “humanity.” (Ian TOPE Item #14).

Not only does Ian indicate that he picked the less scientific explanation because of its implications relating to his religious beliefs, he also indicates that he picked this explanation because it is not simply “naturalistic.” Here he recognizes that the more scientific explanation is one that is naturalistic; however, he goes on to explain why that is not his preferred choice.

Only one participant, Frank, chose the more scientific explanation for this TOPE item. In his explanation, Frank states,

I don’t see how you can study “humanity” so I will go with #1. Although I’m not sure I would call their thoughts and emotions as “simple”, I think they are more simple than humans. Therefore, #1 seems to work...I think that God has given humans this complex gift of speech. (Frank TOPE Item #14)

Even in his justification of the more scientific explanation, Frank appears to question both explanations. Furthermore, he is able to incorporate his religious beliefs into his justification.
An analysis of the VNOS results and the Religious Belief Survey results did not show any connections or patterns between those responses and responses for this TOPE item. Overall, there does not appear to be a pattern or connections between the participants’ preferred explanation on this TOPE item and their responses to the Worldview—Nature Interview or the Religious Beliefs survey. Therefore, it seems that this TOPE item might serve to corroborate findings from other areas of this research—conceptions of NOS and worldview beliefs related to nature and the natural world.

**TOPE Item 15**

For this TOPE item, seven of the eight participants picked the more scientific explanation. This TOPE item states,

The goal that geologists have long had is to acquire enough knowledge about earthquakes so that they can be anticipated hours or even days in advance. Now it has been discovered that many animals can do just that. The geologists are still unsure about just how a particular animal senses a quake coming but there are two theories:

1. There are many things in the environment that animals sense such as danger or changes in the weather. This is an ability that modern people have lost due to their remoteness from nature and reliance upon technology.
2. It has now been learned that there are slight almost imperceptible pre-tremors that come hours, sometimes days before a major quake. These pre-tremors are noticed by animals, particularly grazing animals, which then become quite nervous.

Which explanation would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #2.

In their explanations for their choice of the more scientific explanation, several participants stated that they picked that explanation because it was more empirical or natural. For example, Allen states, “I chose #2 because it involves more concrete (physical)
evidence. The word “sense” (from #1) seems to involve something mysterious” (Allen TOPE Item #15). Likewise, Ian explains,

I prefer explanation #2. This is a natural explanation that makes sense (no pun intended—see next sentence). Animals have greater awareness thru their senses. Explanation #1 implies people had this ability at one time but I don’t think there is any evidence of that. (Ian TOPE Item #15)

In the same way, Carl also refers to the idea of empirical observations in his justification for his choice of the more scientific explanation. He states,

#2 seems the best choice because it is based on the facts [observations] of pre-tremors that are known to exist while #1 is an observation of how human population has changed over time but not necessarily showing a connection between the two. (Carl TOPE Item #15)

Several participants, even though they picked the more scientific explanation, they explain their choice by referring to their scientific content which implies they may have forgotten that the scenarios in the TOPE are fictitious. For example, Frank explains,

#2 seems very reasonable considering that many animals have senses that are much more developed than humans. If many animals can smell 50x better than a human it seems reasonable that they may also be able to perceive these tiny tremors. My problem with #1 is that it doesn’t really say what they think animals are sensing to be tipped off. (Frank TOPE Item #15)

Likewise, Grace explains, #2...Dogs can hear things we can’t, some animals can see in the dark, so it makes sense that some could feel things that we cannot feel)” (Grace TOPE Item #15). Nevertheless, these do pick the more scientific explanation and justify that by referring to empirical evidence they have encountered and other rational explanations this scenario.

One participant, Betty, picked the less scientific explanation for this TOPE item. In her response, she states,

#1 works for me. I do think that animals are more in tune with nature and would be able to read the signs of imminent danger much better than humans. We have become separated from nature and don’t have much
ability (in ourselves apart from technology) to read the signs. (Betty TOPE Item #15)

In her response, she does not state anything that would disagree with the more scientific explanation. Rather, she seems to focus on the idea that since humans live in an increasingly technological society, they do not interact with nature as much on a personal level.

**TOPE Item 16**

For this TOPE item, seven of the eight participants picked the more scientific explanation. This TOPE item states,

Certain planetary bodies appear to deviate slightly from their calculated position in space. The deviation is extremely small. Everyone working in this field agrees:

a) That the deviation exists, and
b) That Relativity Theory offers the most likely explanation.

When asked why they supported this explanation workers gave different reasons:

1. It is difficult to make accurate measurements and existing experimental evidence lends only weak support for the theory. Nevertheless, the evidence gives better support to this theory than to any other.
2. The explanation was published by one of the most distinguished scientists of the 20th century. There is no doubt that he knows more than anyone else in the world about this particular phenomenon.

Which explanation would you be more likely to support? Explain.

The more scientific explanation for this item is choice #1.

In their explanations for their choice of the more scientific explanation, most of the participants stated that they picked that explanation because of the scientific characteristics, such as measurement, data, and experimental evidence, reflected in the more scientific explanation. For example, Betty explains, “explanation #1 is my choice because it is based on evidence (albeit weak) rather than assumption” (Betty TOPE Item #16). Likewise, Carl states, “explanation #1 makes note of measurement error and the fact
that there is some support for the theory. It focuses on the data and measurements while

#2 focuses on the scientist” (Carl TOPE Item #16).

In their responses, Damon and Elizabeth both allude to the tentative aspect of NOS.

For example, Damon explains,

I’d pick #1 mainly because in the area of relativity, the only reason that it is
accepted as an explanation of any phenomenon is that its predictions agree
with experimental results. Not because of who thought of it originally but
because it works. If some experiments or observations come along
someday and disagree with Relativity, then it will be changed or thrown out
in favor of a theory that correctly meshes with observation. (Damon TOPE
Item #16)

Likewise, Elizabeth states,

At the present time, if the evidence gives better support to this theory –
than that is a good theory to support. If, in the future, other evidence
comes along to reject this theory, then views can change. I would rather
look at evidence than believe in just one knowledgeable scientist. (Elizabeth
TOPE Item #16)

In these responses, they also refer to the experimental component of science and the

empirical aspect of NOS.

Ian was the one participant who picked the less scientific explanation. In his

response, he states,

I prefer #2. Although the scientist was not mentioned I think it was Einstein.
The last sentence in #2 would probably have been true “at that time”, i.e.
when the explanation was given. There are many physicists now-a-days
who have taken Einstein’s ideas further. The Relativity idea for planetary
deviation goes beyond classical physics, and Relativity Theory is one of the
most substantiated theories in all of physics. (Ian TOPE Item #15)

Here, Ian seems to apply his scientific content knowledge and forget that these TOPE

scenarios are supposed to be fictitious. Therefore, his response focuses on this content

knowledge instead of other reasons for his choice.
TOPE Item 17

For this TOPE item, seven of the eight participants picked the less scientific explanation, and only one participant picked the more scientific explanation. This TOPE item states,

A physicist at a well-known university was conducting a unique set of experiments. He was interested in the effect of electrical discharges on the growth rates of a particular type of tree. The methodology was simple. He administered electrical shocks to one set of trees but not to second. Over a period of several months he measured and compared the growth rates of the two groups. The scientist’s work caused a stir amongst his colleagues because he admittedly had no theoretical framework for his research. There were two basic opinions about this kind of experimentation:

1. The highly theoretical nature of physics provides an ample number of research problems for experimental work. Theory guided research is more efficient because there is a greater chance of success. This man has picked an idea out of thin air and pursued it for no other reason than idle curiosity.

2. This man should not be criticized for his unique albeit different research problem. All too often progress in many fields is thwarted by over-conservatism and rigid adherence to theory. Creativity and independence should be encouraged so that more discoveries can be made and the understanding of nature increased.

Which opinion would you be more willing to accept? Explain.

The more scientific explanation for this item is choice #1.

Seven of the eight participants picked the less scientific explanation. Most of these participants, in their explanations for their preferred explanation, refer to the process of creativity and curiosity. For example, Carl states, “while I believe that experiments based on theory and guided by theory are very beneficial I do think there is space for experiments that are just based out of curiosity” (Carl TOPE Item #17). Likewise, Elizabeth states,

I think there needs to be room for creativity and curiosity in science. Although it may be true that there could be a better chance for success using theory-guided research (at least most of the time), I believe that not all success is a result of this. Sometimes accidents happen and it is a wise person who follows up because of curiosity rather than just throwing it...
away (penicillin). There will usually be a well-thought out, theory driven reason for most research but not all the time. (Elizabeth TOPE Item #17)

Damon communicates this same idea when he states,

I think that many first steps in scientific discovery were made by people who either purposely did something no one had thought to do before or were trying to “toe the line” but got an unexpected result. Historically many of them were also criticized for their work also but some of it ended up being very important and led to a broadening of the current theories or a shift to a new theory. I think that this man, while maybe a little nutty, may also be a genius for looking for a connection between areas that were thought to be distinct – electricity and plant growth. Creation is tied together so there’s no telling how many connections there might be that we just have not thought to look for. It is sometimes the experiment that looks foolish that turns out to be the one that allows a leap forward. (Damon TOPE Item #17).

This TOPE item relates several aspects of NOS: the subjective and theory-laden NOS, the idea of the creative aspect of NOS, and the idea of the scientific method and how scientists work. The participants who picked the less scientific explanation for this TOPE item all mentioned the creative aspect of NOS. In addition, most mentioned that there is an important place for theory-guided research, but also want to leave room for experiments and scientific activities that are not theory-guided. This reasoning appears to be quite scientifically compatible.

Only one participant, Allen, chose the more scientific explanation for this TOPE item. In his explanation, Allen states, “the question I have is why did he do this? The scientific method has a basic outline to follow” (Allen TOPE Item #17). Although Allen may have picked the more scientific explanation, his response does not necessarily indicate more scientifically-compatible worldview beliefs. In fact, his response appears to indicate a naïve view of the scientific method aspect of NOS.
Allen was one of the two participants who articulated naïve views of the scientific method aspect of NOS. In his response to his choice of explanation of this TOPE item, he refers to the scientific method and how “the scientific method has a basic outline to follow” (Allen TOPE Item #17). The other participant who did not have an informed view of NOS in terms of the scientific method was Ian. In his response explaining his choice of the less scientific explanation for this TOPE item, Ian states,

There are many instances in physics/astronomy where experiment was done first and theory followed. (An example would be in what are known as Kepler’s Laws. Kepler’s theory giving rise to Kepler’s Laws was developed after experimental data recording the planetary positions of Mars was gathered by Tyco Brahe for more than 20 years. Another example comes from electricity. The behavior of a magnet around a wire carrying electricity was observed and measured long before electrical theory explained why it happened. #1 mentions “theory guided research”. It is true that theory guided research is also successful but it is certainly not the only approach worth taking. (Ian TOPE Item #17)

Here, Ian seems to be explaining how data and empirical evidence is used to build theories. Although he does not specifically mention the idea of the scientific method, there may be a connection between his understanding of the scientific method and the use of data and evidence. In fact, in his explanation of his understanding of the scientific method (from his VNOS Questionnaire responses), Ian clearly stated that the scientific method consisted of very distinct steps that always needed to be followed in a precise, and sequential order (see Figure 14). Therefore, it is interesting that Ian did not choose the more scientific explanation for this TOPE item since it would seem to give more support to his idea and understanding of the scientific method. However, it might be that when Ian is presented with a concrete situation, he might articulate his understanding of the scientific method of NOS in a much different way.
I like to think of the Scientific Method as 3 easy steps:
1. Observation
2. Explanation
3. Experimentation

*This method must be followed* (to do things scientifically)!!!

Here’s why:

**Step 1 Observation**—This is where a person says “Hey, look at that!” You must see (or hear or taste) something happen. If you cannot somehow observe, then you are dead. There has to be some sensory input otherwise we will be unaware and unable to do any more (Step 2 & Step 3).

**Step 2 Explanation**—This is where a person says “I bet I know why that happened!” This is where a hypothesis is made.

**Step 3 Experimentation**—This is where a person says “Let’s check it out!” This is where we work with controlled variable and attempt to check out our explanation in step 2. *Whenever step 3 is done it always leads us back to step 1* which may then lead us to revise step 2 which will lead again to step 3 which then cycles back to step 1...
It’s a never-ending-cycle...
Step 1, 2, 3, 1, 2, 3, 1, 2, 3...

*Figure 14.* Ian’s VNOS Questionnaire response regarding the scientific method.

From the participant responses to this TOPE item for this group of participants, it appears that this TOPE item elicits responses related not only to causality but to the creative aspect of NOS and the subjective aspect of NOS. Many of the subjects, although they picked the less scientific explanation, articulated scientifically compatible reasoning for their choices. However, there does not appear to be a pattern between participant responses to this TOPE item and those aspects of NOS. Bell and Lederman (2003) found a similar lack of correlation between understandings of NOS and, in their study, decision making on science and technology issues. In addition, they found that participants made decisions based on personal values, morals and ethics, and social concerns rather than simply on their understanding of NOS. More is discussed on this in the Discussion and Implications section.
Participant Case Studies

Each participant completed a demographic information form, a Religious Belief survey, a VNOS Questionnaire and Follow-Up Interview, a Worldview—Nature Interview, a TOPE Questionnaire, and final Follow-Up Interview. That data helped construct the following case studies. Each case study provides basic background information about the participant, a summary of the participant’s conceptions of NOS based on the VNOS Questionnaire he or she completed and NOS Follow-Up Interview, a summary of the participant’s worldview beliefs based on the Worldview—Nature Interview, and a summary of the participant’s responses regarding causality on the TOPE instrument. In addition, each case study contains a first person interpretive narrative constructed using the best interpretation of the participant’s conceptions of NOS, the participant’s worldview beliefs based on the Worldview—Nature Interview, and the participant’s responses regarding causality on the TOPE instrument. Within each interpretive narrative, superscripts show from which data that section of the narrative is taken.

Allen

Demographic Information

Allen is a 60-year-old male. He has 38 years of teaching experience in a variety of settings and subject areas including K-8 PE (16 years), algebra (2 years), 9th grade PE (30 years), biology (9 years), and physical science (21 years). His undergraduate degree was in physical science and group science, and he has a master’s degree in education.

Views of Nature of Science

Allen’s scores on the VNOS continuum show he has an informed view of the empirical aspect of NOS. His views of the tentative, subjective, creative, social and cultural,
and observation and inference aspects of NOS are emerging. His views of the theories and laws and scientific method aspects of NOS are naïve. Figure 15 summarizes Allen’s VNOS continuum scores. A radar plot also visually illustrates Allen’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 16 shows a radar plot of Allen’s VNOS continuum scores.

**Tentative.** Allen’s responses to the VNOS Questionnaire and NOS Follow-Up Interview illustrate a mixed view of the tentative aspect of NOS. Several of his responses illustrated an informed view of the tentative aspect of NOS. For example, Allen explains, “as more evidence is gained, theories are restructured or tweaked” (Allen VNOS Questionnaire).

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Figure 15. Allen’s VNOS continuum scores. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
In addition, he states, “we learn scientific theories so we have information to reinvestigate or use for other experiments” (Allen VNOS Questionnaire). Likewise, he asserts, “theories do change. Theories change because it’s based on the given information they have at the time...it’s the best model that we have. It could change” (Allen NOS Follow-Up Interview).

Allen does seem to assert that everything in science is subject to change.

Furthermore, Allen provides several examples to illustrate his understanding of how science has and continues to change. In one instance, he explains,

As an example, when Rutherford did his gold foil experiment he hypothesized (from Thomson’s model) that most alpha particles that were sent would go straight through the gold foil. But his actual results showed that some alpha particles were greatly deflected. These results changed this atomic model to include the nucleus. (Allen VNOS Questionnaire)
Likewise, in his NOS Follow-Up Interview he explains,

> Just like certain animals that they thought were carnivores, now they are revisiting and saying that they might be herbivores. And I think, based on the evidence that they have, this is what it looks like. But as they have more discoveries, it changes again. (Allen NOS Follow-Up Interview)

And once again in his NOS Follow-Up Interview Allen asserts,

> If scientists find something other than what they think of as the Higgs particle. What holds everything together? This is what the Higgs particle is supposed to do. So if all of a sudden they find two more particles...I think that in the matter of the next five years we will know some of this. But maybe they will find something different. This theory of the Higgs particle has held together since 1967, but it might not hold true. (Allen NOS Follow-Up Interview)

Given these statements and examples, Allen’s view of the tentative aspect of NOS seems to be informed.

However, just as Allen appears to acknowledge the tentative aspect of NOS, he also makes several assertions that support the idea that scientific knowledge might not always be subject to change—that there may be some absolutes and certainties. For example, Allen explains that scientists are “very certain” about the structure of the atom (Allen VNOS Questionnaire) and that “there are some things that you may be able to prove—there are some absolutes” (Allen NOS Follow-Up Interview). In addition, while he is explaining his views on the difference between theories and laws, Allen explains, “A theory is an idea based on the evidence that you have at the time. They are just not sure that it is totally proven” (Allen NOS Follow-Up Interview). By alluding to the idea that one can *totally prove* some ideas and concepts in science, Allen demonstrates a more naïve understanding of the tentative aspect of NOS. However, since a number of Allen’s responses to the VNOS Questionnaire items and NOS Follow-Up Interview questions articulated a more informed
view of the tentative aspect of NOS, Allen’s overall view of the tentative aspect of NOS is emerging.

**Subjective.** Allen articulated an emerging view of the subjective aspect of NOS. Again, his responses on the VNOS Questionnaire and NOS Follow-Up Interview appear to be somewhat mixed. At one point, in response to a question regarding how different scientists could get different conclusions if they are looking at the same data, Allen articulates a naïve understanding of the subjective aspect of NOS. He explains that he thinks eventually the scientists could agree, “if they become more well-versed in how the Earth works...I think they will get more information as people do more and more experiments. This will help them come to a better conclusion” (Allen NOS Follow-Up Interview). Likewise, in response to whether scientists working separately with the same questions and same data collection procedures will come to the same conclusions, Allen explains, “I would hope the come to the same conclusion” (Allen NOS Follow-Up Interview). Allen goes on to further describe this as he explains, “I don’t think that anything is concrete and in stone. At least we are not that far in our science yet” (Allen NOS Follow-Up Interview). These responses seem to reflect a belief that science and scientists are subjective only because they do not have all the possible data available to them. That is, if scientists had access to enough data, they would be able to remove the subjective aspect of NOS from their work.

One of the differences Allen cites between science and other disciplines of inquiry is that, “much more of it [science] is concrete...you can’t just make theory, you have to have substance too. You need things to substantiate at least part of the theory” (Allen NOS Follow-Up Interview). This seems to allude to Allen’s understanding that science is more
concrete and objective than other disciplines. This objectivity does not reflect an informed view of the subjective aspect of NOS.

Although several of Allen’s responses reflect a naïve view of the subjective aspect of NOS, he did articulate a more informed view in several of his responses. For example, Allen explains,

That is why you have different scientists doing the same experiment the same way. That is why the scientific method is so important because it gives you the format to do it all the same. I think they will come to the same conclusions, but sometimes they don’t. They do not interpret or analyze the data the same way. I just think of my own students. I give them a set of data about a pendulum experiment, and they come up with all kinds of different explanations. (Allen NOS Follow-Up Interview)

In addition, when responding to the question about how different scientists using the same set of data reach different explanations, Allen responded, “I am sure both have evidence to support their claims” (Allen VNOS Questionnaire). This reflects an informed view of the subjective aspect of NOS since it recognizes that different conclusions based on the same data are possible since the background, education, and other beliefs of scientists may affect the development of their explanations. Therefore, since Allen provided responses that demonstrated a naïve view but also some responses that reflected a more informed view of the subjective aspect of NOS, Allen appeared to articulate an emerging view of the subjective aspect of NOS.

**Empirical.** Allen articulated an informed view of the empirical aspect of NOS. For example, he explains, “science is different from other disciplines in that it is more concrete” (Allen VNOS Questionnaire). When answering the question regarding whether or not the development of scientific knowledge requires experiments, Allen explains, “in Greek times, Aristotle and many Greek thinkers came up with how nature worked. They developed the
four-element theory. It was based on logic and reasoning not actual scientific experiments” (Allen VNOS Questionnaire). Likewise, in his interview, he states, “I think you have to be able to do experiments and repeat things” (Allen NOS Follow-Up Interview). These responses imply that Allen believes that logic and reasoning are not sufficient for science. Therefore, this would support a more informed view of the empirical aspect of the NOS. In addition, Allen mentions the idea of scientists collecting and using evidence at several different points in his VNOS Questionnaire and NOS Follow-Up Interview. Therefore, Allen’s responses reflect an informed view of the empirical aspect of NOS.

**Creative.** Allen articulated an emerging view of the creative aspect of NOS. For example, when asked whether scientists use creativity and imagination during their investigations, Allen responds,

> Yes, to set up the experiment, you have to use some imagination and creativity. To come up with experiments, for example the atom. I think that certain people really know how to design experiments better than others. To do that, to me, you have to be creative. I cannot do that very well. I can do the simple ones. But to design an experiment so that you can isolate variables and that kind of stuff. I think is a real gift. I think that scientists have to use creativity and imagination when designing experiments. (Allen NOS Follow-Up Interview)

Furthermore, Allen responded to a follow-up question regarding using creativity and imagination in data collection and data analysis by stating, “I can’t think of any, but I am sure that they do…I would think so. I guess do not want to put limits on how things are done” (Allen NOS Follow-Up Interview).

One interesting aspect of Allen’s responses regarding creativity and imagination is his reference to the scientific method. For example, Allen explains, “I believe a scientist would use their imagination and creativity in all steps of the scientific method. One
conclusion or step might provoke a few more thoughts or possibilities” (Allen VNOS Questionnaire). This explanation does support the notion that Allen does believe that scientists use imagination and creativity. However, since he talks about using creativity in the scientific method, it is important to identify what he is referring to as the scientific method. (A later section discusses his views on the scientific method aspect of NOS in more detail). His notion of the scientific method aspect of NOS is emerging; therefore, this emerging notion limits the scope and ability of scientists to be creative. Thus, since scientists might actually follow some type of scientific method, they cannot be as creative as they would be if scientists could work in ways that are more diverse. Therefore, Allen’s responses reflect an emerging view of the creative aspect of NOS.

**Social and Cultural.** Allen demonstrated an emerging view of the social and cultural aspect of NOS. For example, in his VNOS Questionnaire, Allen states, “I believe science is universal because water is H₂O no matter where you go” (Allen VNOS Questionnaire).

However, in his NOS Follow-Up Interview, Allen states,

> I think that science is affected by social, political, and philosophical values. If you go to certain countries that are theocracy, I’m sure they have much of their science based on what their beliefs are. Which in many cases may be just like taking the Bible and saying that it is a science textbook, which it is not. I think that, depending on where you are, it really does reflect some of the social and cultural values. Good scientists try to do science without all of those things. Science does reflect the social and cultural values. (Allen NOS Follow-Up Interview)

It appears that Allen is developing his understanding of the social and cultural aspect of NOS as he processes ideas about science as “both a collection of facts and a process” (Allen NOS Follow-Up Interview). Therefore, he articulated an emerging view of the social and cultural aspect of NOS.
**Theories and Laws.** Allen demonstrated a naïve view of the theories and laws aspect of NOS. In his VNOS Questionnaire response related to theories and laws, he simply copied from the textbook that he teaches from, complete with a citation. Therefore, it provided no information regarding what Allen’s personal views were regarding theories and laws.

However, his responses in the NOS Follow-Up Interview, Allen explains,

> A theory is an idea based on the evidence that you have at the time. They are just not sure that it is totally proven. Or there is some room for movement there. Like the Big Bang theory: there is some evidence out there for it, but I think that it is not absolute at this time. A scientific law describes much of what happens. For example, Charles’s Law: When you increase the temperature, you increase the volume of the gas. At this point, almost everyone agrees that it is true. And so to me, if you compare the two, the law is the stronger one as compared to a theory. (Allen NOS Follow-Up Interview)

This response alludes to a hierarchical relationship between theories and laws and the idea that theories are less proven and subject to change. This is a naïve view of the theories and laws aspect of NOS.

**Observation and Inference.** The scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough information regarding participants’ views of the observation and inference aspect of NOS. Given this limited data, Allen articulated an emerging view of the observation and inference aspect of NOS. For example, as Allen explains his understanding of the difference between indirect evidence and inference, he states,

> It is getting evidence without actually touching, feeling, or seeing it. So how do you figure it out? It is by the behavior that is exhibited during the experiment itself... so, that is what is meant by indirect evidence. Even though you can’t see it, it is based on the behavior of the different particles, in this particular case. You could get patterns for indirect evidence. That’s
how you could determine whether something is there or what it is. (Allen NOS Follow-Up Interview)

Following this explanation, Allen responded regarding if the *indirect evidence* he had described was the same thing as *inference*. He explained, “No. You infer after you see what happened. In other words, you see what has happened. And then you infer from that” (Allen NOS Follow-Up Interview). Although the data he provides is limited, it reflects an emerging view of the observation and inference aspect of NOS.

**Scientific Method.** Allen articulated a naïve view of the scientific method aspect of NOS. For example, Allen refers to the step-wise scientific method when he explains, “science is different from other disciplines in that it is more concrete and usually uses a methodology” (Allen VNOS Questionnaire). In his VNOS Questionnaire response, Allen states, “to me, because of how I think, it seems only logical to use [the scientific method]. To me there must be standards and procedures so others can replicate and verify what one has done” (Allen VNOS Questionnaire). Likewise, in his NOS Follow-Up Interview, Allen explains, Really generalized, to me, it [the scientific method] is just problem-solving. It is a structure or a rubric basically to try to figure out answers to some questions that they don't know. That, to me, is what the scientific method is. That's where I get to concrete and the abstract. Although, the abstract is also solved that way as well. If you didn't have an experiment, you wouldn't be able to figure out things like pills. You know, like whether or not it will work. So you set up an experiment so that it helps prove or disprove your hypothesis. (Allen NOS Follow-Up Interview)

Allen goes on to explain, “I think that you have to follow certain designs of experiments and how you record it” (Allen NOS Follow-Up Interview). This reference to various standards and procedures alluding to a universal step-wise method reflects a naïve view of the scientific method aspect of NOS.
Worldview—Nature and the Natural World

During his Worldview—Nature Interview, Allen discussed nature and the natural world in terms of his scientific understanding of the world, his specific content area (biology), his religious beliefs, his personal experiences, the aesthetic qualities he sees in nature and the natural world, his interest for nature and the natural world, and his personal concern for care of the natural world. During his Worldview—Nature Interview, Allen’s responses reflected his scientific understanding of the world. For example, Allen refers to nature and the natural world as “things that I see, I deal with, I touch, I feel, all the time” (Allen Worldview—Nature Interview). This reflects an empiricist view of nature and the natural world that is consistent with a scientific understanding of the world and an understanding of the empirical NOS. Furthermore, Allen’s responses reflect his specific scientific content area (biology). For example, Allen explains,

It’s very complex...Food webs are an example. Complexity of DNA and genes. In the complexity of how living and nonliving things work. If you take it out of a certain community or ecosystem, the effects that has. And so the interrelationships between all of them is very complex. Even within, I mean, climate. Even within certain biomes, and things like that. (Allen Worldview—Nature Interview)

Likewise, when summarizing his ideas regarding nature and the natural world, Allen explains,

I don’t believe that we keep everything the same. Because history shows that we’ve had extinction, and man wasn’t even the problem. I do think that we have to allow certain things to change. The problem is that we have accelerated extinction tenfold, and what we do to the environment and the effects there. So going over environmental issues like global warming. And there’s so many. Whether it’s the ozone or other things. So to me, nature is a gift. (Allen Worldview—Nature Interview)
During his interview, Allen also talked about nature and the natural world in terms of his religious beliefs. For example, Allen explains that nature is “something to be appreciated; something that is a gift that God has given us...It strengthens my faith. Let’s put it that way. I see God in nature” (Allen Worldview—Nature Interview). In addition, personal experiences were also a part of Allen’s description of nature. For example, Allen explains, “if I want to get away, that’s where I go. That is why I camp. A sense and feeling of calmness that it puts over me. And it does give me good peace” (Allen Worldview—Nature Interview).

Allen describes his personal feelings regarding the aesthetic qualities of nature and the natural world as he explains, “Beautiful. And this is simply from the way that I look at it, and I think it’s very aesthetic. And yes, yes I do think it is. Even some of the ugliest creatures and all that kind of stuff” (Allen Worldview—Nature Interview). Likewise, Allen explains, “I see beauty in nature. Absolutely. Even ugly creatures” (Allen Worldview—Nature Interview).

Finally, Allen communicates a great interest for nature and the natural world and personal concern for the care of the natural world. Allen explains, “Of course, I like trees and flowers. And I learned a new flower this year, and I was very excited about it! And today I saw a snake! It was huge!” (Allen Worldview—Nature Interview). His concern for the care of the natural world is reflected when Allen explains,

Nature needs to be protected. Again, I think God put it there for a reason. And I believe in sustainability which means we are to use it. But if there are forests there, we don’t knock down all the trees...we are getting better at it, and we’re taking some trees down and then replant some trees. But to do it like they do in the rain forest where they knock it down for agriculture, then it’s a problem. So sometimes nature does need to be protected from the abuses of man. (Allen Worldview—Nature Interview)

Allen integrates his interest and concern for nature and the natural world as he explains,
The **wow** factor. When I look at exciting, it’s the wow of nature. I mean, wow! I don’t know about you, but when I go out and I look at it, I think, “oh my!” This is incredible. Beautiful. It strengthens my faith. That God put this here for us to enjoy and to also to use. To use it in a way that is, obviously, a benefit to us without destroying nature. (Allen Worldview—Nature Interview)

*Worldview—Causality*

Assertions relating to causality relied on Allen’s TOPE responses and his explanations regarding his responses. Allen picked the more scientific explanation for 11 of the 17 TOPE items and the less scientific explanation for 6 of the 17 TOPE items: Items #2, 5, 7, 8, 10, and 14. Therefore, his overall TOPE score is below the average score for the group of participants ($M = 11.75$). For the items where Allen picked the more scientific explanation, his reasoning for his choice seems to reflect a scientific way of thinking about the world. For example, his explanation for TOPE Item #3 states, “It is a matter of science vs. magic. I do not believe in magic” (Allen TOPE Item #3). Figure 17 contains TOPE Item #3. In addition, in response to TOPE Item #15, Allen explains, “I choose #2 because it involves

Some people were observing a demonstration that involved a miniature red train car, a bit of track, and a tunnel. When the demonstrator pushed the train car into the tunnel a blue car came out the opposite side. When the blue car was pushed back into the tunnel, the red car reappeared out the other side. People suspected that there were really two cars, originally the blue one being hidden by the tunnel. To test this idea they listened carefully when the red car was pushed into the tunnel feeling sure that they would hear it knocking the blue car out the opposite side. Try as they might, they could hear no sound of a collision. The people then fell into two groups over the matter:

1. Some people found the demonstration intriguing and amusing. They considered the demonstrator to be a kind of magician who was proving that the hand really is quicker than the eye.
2. Other people recalled that like-poles of magnets repel each other. So perhaps there were two cars each with a magnet. Like poles faced each other so that one car entering the tunnel drove the other out without ever touching.

Which explanation would you be more willing to accept? Explain.

*Figure 17. TOPE Item #3.*
The goal that geologists have long had is to acquire enough knowledge about
earthquakes so that they can be anticipated hours or even days in advance. Now it has
been discovered that many animals can do just that. The geologists are still unsure about
just how a particular animal senses a quake coming but there are two theories:
1. There are many things in the environment that animals sense such as danger or
changes in the weather. This is an ability that modern people have lost due to their
remoteness from nature and reliance upon technology.
2. It has now been learned that there are slight almost imperceptible pre-tremors that
come hours, sometimes days before a major quake. These pre-tremors are noticed
by animals, particularly grazing animals, which then become quite nervous.

Which of the above explanations would you be more willing to accept? Explain.

Figure 18. TOPE Item #15.

more concrete (physical) evidence. The word “sense” (from #1) seems to involve something
mysterious” (Allen TOPE Item #15). Figure 18 contains TOPE Item #15.

Several of Allen’s descriptions for his choices of TOPE item explanations refer to his
religious beliefs, and he appears to refer to religious beliefs more frequently in his
descriptions of explanations that are the less scientific explanation choice for a TOPE item.
In fact, Allen’s refers to religious beliefs in 50% of his less scientific explanation choices and
only in 18% of his more scientific explanation choices. For example, his description for the
less scientific explanation for his choice for TOPE Item #2 states, “although it is true that
many physical bodies emit radio waves (all the suns do), there is a possibility there is a far
off civilization. To say no would limit what God is capable of doing” (Allen TOPE Item #2).
Figure 19 contains TOPE Item #2. In addition, his explanation for TOPE Item #7 states, “I
know that the Holy Spirit can live in us but what happens when our body dies is still a
mystery to me. I do know I will have “eternal life” (John 3:16)” (Allen TOPE Item #7). Figure
20 contains TOPE Item #7. Although not a direct reference to his specific religious beliefs,
Allen’s explanation for his response to TOPE Item #14 states, “I would also include in #2 that
Recently astronomers have observed an increase in radio wave activity of particular frequency from a particular sector in the sky. This observation has caused a stir and a great deal of speculation as to its explanations. So far there are two explanations that the astronomers are arguing most about:

1. Man has often doubted that he was alone in this vast universe. These radio waves might well be radio signals from some far civilization upon which we have stumbled or indeed they may even be meant for us.
2. There are many physical bodies in the heavens which emit radio waves. These emissions fluctuate and chances are these new emissions will be found to fall within the regular patterns of chance fluctuation.

Which explanation would you be more willing to accept? Explain.

**Figure 19. TOPE Item #2.**

In the past when a man's heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man's heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.
2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more willing to accept? Explain.

**Figure 20. TOPE Item #7.**

humans have a soul. This would be included in “humanity” (Allen TOPE Item #14). Figure 21 contains TOPE Item #14.

A scientific way of thinking leads Allen to choose the more scientific explanation for most TOPE items (11 of 17 items). However, there are TOPE items where his religious beliefs
People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal. Which explanation would you be more willing to accept? Explain.

*Figure 21. TOPE Item #14.*

appear to be in conflict with his understanding of a scientific way of thinking. For example, in response to TOPE Item #2, Allen states, “although it is true that many physical bodies emit radio waves (all the suns do), there is a possibility there is a far off civilization. To say no would limit what God is capable of doing” (Allen TOPE Item #2). (See Figure 19 on previous page for TOPE Item #2.) Nevertheless, Allen does integrate his religious beliefs and ideas regarding science and scientific inquiry when he states, “I believe we will always progress through scientific inquiry. It is a gift from God to preserve knowledge” (Allen TOPE Item #13). Figure 22 contains TOPE Item #13.

Allen’s TOPE responses may also reflect some of his conceptions of NOS. For example, Allen’s VNOS responses indicated he has an informed view of the empirical aspect of NOS. Allen articulates this idea in his response to TOPE Item #15 where he states, “I choose #2 because it involves more concrete (physical) evidence. The word “sense” (from #1) seems to involve something mysterious” (Allen TOPE Item #15). (See Figure 18 on page 212 for TOPE Item #15.) However, Allen’s TOPE score (11) was below the group average (11.75), and his VNOS continuum ratings also were low compared to the other participants.
Is it logically possible for a system to explain itself? It appears to be a tautological dilemma since to explain itself a system can only explain the system in terms of itself. For instance is it possible to know how the brain really works since any theory put forward is a product of the human brain? The dilemma seems very discouraging yet scientists are undeterred.

1. The key to understanding any system, no matter how complicated, is in its parts which are necessarily less complicated than the whole. By examining and experimenting with the parts we eventually will learn enough about the whole brain to enable us to restore all neurological disorders.

2. Science has enjoyed great progress in understanding natural phenomena and scientists as a result have come to take progress as a scientific right. They have lost sight of the fact that all human endeavors including progress are limited and unending progress is not to be expected. If neuro-scientists were to remember that then their present viewpoint on the human brain would certainly be more humble.

Which of the above positions would you be more willing to accept? Explain.

*Figure 22. TOPE Item #13.*

(tended more towards the naïve end of the VNOS continuum than other participants).

Therefore, there may be a relationship between his lower than average (for this group of participants) conception of NOS and his likelihood to more frequently choose less scientific explanations for causality as indicated by TOPE responses. However, this is by no means a predictive relationship. Therefore, it may simply reflect an overall less informed view of the nature of science and a less scientific view of the world (in terms of causality).

**Interpretive Narrative**

A narrative presents Allen’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Allen’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Allen’s Worldview—Nature Interview, a concept map created based on his Worldview—Nature Interview, and his responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Allen read over the narrative and modified it such that he believed it accurately described his conceptions of NOS, beliefs regarding nature and the natural world, and
beliefs regarding causality. The following is the first person interpretive narrative created from Allen’s questionnaire responses, interview transcripts, and subsequent concept map:

Nature and the natural world are complex and diverse. For example, we can see this complexity in food webs, DNA and genes, ecosystems, biomes, and the vast variety of species of plants and animals. This complexity can seem confusing at times, but we can study and learn about nature and the natural world so that we can understand it. Being able to understand the natural world also helps us appreciate it and should encourage us to care for it and protect it.

The natural world is knowable and very orderly. The balance of nature and classification illustrates this orderliness. This orderliness also helps us predict and be able to explain things that happen in nature. However, nature can seem unpredictable and mysterious at times. The beautiful and powerful aspects of nature, like tornadoes and earthquakes, can be frightening, dangerous, and exciting.

God created nature and the natural world. Therefore, they have qualities such as sacred, spiritual, and holy. In addition, since God created the natural world, it has a purpose and is not “just there.” This purpose and God’s call for us to care for the natural world should influence the human interactions we have with nature. Since nature and the natural world include both material (living and non-living) and energy resources, our use of the natural world can help determine the type of lifestyle we have. Many of our human actions have been exploitative and abusive. This has led to destruction, extinctions, and pollution such as toxins and invasive species. However, it is not doomed. Therefore, God calls us to protect nature and work for restoration.

Science is the study of nature and the natural world. Science is empirical and deals with things that we can see, hear, touch, etc... When we cannot see, hear, or touch something, we can still glean induced or indirect evidence. After you observe something, you can make an inference about it. Therefore, science is concrete and fact-based. Science also requires experiments. We need experiments so our knowledge is not based solely on opinion—experiments give us standards and procedures. When we “do” science, we do not necessarily follow particular ordered steps. Rather, we can use creativity in the design, data collection, and data analysis stages of experimentation.

Furthermore, although people do science and social and cultural aspects are part of our background, science aims to have no social or cultural influences. However, science can greatly influence the social and cultural aspects of our lives. For example, newer, cheaper, and more available energy resources would obviously affect our lifestyles. And for some parts of science, there is no social or cultural influence. For example, water is H₂O everywhere!
Science also progresses. We can take prior ideas and new evidence and use that information to revise and change the theories that we have. Both knowledge and theories can change as we get more data. In some cases where scientists currently disagree about something, if they were given enough evidence, these scientists would eventually agree. However, this is not necessarily true in all cases. Theories can also help “set the stage” for other experiments. Experiments can use theories and laws. Laws describe things and tend to be more proven than theories.

Science can also explain how and why many things happen in the world. When we are looking for a cause for something, we can usually try to look for the reason that supports the scientific evidence that we may find. If an explanation is more scientific than the other, I would tend to choose that explanation. However, there are some situations where I would say that we might not be able to use a science to explain how or why something happened. That is, there are times that things happen that we just cannot explain. Sometimes this might be due to intervention from God. I know that God is powerful, and there is no limit to what God can do. But for the most part, we are able to find scientific explanations for why things happen.

Betty

Demographic Information

Betty is a 51-year-old female. She has an undergraduate degree in biology and a master’s degree in educational technology. She has been teaching for 15 years in a variety of subject areas including biology (5 years), physical science (2 years), physics (3 years), general science (10 years), Bible (5 years), math (3 years), and English (6 years).

Views of Nature of Science

Betty’s scores on the VNOS continuum show she has an informed view of the tentative, empirical, and theories and laws aspects of NOS. Her views of the subjective, social and cultural, observation and inference, and scientific method aspects of NOS are emerging. Her view of the creative aspect of NOS is naïve. Figure 23 summarizes Betty’s VNOS continuum scores. A radar plot also visually illustrates Betty’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and
effectively supported conceptions of NOS. Figure 24 shows a radar plot of Betty’s VNOS continuum scores.

Tentative. Betty articulated an informed view of the tentative aspect of NOS. Not only does she explain how everything in science is subject to change, she also describes this in her own words and tries to provide an example. For example, Betty explains,

A theory can change as new evidence is developed...as new knowledge comes on the scene that would help. I think of a theory as something that explains how something works and why it does what it does. If new knowledge comes on the scene that wasn't used in the development of the theory, then using that knowledge to redesign the theory would lead to a different theory. I would say they usually build on each other. I'm thinking of examples like the atomic theory. Where new knowledge comes to light and changes how you look at the theory. (Betty NOS Follow-Up Interview)
In addition, Betty goes on to explain, “We choose the best explanation... I’m trying to think of a situation where in the scientific community there are different explanations for different... there are. There are different theories” (Betty NOS Follow-Up Interview).

Furthermore, she explains, “different theories must coexist until further evidence brings new information to bear on the theories” (Betty VNOS Questionnaire). Betty appears to recognize that science changes as new evidence comes to light. Her views regarding the tentative aspect of NOS are informed and articulated in her own words; thus “++” is her VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Betty articulated an emerging view of the subjective aspect of NOS. At one point, Betty defines *scientific* as “systematic, objective, measurable” (Betty NOS Follow-
Up Interview). In addition, at several other times in her VNOS Questionnaire responses and NOS Follow-Up interview, Betty refers to science as objective. This idea of objectivity would seem to characterize her view of the subjective aspect of NOS as naïve.

In her NOS Follow-Up Interview, Betty explains, “when designing an experiment, even as objective as we want to be, there is some subjectivity to it. And there is some subjectivity that we are probably not even aware of” (Betty NOS Follow-Up Interview). Betty seems to recognize that some subjectivity is involved in science; however, she sees subjectivity as something negative and to be avoided, if possible, rather than something that is inherent in the process of science. In addition, she explains,

Subjective means, to me, it has more to do with your opinions and your inferences are what you see, or think, or feel. Is there room for it? I think yes. We have to make inferences because we can’t, even in science, you can’t always repeat things that have happened in the past. So trying to think about how everything came into being, or to think about what a black hole is. All of those things require little subjectivity because we can’t go out there and physically hold them, weigh them, and measure them. (Betty NOS Follow-Up Interview)

In this response, Betty appears to recognize the role that subjectivity plays in science. Given her mixed responses regarding subjectivity, her views regarding the subjective aspect of NOS are emergent.

**Empirical.** Betty articulated an informed view of the empirical aspect of NOS. For example, she identifies the important components of scientific inquiry as “objectivity, evidence, repeated tests, and objective analysis of data” (Betty VNOS Questionnaire). In addition, in response to the question, “What makes science different from other disciplines of knowledge?,” Betty explains,

It’s more systematic. It’s based more on material, objective things. Where philosophy and theology and those types of subjects—a lot of it is just in
people's heads: what they think and what they believe. Whereas science is more measurable...measurable, tangible, physical, material things. (Betty NOS Follow-Up Interview)

In addition, in response to the NOS Follow-Up Interview question regarding dinosaurs, Betty responds,

I know they found fossils of skeletons. They found bones and skeletons, and they have been able to build what they think the rest of the animal would look like around those bones. They have also found fossils of prints, portions, and even maybe eggs and babies or embryos of dinosaurs. (Betty NOS Follow-Up Interview)

In this statement, Betty recognizes the dependence that the development of scientific knowledge has on observation and the empirical aspect of NOS and articulates an informed view of the empirical aspect of NOS.

**Creative.** Betty articulated a naïve view of the creative aspect of NOS. For example, she states,

Yes, creativity and imagination are useful in some of the steps of scientific investigation. In planning and design, creativity helps scientists develop tests, control unwanted variables, consider many valid hypotheses (before selecting one to test). After this step, objectivity must rule. Carrying out the experiment, collecting data, and analyzing data are not facilitated by creativity, and may be negatively affected by it. (Betty VNOS Questionnaire)

Betty stresses that “objectivity must rule” and that the process of scientific investigation might be “negatively affected” by the use of creativity and imagination (Betty VNOS Questionnaire). This is why her view of the creative aspect of NOS is naïve. Likewise, in response to a question regarding if data collection and data analysis should incorporate creativity and imagination, she explains,

It may be. You may need to have creativity and imagination in developing a way to measure something, or a new tool to measure whatever you are wanting to find out about. But not in the interpretation of data. Or in the analysis of it. I would not think so. (Betty NOS Follow-Up Interview)
Therefore, even if Betty was going to allow the development and design of a scientific investigation to incorporate creativity and imagination, she does not feel it is appropriate for processes beyond experimental design to employ creativity and imagination.

**Social and Cultural.** Betty articulated an emerging view of the social and cultural aspect of NOS. For example, Betty states, “I think that it is impossible to transcend the social and cultural values, even in science. I believe that science makes every effort to be totally objective and not influenced, but still probably is influenced” (Betty VNOS Questionnaire). In addition, she explains that

I think there is more of an effort to be objective and scientific. There is more of an awareness of how the social and cultural systems have affected science in the past. And I guess there is more of an effort to have it not affect it now...I mean, that is diminishing because of the efforts of science to be pure and not affected by anything. But I do not think it is actually possible to have it [social and cultural influence] not be there. But I think there’s more of an effort to have it not be there or to have less of a social and cultural influence. (Betty NOS Follow-Up Interview)

Betty appears to recognize the social and cultural aspect of NOS; however, she still seems to hold to the idea that scientists try very hard to eliminate social and cultural influences.

Therefore, Betty’s view of the social and cultural aspect of NOS seems to be developing and emerging.

**Theories and Laws.** Betty articulated an informed view of the theories and laws aspect of NOS. In addition, she articulated this understanding in her own words and provided supporting examples. In her VNOS Questionnaire, Betty states,

A scientific law is a statement about something that happens in the natural world—e.g., things fall toward the earth. It is based on observation, and it is something that occurs without exception. A scientific theory is the explanation of why the law occurs (based on scientific experimentation). The force of gravity pulls all objects with mass toward each other. Objects
with larger mass have greater pull—therefore, things fall toward the earth.
(Betty VNOS Questionnaire)

She illustrates her understanding with an example as she explains,

From what I know, a scientific law as something that describes something that happens in the natural world over and over again...The Law of Conservation of Matter: matter cannot be created or destroyed. That is something that we observe. A theory would be how you explain that in, say, a chemical reaction. The mass of the reactants will be the same as the products even though they will be arranged differently. So explaining exactly why that happened and why matter is never lost would be the theory. (Betty NOS Follow-Up Interview)

As one can see, she has a clear understanding of the differences between theories and laws, articulates this in her own words, and illustrates it with the example of the Law of Conservation of Matter and a corresponding theory of trying to explain why matter is never lost. Thus, “+++” is her VNOS continuum score for the theories and laws aspect of NOS.

**Observation and Inference.** As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicitied enough information regarding participants’ views of the observation and inference aspect of NOS.

Given this limited data, Betty demonstrated an emerging view of the observation and inference aspect of NOS. For example, as Betty explains her understanding of the difference between indirect evidence and inference, she states,

I think inference is when you have physical evidence or something that you have observed, and you apply what you know. So, I do not think that indirect evidence and inference are the same thing. The fall color of the trees, if you look at the map of the United States and at the peak time of leaf color change, you can look for patterns. Just say what you see as the pattern would be an observation. Saying that the peak time is earlier the farther north you go in latitude would be an observation. The inference in that would be based in what you know, that the temperature affects when photosynthesis begins the start of the season. The northern latitudes would
have the cooler temperatures; therefore, the leaves will change color earlier there. That would be an inference. That’s not really the same as indirect evidence. (Betty NOS Follow-Up Interview)

Betty recognizes the difference between observation and inference. However, the limited information she provides regarding her views of the observation and inference aspect of NOS leads to her classification of having an emerging view of the observation and inference aspect of NOS.

**Scientific Method.** Betty articulated an emerging view of the scientific method aspect of NOS. For example, she explains,

> I think the steps of the scientific method are basically the same in all good science, but they might not always be in the same order or look exactly the same to an outsider. For an experiment to be credible and the results to be considered valid, certain steps must be followed. If the results of an experiment are to be useful to the scientific community, then there must be a consistent overall process that all scientists agree on and use. (Betty VNOS Questionnaire)

This response appears to reflect the naïve view that science has a particular, step-wise method that must be followed. However, in her NOS Follow-Up Interview as she reviews and comments on this response, she explains,

> But here I said yes, but I was thinking more of experiments. I guess, if the doing of science is making observations of the natural world, trying to find correlations, coming up with theories about laws, I don’t think it necessarily has to be in the form of an experiment (which would mean the scientific method). But I think that it still needs to be done scientifically. So it doesn’t necessarily have to be the scientific method. I don’t think that you need to do everything in that specific order. It’s more of a process. You might get to a point that you realize that you have to change the experiment because something isn’t working. And then it becomes more of a cycle than actually a step-by-step linear thing. It would usually, I guess, lead to further experiments or tweaking to test something a little differently. (Betty NOS Follow-Up Interview)
Her views of the processes of science and the scientific method aspect of NOS appear to be emerging. She seems to be trying to hold on to some type of procedure to use scientific experiments. However, she does seem to recognize the need for other types of ways to do science. Therefore, her overall view of the scientific method aspect of NOS is emerging.

**Worldview—Nature and the Natural World**

During her Worldview—Nature Interview, Betty discussed nature and the natural world in terms of her scientific understanding of the world, her specific content area (biology), her religious beliefs, her personal experiences, the aesthetic qualities she sees in nature and the natural world, her interest for nature and the natural world, and her personal concern for care of the natural world. For example, Betty alludes to a scientific understanding of the world when she discusses the empirical aspect of nature and the natural world when she explains that nature is “made of matter, diverse, material, orderly, living, predictable” (Betty Worldview—Nature Interview). In addition, Betty talks about the nature and the natural world while referring to her specific content area (biology). For example, she states,

> Some animals are endangered. Some plants are endangered. But depending on if you talk about nature as a whole, it's probably not endangered. There will always be some sort of nature. Even if invasive species take over, it will change, but it won't be gone. (Betty Worldview—Nature Interview)

Likewise, she explains “thinking about the intricacies of an eye of an insect for example, or just how the reproductive system in a human works, just all the different complexities you see in nature” (Betty Worldview—Nature Interview).

Betty also references her religious beliefs as she talks about nature and the natural world. For example, she comments, “I feel my spirit communicating with God through
“nature” (Betty Worldview—Nature Interview). In addition, she states, “since I believe there is a Creator, that nature is everything God created” (Betty Worldview—Nature Interview). Betty’s personal experiences help to color her beliefs regarding nature and the natural world. For example, she explains,

Being from Kentucky, and I just got home from Louisville...Just seeing how they are leveling the mountains. Strip mining isn’t done anymore. And now they just take off the whole top of the mountain to get the coal. And even if they replant, it’s that many feet lower than it was, and it changes the whole topography. (Betty Worldview—Nature Interview)

In addition, Betty references the aesthetic qualities she finds in nature when she explains, “I think nature is beautiful. Even the things that are not aesthetically beautiful are beautiful as they are natural” (Betty Worldview—Nature Interview). These aesthetic qualities may contribute to her interest for nature and the natural world. She describes this interest in nature and the natural world when she explains,

To me nature is mysterious. Probably not, to me, since I have studied it more than the average person. There is still some mystery, some things I don’t understand. Even if I learned about how it works, I still am amazed that it happened. So I guess I would call that mysterious. (Betty Worldview—Nature Interview)

Not only is Betty interested in nature and the natural world, but she also has a personal concern for the care of the natural world. For example, she explains, “I think there are enough people who are wanting to make amends for what we’ve done wrong. To help...I still have hope that it’s going to be okay” (Betty Worldview—Nature Interview). Betty goes on to explain that this personal concern is also tied to her religious beliefs when she explains, “I see in nature, the work of God. I see beauty. And since I’m concerned about pollution and the damage it does, then I think it is to be protected” (Betty Worldview—Nature Interview).
Worldview—Causality

Assertions relating to causality relied on Betty’s TOPE responses and her explanations regarding her responses. Betty picked the more scientific explanation for 12 of the 17 TOPE items, and the less scientific explanation for 5 of the 17 TOPE items: Items #5, 8, 14, 15, and 17. Therefore, her overall TOPE score is slightly above the average score for the group of participants (\(M = 11.75\)). For the items where Betty picked the more scientific explanation, her reasoning for her choice seems to reflect a scientific way of thinking about the world. For example, her reasoning for TOPE Item #12 states, “#2 is a more logical explanation. Once again, it is based on objective, testable ideas. #1 is too vague and not testable. How would we know what “feels wrong” to a bird??” (Betty TOPE Item #12). Figure 25 contains TOPE Item #12. In addition, in her response to TOPE Item #11, Betty explains, “#1 makes more sense to me. It relies more on objective reasoning: the use of nutrients in the soil. #2 sounds good, but it is not based on any reasonable evidence” (Betty TOPE Item #11). Figure 26 contains TOPE Item #11.

Bird migrations are an interesting phenomenon. For instance some geese can fly thousands and thousands of kilometers from one point on the earth to another never getting lost. This remarkable feat of navigation is of great interest to biologists and also controversial. There are two much debated explanations:
1. Some biologists view bird navigation as a kind of natural movement. For instance, humans, can both walk and crawl; but they always walk because that is what is natural for them to do. It is possible for geese to fly in the wrong direction but that would be like humans crawling. They do not do it because it is unnatural.
2. Some biologists are quite convinced that wind currents act like Coriolis forces on the birds. The geese are sensitive to very slight variations in wind force and direction. By instinct they react to these variations and thus maintain their course.

Which of the two explanations would you be more willing to accept? Explain.

*Figure 25. TOPE Item #12.*
When plant seeds are grown in small pots it is possible to quicken their growth rate by periodically shaking the pots. This "shaking effect" is poorly understood but there are two schools of thought on the matter:

1. The roots of plants use up first the nutrients in the soil which are closest. The result is that the amount of soil nutrients increases with distance from the roots. Shaking stirs up the soil and helps bring richer but distant soil into contact with the roots.

2. All living things benefit from an occasional but gentle stirring up of their environment, and even of themselves. It gets the juices, fluids and chemicals moving and flowing. It provides fresh air and removes the stale. It encourages, one might say, the processes of life.

Which explanation would you be more willing to accept? Explain.

*Figure 26. TOPE Item #11.*

her response to the explanation she states,

I would be more likely to accept #1, even though it doesn’t line up with my normal, objective thinking. I think that traditional and herbal medical practices are often based on natural ingredients that have an underlying medical benefit. Many current medicines are based on components of plants and fungi, so why wouldn’t “natural” medicines also be valid? There are ways that these traditions could be studied scientifically by researchers. (Betty TOPE Item #8)

Therefore, it appears that even in some instances where Betty picks an explanation that is less scientific, her reasoning for her response reflects a scientific way of thinking about the world. Figure 27 contains TOPE Item #8.

For one of the TOPE items where Betty picked the less scientific explanation, she refers to her religious belief in her response. For example, Betty states,

I guess #2 is a better explanation for me. I do believe that man is separated from the other animals, being made in God’s likeness. Our “humanity” could be explained as having speech, emotions, rational thought, and the desire to “understand” the world around us. I do think that other animals communicate with each other, however, and wouldn’t be at all surprised to learn that chimps are “talking” to each other with the noises they make. Just because we don’t understand their “language” doesn’t mean they don’t have one. (Betty TOPE Item #14)
In many areas of the world today the health of the people is looked after by traditional and herbal medicine practitioners. These traditional physicians practice a healing art based on generations of accumulated knowledge. In spite of this, the modern study of medicine does not include any areas of this traditional knowledge. Recently doctors concerned about this issue have divided into pro and con groups:

1. The study of modern medicine is the study of western medicine. This should tip us off to the real reason behind the resistance to the scientific study of traditional herbal medicine. It is pure and simply western chauvinism. From the scientific point of view there is no reason for not carefully researching well-documented traditional cures. The findings would benefit all of mankind; and in addition there would be a greater appreciation of the traditions of non-western peoples.

2. Modern experimental medicine has been successful largely because it is directed by rational theory. The theoretical structure of a science tells the investigator which avenues of experiments are most likely to be profitable, thus avoiding many dead ends. Since there is no such structure in traditional medicine a researcher would be left to follow dozens, even hundreds of nebulous accounts of "cures that work." Such ad hoc experimenting is wasteful and inefficient. It is for this same reason that "home cures" that so many families use are not pursued by researchers.

Which position would you be more willing to accept? Explain.

Figure 27. TOPE Item #8.

Figure 28 contains TOPE Item #14. However, she also references her religious beliefs for TOPE items where she picked the more scientific explanation. For example, for TOPE Item #7, Betty states,

Although I do believe that a man’s spirit doesn’t die, I don’t think these near death experiences are actually what one might call “heaven.” I think the explanation that the brain doesn’t immediately stop when the heart stops is a better explanation. (Betty TOPE Item #7)

Therefore, Betty’s religious beliefs do not appear to affect her understandings of causality such that she would be more likely to pick explanations that are less scientific. Figure 29 contains TOPE Item #7.

One of Betty’s TOPE responses also directly reflects her conceptions of NOS, particularly her conception of the creative aspect of NOS. For example, in Betty’s response to the final TOPE item, she states,
I think that creativity has a place in the first steps of experimentation (choosing a problem and developing a hypothesis). In the latter stages (experimentation and analysis of data), objectivity must rule. This scientist seemed to use objective, scientific practices in his experimentation. We would not have gotten as far as we have in our quest for knowledge if creativity and independence had not been part of the first stages of experimentation. (Betty TOPE Item #17)
A physicist at a well-known university was conducting a unique set of experiments. He was interested in the effect of electrical discharges on the growth rates of a particular type of tree. The methodology was simple. He administered electrical shocks to one set of trees but not to second. Over a period of several months he measured and compared the growth rates of the two groups. The scientist’s work caused a stir amongst his colleagues because he admittedly had no theoretical framework for his research. There were two basic opinions about this kind of experimentation:

1. The highly theoretical nature of physics provides an ample number of research problems for experimental work. Theory guided research is more efficient because there is a greater chance of success. This man has picked an idea out of thin air and pursued it for no other reason than idle curiosity.
2. This man should not be criticized for his unique albeit different research problem. All too often progress in many fields is thwarted by over-conservatism and rigid adherence to theory. Creativity and independence should be encouraged so that more discoveries can be made and the understanding of nature increased.

Which opinion would you be more willing to accept? Explain.

Figure 30. TOPE Item #17.

Figure 30 contains TOPE Item #17. Likewise, in her responses to the VNOS Questionnaire and NOS Follow-Up Interview, Betty’s responses indicated she had a naïve understanding of the creative aspect of NOS as she states,

Creativity and imagination are useful in some of the steps of scientific investigation. In planning and design, creativity helps scientists develop tests, control unwanted variables, consider many valid hypotheses (before selecting one to test). After this step, objectivity must rule. Carrying out the experiment, collecting data, and analyzing data are not facilitated by creativity, and may be negatively affected by it. (Betty VNOS Questionnaire Response)

It appears that there may be a relationship between a naïve understanding of the creative aspect of NOS and a preference for a less scientific explanation of causality. However, this is by no means a predictive relationship.

**Interpretive Narrative**

A narrative presents Betty’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Betty’s responses to the VNOS
Questionnaire and NOS Follow-Up Interview, transcripts from Betty’s Worldview—Nature Interview, a concept map created based on her worldview—nature interview, and her responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Betty read over the narrative and modified it such that she believed it accurately described her conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Betty’s questionnaire responses, interview transcripts, and subsequent concept map:

Nature itself, in an objective sort of way, is very complex and diverse. Just look at the intricacies of an insect eye or the human reproductive system to see just how complex it is. The natural world is a material world of matter that is made of both living and non-living things. Nature is very orderly, even though it may, at times, seem chaotic. This orderliness can be seen in the patterns in nature that help us understand the natural world and make it predictable. In addition, the complexity of the natural world can make it seem confusing at times. However, it is understandable and knowable, even if it is a little mysterious sometimes. Learning and studying about nature can also help us care for it.

Nature and the natural world are created by God. This means that nature has a purpose; it is not just there. Since it is created by God, we can understand nature in spiritual ways. We think of nature as having spiritual qualities such as sacred and holy because God has created it. Because the natural world was created by God, we need to care for it. However, many of our human actions using the resources of nature to improve our lifestyle cause damage to the natural world that leads to pollution and exploitation such as mountain top removal during mining in Kentucky. This damage can endanger parts of the natural world. Therefore, we need to protect the natural world from human actions and work to restore parts of the natural world that we can. For example, we can replant trees, but we cannot replace coal.

Nature and the natural world are very powerful. This power can be very exciting. However, it can also be frightening. There are parts of the natural world that are dangerous such as hurricanes, tornadoes, and tidal waves. And even smaller things like seeing a spider or snake can be frightening to some people. Nature is also beautiful and peaceful. For me, this causes a pleasant emotional response.

Science is a systematic study of the natural world around us as well as a body of knowledge. Important components of science are objectivity, evidence, and repeated tests. Science deals with measurable, tangible,
physical, and material things. In addition, science requires experiments and testing. Scientists conduct experiments to measure and test things. Creativity and imagination are very useful in the planning and design of an experiment; however, creativity and imagination are not appropriate in the actual experimentation and data collection or analysis stages of testing. Scientists also use observations and inferences in their experimentation. Inferences involve applying what you know.

Although science makes every effort to be totally objective and not influenced, it is impossible to completely transcend social and cultural values. However, the social and cultural influence on science is diminishing with time and its influence is less perceptible. In addition, there is some subjectivity involved, even if scientists are trying to be totally objective.

Science and scientific knowledge progresses. Scientific theories can change as new evidence and knowledge is discovered. A scientific theory tries to explain what happens, and scientific theories can change and be redesigned when new knowledge comes to light. A scientific law describes something that happens in the natural world.

Science can also explain how and why many things happen in the world. To do this, science tries to use objective reasoning to determine the cause for events and explanations for evidence we find. If an explanation is more scientific than the other, I would tend to choose that explanation. Most of the things that happen in the universe can be explained by natural causes. However, sometimes we do not understand everything about the natural world. We can discover most causal explanations by using objective, scientific practices in our experimentation.

**Carl**

**Demographic Information**

Carl is a 30-year-old male. He has 8 years of teaching experience in several different courses including chemistry enhanced (8 years), honors physical science (3 years), physical science (4 years), and regular chemistry (2 years). He has an undergraduate degree in chemistry and a master’s degree in educational leadership.

**Views of Nature of Science**

Carl’s scores on the VNOS continuum show he has an informed view of the scientific method, theories and laws, creative, subjective, and tentative aspects of NOS. His views of the observation and inference and empirical aspects of NOS are emerging. His view of the
social and cultural aspect of NOS is naïve. Figure 31 summarizes Carl’s VNOS continuum scores. A radar plot also visually illustrates Carl’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 32 shows a radar plot of Carl’s VNOS continuum scores.

**Tentative.** Carl articulated an informed view of the tentative aspect of NOS. Not only does he explain how everything in science is subject to change, he also describes this in his own words and tries to provide examples. For example, Carl explains,

> Scientific theories definitely can and do change over time...One example of theories changing relates to the flat earth theory. Scientists observed that it appeared that the earth came to an end at a certain distance but after further experimentation the theory was changed to explain that the earth is in fact a sphere with no end or beginning and that it was merely that light travels in straight lines that explain why the earth appeared to end. Thus the explanation/theory of why the earth seemed to end was changed from...
a flat earth to the fact that light waves travel in straight lines. We still continue to use and learn theories because they are usually very well supported, and they are useful in making predictions for future experiments. Just because theories can change…does not mean that they are useless or undependable…students can learn a great deal from looking at different theories even if they might change twenty years from now. (Carl VNOS Questionnaire)

In addition, Carl goes on to explain,

Theories are just ways of trying to explain a relationship or explain something that you see out there. So if new data comes about, for example the atomic theory, going through the whole thing there with Dalton to thinking it was just a single spherical marble to all the way to where we are now with orbitals and so on…theory is kind of using the data you have now to try to explain something….I do think they change over time depending on new data and so on. (Carl NOS Follow-Up Interview)
Carl appears to recognize that science changes as new evidence emerges and that scientific knowledge develops. His views regarding the tentative aspect of NOS are informed, articulated in his own words, and supported with examples; thus “+++” is his VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Carl articulated an informed view of the subjective aspect of NOS and was able to articulate his understanding in his own words. For example, while explaining how scientific theories change, Carl states,

> A theory is merely a proposed explanation for the results obtained from numerous experiments. It is this proposed explanation that makes theories somewhat subjective because two different scientists looking at the same data/results can and often times interpret the results quite differently. (Carl VNOS Questionnaire)

Likewise, Carl explains,

> I think inherently with people involved, I think there is going to be some form of subjectivity. Especially since theories are when you are trying to explain why something happened. I think that is just impossible for you to try to explain something and why it happened and to be totally objective. (Carl NOS Follow-Up Interview)

In addition, when Carl responds to the question asking how scientists could arrive at different explanations while using the same set of data, Carl states,

> In this case, the evidence would seem to support the notion of a catastrophic event that dramatically changed the climate of the earth but the cause of this catastrophe is unknown. From here scientists look at the data and make the best educated guess as possible. Each group looks at the data but interprets it differently. It is like people watching an accident, there are probably at least three different explanations for why the accident happened because each person has their own point of view. It is clear that there was an accident but one person may say it was due to ice, while another may say that the driver in front braked too hard or the person in back was too close. It could also be like seeing the score of a football game being 6-0. Seeing this score, I might guess that one team has kicked two field goals but another might guess that the team scored a touchdown but missed the extra point. Now as time goes on and new data comes to light
one of the extinction theories might be supported more than the other. (Carl VNOS Questionnaire)

Carl’s views regarding the subjective aspect of NOS are informed, articulated in his own words, and supported with examples; thus “+++” is his VNOS continuum score for the subjective aspect of NOS.

**Empirical.** Carl articulated an informed view of the empirical aspect of NOS. He articulated this view in his own words and provided supporting examples. Throughout his VNOS Questionnaire and NOS Follow-Up Interview, Carl frequently refers to data and evidence that science and scientists use. This data and evidence might be in the form of observations or experiments as Carl explains,

I do feel like you can obtain scientific knowledge just through observation, observing the world around you. Observing how things work. But I do think the majority of scientific knowledge is through experimentation. But I do not necessarily think that it has to be all the time. I wonder if that story of Newton and the apple is really true. But if it is, that wasn’t really an experiment but was really just an observation. (Carl NOS Follow-Up Interview).

In addition, Carl explains, “within the scientific community there needs to be data and proof to support the hypothesis” (Carl VNOS Questionnaire). Carl also alludes to the empirical aspect of NOS as he highlights the differences he perceives between science and other differences. For example, he states,

I would say that science is the study of nature... I do believe that science is different from other disciplines of inquiry, such as religion and philosophy, because the results of science are often times quantifiable while those are religion and philosophy are more qualitative. Within the scientific community there needs to be data and proof to support the hypothesis while in religion and philosophy it is more based on opinion and interpretation. An example, science can show what his happening inside the brain of a drug addict: what lobes are being activated, and what neuro-sensors are being used. Psychology or other social sciences would look at factors in that person’s life that might cause them to be a drug addict. In
essence, both are needed in order to paint the entire picture of the drug addict’s life but they are quite different. (Carl VNOS Questionnaire)

Because Carl articulates an informed view, in his own words, supported with examples,

“+++” is his VNOS continuum score for the empirical aspect of NOS.

**Creative.** Carl articulated an informed view of the creative aspect of NOS, and he was able to articulate this understanding in his own words. For example, Carl explains,

I think that good scientists use their creativity and imagination in all aspects of their scientific work. Coming up with new and innovative experiments requires creativity and in-depth knowledge of the science. In addition, the scientists must also come up with ways to measure their results in order to share it with the world. One example of this was Earnest Rutherford who devoted years of his life to investigating the atom and the nucleus in general. He developed an ingenious experiment that involved shooting alpha particles at a gold foil and observing their deflection. He obtained radically different results that what he had expected and he once again used his creativity to change our view of the atom. Scientists are constantly pushing themselves to develop new and useable tests to further investigate their studies and using their imaginations in all aspects of their experiments is a must. (Carl VNOS Questionnaire)

Likewise, Carl provides further examples of creativity and imagination being used in scientific processes as he explains,

I would definitely say yes, scientists use creativity and imagination. If you are dealing with very difficult, not problems, but if you are trying to explain something that is very difficult. You are going to have to think of a very ingenious way to look at it. There is some experiment with a guy trying to detect radiation content in space. And he filled up this massive tank with water, and he measured some type of radioactive isotopes and how they changed over time with radiation came from space. Some sort of odd experiment. But that's crazy. Or even someone finding the mass of the Earth by looking through a keyhole to two rooms over or figuring out the speed of light by looking at light between two different mountains. All those examples are of ingenious planning and design to try to explain something. (Carl NOS Follow-Up Interview)

When asked if scientists use creativity and imagination during data collection or data analysis, Carl responds, “they might be creative in trying to find a relationship that maybe
you would not think of. Or creative ways to measure something” (Carl NOS Follow-Up Interview). Therefore, even though Carl does provide numerous examples of scientists using creativity and imagination during the processes of planning and design, he does not elaborate much on the use of creativity during interpretation of results or while drawing conclusions. As a result, “++” is his VNOS continuum score for the creative aspect of NOS.

**Social and Cultural.** Carl demonstrated a naïve view of the social and cultural aspect of NOS. For example, in his VNOS Questionnaire, he states,

> I believe that science is universal and that scientists may do the best job of disconnecting themselves from the social and political values of their time. From my point of view, scientists are concerned with the facts and with the results of their experiments. (Carl VNOS Questionnaire)

Likewise, he explains,

> I would say that science is universal. I would say that true science is just trying to find relationships and explain things. Hopefully the scientist is not a part of it. That is why I think that you often see collaborations between scientists, all over the world working together. (Carl NOS Follow-Up Interview)

Carl also provides to illustrate this naïve view of the social and cultural aspect of NOS. For example, he states,

> One example that shows [scientists’] disconnection from the social and political values is the collaborations that spring up between scientists in different countries. This seems to show that the scientists are not concerned with the different norms of each culture but with making discoveries. Another example can be found by looking at the number of foreign graduate students who come to the United States for their Masters and Ph.D. work. If cultural norms dictated what they worked on, they most likely would not be and would find it extremely difficult to work with American professors. (Carl VNOS Questionnaire)

As illustrated by his responses, Carl’s view of the social and cultural aspect of NOS is naïve.
Theories and Laws. Carl articulated an informed view of the theories and laws aspect of NOS. He was also able to articulate this understanding in his own words and provide supporting examples. For example, Carl explains,

A scientific law is the stating of the consistent results of numerous experiments while a scientific theory is a proposed explanation for the results. One example of this relates to gravity. Through numerous experiments it has been shown that gravity if the force of attraction that exists between two objects with mass. If you throw a ball up, it will come back down. If you propel it hard enough, you can overcome the force of gravity. These are merely statements of what has been shown to be true. The theory of gravity however is an attempt to explain why objects with mass are attracted to each other. Some propose the existence of “gravitons” which are the fundamental units of gravitational attraction much like atoms are the units of matter but no one has ever witnessed or captured these gravitons, they are merely a proposed theory for why objects are attracted to each other. (Carl VNOS Questionnaire)

Likewise, in his NOS Follow-Up Interview, Carl talks about theories and laws in a similar fashion. For example, Carl states,

A scientific theory is trying to explain why something happens. A scientific law would be just stating a relationship. An example of the law and theory... the law of gravity. Two things are attracted to each other based on mass in the distance apart. If you jump up, you will be pulled back down to earth. A theory would be trying to explain why are two things attracted to each other? So people make hypotheses about individual units of gravity called “gravitrons.” So one is just a statement. A theory is trying to explain why. (Carl NOS Follow-Up Interview)

Because Carl provides an informed explanation of the difference between theories and laws in his own words and provides examples to illustrate his understanding, “+++” is his VNOS continuum score for the theories and laws aspect of NOS.

Observation and Inference. As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough
information regarding participants’ views of the observation and inference aspect of NOS.

Given this limited data, Carl articulated an emerging view of the observation and inference aspect of NOS. For example, as Carl explains how scientists can have knowledge about things they have not seen, he states,

The ability of scientists to describe things that they have never seen before is based on indirect evidence. They are able to observe how other things behave around the nucleus or black holes and draw educated conclusions from this. When you put your trash out in the evening and you wake up and notice it is gone, you can draw the conclusion that the trash company picked it up. You did not directly observe this but based on past experience you can be fairly certain that it happened. (Carl VNOS Questionnaire)

When asked if indirect evidence and inference are the same thing, Carl responded,

It could be. People might use those interchangeably, I probably would not...Maybe they would base it on other things they have observed or something someone said. It's not necessarily based on something like a previous law or fact. So they are similar, but different. (Carl NOS Follow-Up Interview)

Carl recognizes the difference between observation and inference. However, the limited information he provides regarding his views of the observation and inference aspect of NOS leads to his classification of having an emerging view of the observation and inference aspect of NOS.

**Scientific Method.** Carl articulated an informed view of the scientific method aspect of NOS. He was also able to articulate this understanding in his own words and provide supporting examples. For example, Carl explains,

I believe that to do good science, scientists do not always have to follow the scientific method. There are, in fact, many scientific methods that work. I do think that the standard scientific method taught in schools is a good model, but there is no reason to think that it is the only way to do science. Often times, major discoveries come by surprise and were unexpected. Sticky notes are a good example of a scientist performing an experiment at 3M with the intent of making a very adhesive material; but in the end, he made
an adhesive that was quite weak. Also, there are times when a scientist
does not start with an observation or problem but simply begins with a
hypothesis or an idea. In essence, I believe there are numerous types of
scientific methods that differ in their starting point or even in their order.
(Carl VNOS Questionnaire)

Because Carl provides an informed explanation of the scientific method aspect of NOS in his
own words and provides examples to illustrate his understanding, “+++” is his VNOS
continuum score for the scientific method aspect of NOS.

**Worldview—Nature and the Natural World**

During his Worldview—Nature Interview, Carl discussed nature and the natural
world in terms of his scientific understanding of the world, his specific content area
(chemistry), his religious beliefs, his personal experiences, the aesthetic qualities he sees in
nature and the natural world, his interest for nature and the natural world, and his personal
concern for care of the natural world. For example, Carl articulates part of his scientific
understanding of the world when he explains,

> We have lots of theories, some more prevalent than others. But there is an
> unexplainability too, it seems like. We don’t know. Unpredictable and
> unexplainable. We do a better job at predicting but explaining can
> sometimes be harder. Sort of a theory and law difference. (Carl
> Worldview—Nature Interview)

In a similar statement about his scientific understanding of the world, Carl explains, “it is a
closed system. So you do have the same amount of material originally as you do now (give
or take a little bit from outer space). But yet, there’s a lot of change going on: dynamic
equilibrium” (Carl Worldview—Nature Interview). Not only does he refer to a scientific
understanding of the world, but Carl also talks about nature and the natural world using
examples from his own content area (chemistry). For example, he comments, “Pure. Made
of one thing. Like maybe an atom or molecule, depending on if you’re talking about an
element or compound” (Carl Worldview—Nature Interview).

As a part of his articulation of his worldview beliefs regarding nature and the natural
world, Carl also referenced his religious beliefs. For example, he states, “nature was created
by God. We are told to take care of it. Does that give it sacredness? I think so” (Carl
Worldview—Nature Interview). In addition, he explains,

I guess everything is fallen, so is nothing holy now? So nature is probably
not holy. Maybe when it is redeemed it will be. Because of that, thanks to
the “Apple Incident,” I am going to say that nature is not holy. Because it is
fallen, maybe it cannot be holy at all. (Carl Worldview—Nature Interview)

Not only does Carl talk about his religious beliefs, but he also puts those religious beliefs into
a personal perspective as he explains, “it is important to understand how things work in
nature. Yes. I think it is. I think that helps you become closer to God” (Carl Worldview—
Nature Interview).

That personal perspective is also reflected as Carl talks about some of his personal
experiences in relationship to nature and the natural world. For example, Carl explains, “it is
very exciting. It kind of brings a thrill on. Sunrise and sunset. The Grand Canyon. Arches,
Bryce, and Zion National Parks, where I just was” (Carl Worldview—Nature Interview).
Likewise, he states, “nature is peaceful. Calm at times. Relaxing. Peaceful round of golf”
(Carl Worldview—Nature Interview).

Carl also mentions the aesthetic qualities he finds in nature and the natural world.
For example, he states, “I see beauty in nature. I do. Things look nice. Flowers look nice”
(Carl Worldview—Nature Interview). Although Carl expresses interest for and has a pleasant
emotional response to nature and the natural world, he explains, “I would not say that I
yearn for nature. I’m not a huge outdoorsman” (Carl Worldview—Nature Interview. In a somewhat similar fashion, Carl communicates personal concern for the care of the natural world when he explains, “I believe we are called to protect nature and take care of it” (Carl Worldview—Nature Interview). However, he does state,

I am concerned about pollution and the damage it does to nature. I am. But is does not appear that I do much to affect it. So is my concern real? I am concerned about it. But not enough maybe to really change my ways. I do drive a long ways. But I do recycle. (Carl Worldview—Nature Interview)

Worldview—Causality

Assertions relating to causality relied on Carl’s TOPE responses and his explanations regarding his responses. Carl picked the more scientific explanation for 12 of the 17 TOPE items, and the less scientific explanation for 5 of the 17 TOPE items: Items 5, 8, 13, 14, and 17. Therefore, his overall TOPE score is slightly above the average score for the group of participants (M = 11.75). For a number of the items where Carl picked the more scientific explanation, his reasoning for his choice seems to reflect a scientific way of thinking about the world. For example, his reasoning for TOPE Item #7 states, “While #2 might be plausible it is unable to be tested. Explanation #1 provides a path to explain what is happening that is very believable and more backed by scientific explanations” (Carl TOPE Item #7). Figure 33 contains TOPE Item #7. In addition, in TOPE Item #16 Carl states, “Explanation #1 makes note of measurement error and the fact that there is some support for the theory. It focuses on the data and measurements while #2 focuses on the scientist” (Carl TOPE Item #16). Figure 34 contains TOPE Item #16.

For one of the TOPE items where Carl picked the less scientific explanation, he refers to his religious belief in his response. For example, Carl states,
In the past when a man’s heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man’s heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.

2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more likely to accept? Explain.

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**Figure 33. TOPE Item #16.**

Certain planetary bodies appear to deviate slightly from their calculated position in space. The deviation is extremely small. Everyone working in this field agrees:

a) That the deviation exists, and

b) That Relativity Theory offers the most likely explanation.

When asked why they supported this explanation workers gave different reasons:

1. It is difficult to make accurate measurements and existing experimental evidence lends only weak support for the theory. Nevertheless, the evidence gives better support to this theory than to any other.

2. The explanation was published by one of the most distinguished scientists of the 20th century. There is no doubt that he knows more than anyone else in the world about this particular phenomenon.

Which explanation would you be more likely to support? Explain.

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**Figure 34. TOPE Item #17.**

Both explanations seem hard to test but I will settle for #2 because I am unsure that the thoughts and emotions of a chimpanzee are simple but I do believe there is something special about humans, something that God has given us and if the experimenters want to refer to this as humanity then that will work for me. (Carl TOPE Item #17)
A physicist at a well-known university was conducting a unique set of experiments. He was interested in the effect of electrical discharges on the growth rates of a particular type of tree. The methodology was simple. He administered electrical shocks to one set of trees but not to second. Over a period of several months he measured and compared the growth rates of the two groups. The scientist’s work caused a stir amongst his colleagues because he admittedly had no theoretical framework for his research. There were two basic opinions about this kind of experimentation:

1. The highly theoretical nature of physics provides an ample number of research problems for experimental work. Theory guided research is more efficient because there is a greater chance of success. This man has picked an idea out of thin air and pursued it for no other reason than idle curiosity.
2. This man should not be criticized for his unique albeit different research problem. All too often progress in many fields is thwarted by over-conservatism and rigid adherence to theory. Creativity and independence should be encouraged so that more discoveries can be made and the understanding of nature increased.

Which opinion would you be more willing to accept? Explain.

Figure 35. TOPE Item #17.

Figure 35 contains TOPE Item #17. However, this is the only TOPE item where Carl refers to his religious beliefs. Therefore, Carl’s religious beliefs do not appear to significantly affect his understanding of causality such that he would be more likely to pick explanation that are less scientific most of the time.

One of Carl’s TOPE responses also directly reflects his conceptions of NOS, particularly his conception of the subjective and theory-laden aspect of NOS. For example, in Carl’s response to the final TOPE item, he states, “While I believe that experiments based on theory and guided by theory are very beneficial, I do think there is space for experiments that are just based out of curiosity” (Carl TOPE Item #17). Figure 35 contains TOPE item #17.

Carl described a similar understanding of the subjective aspect of NOS in his NOS Follow-Up Interview:

The fact that they are taking data and, in this case, they are both formulating theories...so it would just be your attempt to try explain why something happened. The fact that they came up with two different things doesn’t really surprise me that much because I’m sure a lot of things could
explain it. I guess they are both trying to explain the climate change and so on, which they supposedly think, killed the dinosaurs. Both of those would probably lead to a massive climate change. I know there has been evidence of large meteorites hitting the Earth, and there has been evidence of large volcanic eruptions. I do not think that either one of them necessarily did it the wrong way. I think there are just different ways of looking at the data. (Carl NOS Follow-Up Interview)

Likewise, in this same NOS Follow-Up Interview he also stated,

I think inherently with people involved, I think there is going to be some form of subjectivity. Especially since theories are when you are trying to explain why something happened. I think that is just impossible for you to try to explain something and why it happened for it to be totally objective. (Carl NOS Follow-Up Interview)

Therefore, Carl appears to have an informed view of the subjective aspect of NOS. For this TOPE item, it appears there may be a relationship between an informed understanding of the subjective aspect of NOS and a preference for a less scientific explanation of causality. However, this is by no means a predictive relationship.

*Interpretive Narrative*

A narrative presents Carl’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Carl’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Carl’s Worldview—Nature Interview, a concept map created based on his Worldview—Nature Interview, and his responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Carl read over the narrative and modified it such that he believed it accurately described his conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Carl’s questionnaire responses, interview transcripts, and subsequent concept map:
Nature and the natural world can evoke a host of feelings, thoughts, and perceptions. For example, when I think of nature, I think that it is beautiful; and this beauty can also make it slightly mysterious. I think that nature is also peaceful and can be spiritual. I believe that the natural world was created by God. Therefore, I believe that nature has a purpose and this purpose can help us as we try to understand the natural world. Because God created nature, the natural world has some spiritual qualities and is sacred. In addition, God has also called us to care for His creation.

The natural world is full of resources. As humans, we use many of these resources to help support the lifestyles that we have. However, sometimes the ways that we use resources lead to pollution, endangered and exploited aspects of the natural world. But I do not think nature is doomed, even though it is fallen because of sin. Rather, we need to work to restore nature.

Nature is both the material world of matter that God has created and also the forces that act among the material things (such as gravity, electricity, energy, etc.). Nature can be both living and non-living. I think that nature is very orderly, complex, and diverse. I do not think that nature is very confusing or chaotic. Because nature is so orderly, it is knowable and we can seek to understand how it works. I think that the complexity and order of nature can be very exciting. We can see patterns in nature such as the periodic table in chemistry and classification schemes in biology. These patterns make nature somewhat predictable and help us to try to understand the natural world.

Even though nature is very orderly, I think that nature is also very changeable. We can see this in things such as the changing of the seasons, lifecycles, and evolution. Nature and the natural world can, at times, be very powerful. We can see this in things and events such as storms, mountains, oceans, landslides. This power can sometimes seem very dangerous and frightening. However, I do not think that nature is always dangerous.

Science is the study of nature, and it requires data and evidence. Often, scientists try to be objective when conducting experiments and making observations. However, it is often impossible to be completely objective. That is, because people are involved, science inherently has an aspect of subjectivity.

Experimentation helps scientific knowledge to develop. However, there is not one set method for how experimentation is supposed to occur. Scientific theories change over time with new data. Scientific theories simply try to explain why something occurs or explaining a relationship. In contrast, a scientific law just makes a statement regarding an observation. During scientific experimentation, scientists often use creativity and imagination in all aspects of their work.

Science is universal; that is, scientists can disconnect themselves from the social and political values of their time. We can see examples of
this when we look at scientists from around the world that collaborate with each other. This could not happen if science was not universal.

Science can also explain how and why many things happen in the world. When we look for the cause of something, we can usually try to look for some cause that has been tested and has been observed. Explanations that I find more plausible are usually the ones that are supported by more data and measurements. I know that God is powerful, and that God can intervene with the physical world in ways that we do not understand. I also believe that God has made humans special and sometimes we might not have good explanations for phenomena regarding humans and their thoughts and emotions. However, I think for the most part, we are able to find scientific explanations for why things happen.

Damon

Demographic Information

Damon is a 37-year-old male. He has an undergraduate degree in physics and chemistry and a master’s degree in education with a physics emphasis. He has been teaching for 13 years in several different subject areas including physics (13 years), chemistry (6 years), and advanced placement chemistry (7 years).

Views of Nature of Science

Damon’s scores on the VNOS continuum show he has an informed view of the observation and inference, theories and laws, social and cultural, creative, empirical, and tentative aspects of NOS. His views of the subjective and scientific method aspects of NOS are emerging. Figure 36 summarizes Damon’s VNOS continuum scores. A radar plot also visually illustrates Damon’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 37 shows a radar plot of Damon’s VNOS continuum scores.
Tentative. Damon articulated an informed view of the tentative aspect of NOS, he was able to articulate this understanding in his own words, and he provided examples to support his view. For example, Damon states,

The nature of scientists is that once someone puts forth a plausible explanation, they try to pick away at it to see if it holds up. Sometimes the whole thing collapses. Another time, little bits need to be tweaked here and there. Other times, new evidence and instrumentation comes about. So yes, absolutely theories can change. That’s one of the things that makes it interesting to keep doing it. If it was just, “here it is and it needs to stay that way,” you’d run out of things to investigate. The atomic theory has changed quite a bit. The theory of gravity is still being worked on: why exactly it works that way. No one still knows that. There’s a lot of astronomical theories about how and why things move. Our understanding of that has changed a lot. Theories like evolution have been tweaked and modified as they were first put forth. (Damon NOS Follow-Up Interview)
This recognition of the development of scientific knowledge is illustrated as Damon explains, “as more sophisticated instrumentation or new technologies are developed, theories must be adapted or, in some cases, thrown away for new ones” (Damon VNOS Questionnaire).

Damon also illustrates his understanding of the tentative aspect of NOS with an example. In his VNOS Questionnaire responses, he states,

It’s interesting that your example in the question is atomic theory because that has changed tremendously in the last 100 years or so. It went from hard little spheres in the 1800s, to electrons, to having nuclei, to neutrons, to electron orbits, to probability patterns, to nuclear decay, etc. Each new observation causes a tweak or a major change to the original idea...In physics, theories of motion to relativity; nuclear energy caused a change in the idea of matter; theories change all the time. Theories of the nature of light: waves, photons, vibrations of the ether, electromagnetic waves. None have changed what light is, they just change our perception or model of

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*Figure 37. Radar plot of Damon’s VNOS continuum scores. Dots on the plot can be correlated with continuum scores such that the center = 0 (naïve), first level out = 1 (emerging), second level out = 2 (informed), third level out = 3 (informed and articulated in participant’s own words), and final outer level = 4 (informed and articulated in participant’s own words with examples provided).*
why it is that way. A theory tries to explain why. As you learn more, that explanation can certainly change. (Damon VNOS Questionnaire)

Damon appears to recognize that science changes as new evidence comes to light. His views regarding the tentative aspect of NOS reflect an informed view. He also articulates them in his own words and supports them with examples. Therefore, “+++” is his VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Damon’s responses to the VNOS Questionnaire and NOS Follow-Up Interview were somewhat mixed in terms of his view of the subjective aspect of NOS. Some of his VNOS Questionnaire and NOS Follow-Up Interview responses reflected a naïve understanding of the subjective aspect of NOS. For example, he explains, “there have to be data that are not tied to one’s perceptions, goals, motives, preferences, or preconceived ideas” (Damon VNOS Questionnaire). Likewise, he states, “science is based on observations and measurements as opposed to...I mean, it does have theories, extrapolations, extractions, but true science is based on what we can measure and try to develop models that fit that” (Damon NOS Follow-Up Interview).

However, when discussing whether scientists working on the same question following the same procedures would come to the same conclusions, Damon explains,

I would say, if they asked the same question and had the same procedures, they would come to conclusions about the same thing. But I don't know that they would have to necessarily come to the same conclusion. Because there is always the act of, the last part of the method is, “what am I going to do next? How does that change my hypothesis?” Every experiment and every data has the possibility of error as you try to extrapolate or interpret. We look and say, “it seems like this kind of relationship.” You might have a few data points or observations that are a little bit off. I think that you may not end up at exactly the same conclusion about why that happened. (Damon NOS Follow-Up Interview)
Likewise, when discussing whether scientists working on the same question following different procedures would come to the same conclusions, he explains,

*I think that you could come to the same conclusions. I don't think they would have to either. You try to control all the various things and focus in on the one thing that you're looking at. I guess it also depends on what area you're looking at: how technical or how precise the observations have to be. I mean, you can give your class the same procedures to follow, and they get different conclusions. They don't even have to develop their own procedures, you just tell them to do this and do this, and they still end up all over the place. Due to the variability of perception, they may or may not end up with the exact same, “aha, that's what it is.”* (Damon NOS Follow-Up Interview)

Damon appears to acknowledge some subjectivity when he talks of “variability of perception.” Therefore, since Damon’s responses to the VNOS Questionnaire items and NOS Follow-Up Interview questions seem somewhat mixed, his overall view of the subjective aspect of NOS is emerging.

*Empirical.* Damon articulated an informed view of the empirical aspect of NOS. He articulates this understanding in his own words and provides supporting examples. For example, he states, “science is a system of thinking that relies on observable and measurable results to form patterns and predictions. The emphasis is on the measurable” (Damon VNOS Questionnaire). Likewise, in his NOS Follow-Up Interview he explains,

*Science is based on observations and measurements as opposed to... I mean, it does have theories, extrapolations, extractions, but the true science is based on what we can measure and try to develop models that fit that. Rather than trying to develop a model and see if things fit that which is what I think some philosophies and things try to do. So in science, you start with something you observe, and you work your way to the abstract.* (Damon NOS Follow-Up Interview)

Damon goes on to attempt to provide an example of the empirical basis of science as he responds to the NOS Follow-Up Interview question regarding how scientists know that
Dinosaurs existed despite the fact no one has actually observed a live dinosaur. Damon explains,

Because they find bones in the ground. Sometimes we find whole skeletons. There’s something there. You bury your relatives, and then you could go back later on and find their bones. So something was there. There is evidence for something. (Damon NOS Follow-Up Interview)

Damon’s response reflects an informed view of the empirical aspect of NOS in that it states that scientific knowledge is based on and derived from observations of the natural world. Because he articulated this informed view in his own words and provided an example, “+++” is his VNOS continuum score for the empirical aspect of NOS.

*Creative.* Damon articulated an informed view of the creative aspect of NOS, articulated this understanding in his own words, and provided supporting examples for his view. For example, in his VNOS Questionnaire, Damon states,

If scientists weren’t creative, they couldn’t experiment. Who would think to use the appearance and disappearance of the moons of Jupiter to measure the speed of light? Who would try to shoot alpha particles at a piece of gold foil? Who would notice the swinging of a hanging lamp and investigate pendulums as timepieces or put two pieces of ground glass together to make a telescope? I think creativity is essential at all three of the states you describe [planning and design, data collection, and after data collection]. Creatively deciding how best to isolate the variables to be studies and design instruments to measure the results. Creativity to decide what data to collect and how best to measure it. Even creativity in putting the data together in new ways as Bohr did putting the data about the hydrogen spectrum together with the atomic model of his day. (Damon VNOS Questionnaire)

Damon not only describes and provides examples for how the planning and design stages of experimentation and investigation can incorporate creativity and imagination, he explains and provides examples for how creativity and imagination can be use data collection and data interpretations. His views regarding the creative aspect of NOS are informed,
articulated in his own words, and supported with examples; thus, “+++” is his VNOS continuum score for the creative aspect of NOS.

**Social and Cultural.** Damon articulated an informed view of the social and cultural aspect of NOS, and he articulated his understanding in his own words. For example, Damon explains,

Science reflects social and cultural values. There are some groups of people who use science to prove things. You can look at it and twist it around and use it to prove whatever you want. There are some topics that are so charged right now that you can hardly talk about them without people yelling at each other because it has become a social issue. It is hard to separate the scientific data and observations from what that is going on in terms of cost to society, government regulation of this or that, individual freedoms, or something like that. (Damon NOS Follow-Up Interview)

Likewise, Damon is able to articulate how social and cultural aspects can influence both what and how science is conducted. For example, he states,

Part of the problem today is that people in the general population have, in my view, too broad a definition of science. Science is more limited in what it can discuss than many people would like to think. I also think that values might influences how I go about investigating a certain topic but that doesn’t make the topic good or bad; valuable or not. I could investigate the action of disease-causing bacteria in the genetics lab on mice or I could infect the population of a small town with it. The idea of how the bacteria work is not evil or good. How much I value mice or people will affect how I go about my investigation. (Damon VNOS Questionnaire)

In addition, as a part of his articulation of how social and cultural aspects influence the interpretation and utilization of science, Damon appears to separate the physical phenomenon and empirical aspect of NOS from the interpretation and use of science. For example, Damon explains,

I guess I would say that if I do an experiment and someone else, like a Hindu in India, does the same experiments. I could give them one of my lab sheets from a class, and they can do it. If mine takes 28 seconds to go, theirs might to. I don’t see any reason why that part of it should not be universal. The
molecules don't care. The stars don't care that you're observing them from your own belief system. It's that, "what do we do with the science?" that is often reflective of social and cultural values. (Damon NOS Follow-Up Interview)

Damon also refers to examples of when social and cultural aspects have influenced the practice of science. For instance, when talking about how he personally teaches NOS ideas, Damon explains,

It’s more in the history of how people use that to twist things around. We talk about astronomy and how the church got so involved and started persecuting people just for observing different things. We talk about it in that sense and mention a few of the things that are going on now. And we try to tell kids to be careful that what you are reading is really the picture of what’s going on and not the opinion at the end or that you’re not getting certain things left out. (Damon NOS Follow-Up Interview)

Therefore, since Damon’s view regarding the social and cultural aspect of NOS are informed, articulated in his own words, and supported with examples, “+++” is his VNOS continuum score for the social and cultural aspect of NOS.

**Theories and Laws.** Damon articulated an informed view of the theories and laws aspect of NOS. He articulated his understanding in his own words and provided supporting examples. For example, Damon describes and illustrates his understanding of the difference between theories and laws as he explains,

A theory tells why (or tries to tell why) something occurs. A law tells or describes what is happening. The law of gravity tells that objects accelerate at $9.8 \text{ m/s}^2$ downward near the earth’s surface. It tells that gravitational force and acceleration are proportional to the mass of two objects and inversely to the square of the distance between them. Laws allow for prediction and calculation. The theory of gravity attempts to describe why massive objects attract. What is it about matter that produces only an attraction? How does the attraction come to exist? (Damon VNOS Questionnaire)

Likewise, in his NOS Follow-Up Interview, Damon explains,
I've always been taught, and it makes sense to me that the theory tries to go over the law and explain why it works. The laws are, "when I drop something it accelerates at 9.81 m/s per second." It happened here, it happens in Florida, it happens everywhere, and it works. You can predict how things will happen. The theory tries to get into what it is about the thing that you dropped in the Earth that makes them do that. This is the more subtle question. It's misunderstood often. Most students think that theories are things that you haven't quite figured out yet, and laws are set in stone like the Ten Commandments. The theory tries to... the theory is deeper, I think, than the law. Gravity would be a good example. The law of gravity: there are tons of equations you can use, and constants, and things that let me throw something, and I can predict pretty much when and where it will end up. They sent people to the Moon based on the law of gravity, and it worked fine. But the theory of gravity...why do they do that? What is it about massive objects that make them attractive to each other and not repel? We do the same thing with magnetism and electromagnetism. We can understand the wavelength and frequency and how that works, but why do they fluctuate like that? (Damon NOS Follow-Up Interview)

One very interesting thing Damon mentions is that most students think that theories and laws are hierarchical with theories being lower than laws (a naïve understanding of the theories and laws aspect of NOS). However, he explains that he understands the relationship such that a theory “goes over the law and explains why it works” (Damon NOS Follow-Up Interview). Damon’s response reflects an informed view of the theories and laws aspect of NOS. He is able to explain the nuances of theories and laws in his own words and examples; therefore, “+++” is Damon’s VNOS continuum score for the theories and laws aspect of NOS.

**Observation and Inference.** As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough information regarding participants’ views of the observation and inference aspect of NOS. Given the data obtained, however limited, Damon, demonstrated an informed view of the
observation and inference aspect of NOS. For example, when asked about the role of observation versus inference, Damon explains,

The observation is the thing that you thought you could explain. You look at the surface of the earth, and you notice that the continents move around. You say there must be something causing that, so you try to figure out what's going on. Or you look at how galaxies are held together, and you see that there's not enough gravity to hold it all together. So you look at the laws that you have. If there's something that's unexplainable, you have to look at your observations and make inferences either for new observations, where you would develop a new instrument to see what you couldn't see before, or you have to make an educated guess. I keep thinking of astronomy because I just read about it this summer. They watched Mars go this way and then they watched it go backwards. And so they had all these goofy circles because they couldn't see what was actually happening. It was probably not true, but it was inference made on an observation. (Damon NOS Follow-Up Interview)

Damon recognizes the difference between observation and inference, he explains it in his own words, and he provides an example with the inferred path of the movement of Mars. However, this is the only time during both the VNOS Questionnaire and the NOS Follow-Up Interview where Damon mentions inferences. Therefore, due to the lack of more data, “+” is Damon’s VNOS continuum score for the observation and inference aspect of NOS.

**Scientific Method.** Damon articulated an emerging view of the theories and laws aspect of NOS. In his response to the VNOS Questionnaire he explains,

Because science is a process done by many different people, it is important that we all agree on the general process to follow before an idea is accepted or rejected. The method’s exact steps vary in name and number but generally, there is an initial event that compels further investigation. Some either explicit or implicit guess as to what is going on is needed and variables need to be defined, etc. Most of the method’s benefit is in making my exact procedure and thought process clear so others can subsequently accept or deny or retest what I’ve done. (Damon VNOS Questionnaire)
This view reflects a more naïve understanding of the scientific method aspect of NOS.

However, Damon does explain that there may just need to be a “general process” where the steps can vary in “name and number” (Damon VNOS Questionnaire).

However, in his NOS Follow-Up Interview, Damon seems to be articulating a slightly more informed understanding. For example, he explains,

I don't stress it is much as it was stressed to me: learning the steps and memorizing them all. A lot of the things I've read about the history of science seems like a lot of it was done by accident. They were just fiddling with something and all of a sudden, they get unexpected results. So they didn't necessarily have a hypothesis in that area to start with. But they were doing something... I think that once you get headed down a road, there's a definite, whether you do every step in order every time, but there is a definite, "What am I giving do next? How will that change?" You have to have some idea what will happen. That would be a hypothesis. You need one even to look for what will happen. But I don't know that every scientific investigation does everything piecemeal, one right after the other. So yes, they should follow a method, but I don't know if they need to follow that particular sequence of steps of the time. (Damon NOS Follow-Up Interview)

Damon seems to recognize that not all science may follow a regimented and exact “scientific method.” Therefore, Damon’s view of the scientific method aspect of NOS is emerging.

**Worldview—Nature and the Natural World**

During his Worldview—Nature Interview, Damon discussed nature and the natural world in terms of his scientific understanding of the world, his specific content areas (chemistry and physics), his religious beliefs, his personal experiences, the aesthetic qualities he sees in nature and the natural world, his interest for nature and the natural world, and his personal concern for care of the natural world. Damon articulates a scientific understanding of the world and also integrates his content areas (chemistry and physics) when he explains,
Some of it is material: rocks, dirt, sand, sky, plants. Other things are not: electromagnetism and gravity...I think of material as stuff. A lot of nature is stuff, but a lot of it is not stuff. It can be forces in action and things like that. (Damon Worldview—Nature Interview)

Likewise, he states, “it is stuff, but also energy and not stuff” (Damon Worldview—Nature Interview).

Damon also integrates his religious beliefs into his worldview beliefs regarding nature and the natural world. For example, he explains, “God provides for us through nature a lot more than we think He does” (Damon Worldview—Nature Interview). Likewise, he states, “[nature is] sacred in the sense that it is a revelation of the Creator. It is a way that we can get to know Him. In that sense, I would say that nature is sacred” (Damon Worldview—Nature Interview).

Damon refers to his personal experiences and ideas about aesthetic qualities when he talks about nature and the natural world. For example, Damon explains,

There are times that you are more impressed with the scope and of the variety of it and everything that is out there. Like when we were out West. But when you’re driving down the street or when you’re trying to make dinner or something, you’re probably not really thinking about how amazing it is that we can grow all these things and that you can turn the flour into bread and so forth. (Damon Worldview—Nature Interview)

Likewise, he goes on to explain, “whitewater rafting was somewhat dangerous. Weeds in my driveway are not dangerous” (Damon Worldview—Nature Interview). Damon refers to the aesthetic qualities of nature and the natural world when he states,

When we were in Colorado, it was very beautiful. The ocean is very beautiful. I don’t know if beautiful would describe a picture of, like the picture where the leopards are ripping the throat out of a wildebeest...I think it is more beautiful than not beautiful though. (Damon Worldview—Nature Interview)

In addition, he explains,
Those pictures that I looked at earlier, like the electron micrograph of the bug. Some students, I though, would say, yuck! But I think all the details are very beautiful even if they’re used for things like biting and other sorts of ugliness (Damon Worldview—Nature Interview)

Damon also communicates an interest for nature and the natural world. For example, he states, “I think we were put here and given abilities and curiosities to study nature. If it wasn’t knowable, that would be cruelty on the part of the Creator” (Damon Worldview—Nature Interview). Likewise, he explains, “I find nature exciting. I think it is neat about how it is all put together. I think it’s very interesting and exciting” (Damon Worldview—Nature Interview). Not only is Damon interested in nature and the natural world, but he also has personal concern for the care of the natural world. For example, he states, “I think there is a sense of stewardship or ownership or conservation or something like that” (Damon Worldview—Nature Interview). Likewise, he explains,

It’s important to understand how things work. We were commanded to live in the earth and subdue it, and rule over it. If you’re going to be effective in that capacity, you better know something about it...so if you’re going to take care of the Earth, you should know about it and how it works. (Damon Worldview—Nature Interview)

Worldview—Causality

Assertions relating to causality relied on Damon’s TOPE responses and his explanations regarding his responses. Damon picked the more scientific explanation for 12 of the 17 TOPE items, and the less scientific explanation for 5 of the 17 TOPE items: Items #7, 9, 13, 14, and 17. Therefore, his overall TOPE score is slightly above the average score for the group of participants (M = 11.75). For the items where Damon picked the more scientific explanation, his reasoning for his choice seems to reflect a scientific way of thinking about the world. For example, his reasoning for TOPE Item #1 states,
I tend to be more skeptical of psychic phenomena. It would make more sense to me if the effect causing the emission of light was more closely related to other well-studied and documented processes that show one substance/effect causing light to be emitted. The first explanation follows more naturally from the effects/reasoning that I have already studied. (Damon TOPE Item #1)

Figure 38 contains TOPE Item #1.

However, several of Damon’s responses reflected a way of thinking about the world that was not entirely scientific. For example, Damon chose the less scientific explanation for TOPE Item #7 and explains his choice by saying,

I don’t know if I agree with the use of the phrase “first empirical evidence” because the data cannot be repeated by other experimenters – it’s not scientific. However, it seems that people describing personal experiences in these situations have some similarities to their accounts. (Damon TOPE Item #7)

Figure 39 contains TOPE Item #7. Damon not only chooses the less scientific explanation, but he also appears to identify his choice as the less scientific choice. Likewise, in TOPE Item #9, Damon states, “I think we sometimes give too little credit to non-technological solutions to problems. Sometimes a simple solution is the best one—be in tune with your
environment” (Damon TOPE Item #9). Figure 40 contains TOPE Item #9. Once again, Damon appears to know that he has picked the less scientific explanation.

One of Damon’s TOPE responses also directly reflects his conception of NOS, particularly his conception of the observation and inference aspect of NOS. For example, in Damon’s response to TOPE Item #2, he states,

This one is a bit harder because I’ve seen some people who were gifted with sleight of hand who could make fluid exchanges/tricks that you could not notice up close. I also know, because we have little cars with magnet attached, that they can move each other without making any noise. I guess I’m disappointed that all the people thought to do was listen – there might have been other clues about the train(s) such as small details in the design or whatever that could prove there were two trains. I’d be willing to accept either explanation, however, since I have to choose one, I’d say that the sleight of hand “tricks” usually have some method or basis such as magnets or something like that so that’s why I chose #2. (Damon TOPE Item #2)

Figure 41 contains TOPE Item #2. In addition, for TOPE Item #3, Damon states,
A startling discovery has recently been made amongst a pre-modern group of people in a remote region of the Amazon Basin. An anthropologist living with these people for a year noted that the council of elders had a perfect record on predicting rainy days. Out of 365 days there were 109 days on which rain began to fall. All of these days were correctly predicted two to four days in advance. For the same period of time the government meteorological forecasts were much less accurate. The elders based their predictions upon the pattern made by dried chicken bones which they would cast a specific number of times each day. The scientist was impressed with the accuracy but skeptical that the bones had much to do with it. He got the elders to cooperate in a number of experiments by which he hoped to determine the real nature of their predictions. None of his hypotheses were confirmed, all were rejected. In the end he was convinced that the predictions must indeed rest upon the chicken bones. Later the anthropologist reported his findings at the symposium; and although his peers agreed with his conclusions they disagreed in their reasons:

1. Pre-modern people although pre-modern are still clever. They skillfully put to use the collective observations and knowledge of their ancestors, as in this case. Modern people are surprised by their achievements only because they think of the pre-modern man as naive and unintelligent.

2. First of all the anthropologist's studies were rationally designed and carefully conducted. Secondly, his findings are corroborated by the work of other anthropologists amongst other types of people. Thirdly, chemists have recently found that dry bones absorb moisture from the air and that the amount of "bounciness" in the bone depends on how much moisture has been absorbed.

Which side do you find more acceptable? Explain.

Figure 40. TOPE Item #9.

Recently astronomers have observed an increase in radio wave activity of particular frequency from a particular sector in the sky. This observation has caused a stir and a great deal of speculation as to its explanations. So far there are two explanations that the astronomers are arguing most about:

1. Man has often doubted that he was alone in this vast universe. These radio waves might well be radio signals from some far civilization upon which we have stumbled or indeed they may even be meant for us.

2. There are many physical bodies in the heavens which emit radio waves. These emissions fluctuate and chances are these new emissions will be found to fall within the regular patterns of chance fluctuation.

Which explanation would you be more willing to accept? Explain.

Figure 41. TOPE Item #2.

There have been many astronomical observations that have lacked explanation until observational techniques and instrumentation caught up with the initial observation to give more detail. Pulsars, quasars, background radiation, gas clouds, could all be causes of the “new” radio signal. Until the
Some people were observing a demonstration that involved a miniature red train car, a bit of track, and a tunnel. When the demonstrator pushed the train car into the tunnel a blue car came out the opposite side. When the blue car was pushed back into the tunnel the red car reappeared out the other side. People suspected that there were really two cars, originally the blue one being hidden by the tunnel. To test this idea they listened carefully when the red car was pushed into the tunnel feeling sure that they would hear it knocking the blue car out the opposite side. Try as they might, they could hear no sound of a collision. The people then fell into two groups over the matter:
1. Some people found the demonstration intriguing and amusing. They considered the demonstrator to be a kind of magician who was proving that the hand really is quicker than the eye.
2. Other people recalled that like-poles of magnets repel each other. So perhaps there were two cars each with a magnet. Like poles faced each other so that one car entering the tunnel drove the other out without ever touching.
Which explanation would you be more willing to accept? Explain.

Figure 42. TOPE Item #3.

radio waves themselves and/or the part of the sky from which they originate are studied more closely, I’d tend to side with the “chances are” explanation found in #2. (Damon TOPE Item #3)

Figure 42 contains TOPE Item #3. Likewise, in his responses to the VNOS Questionnaire and NOS Follow-Up Interview, Damon’s responses indicated he had an informed understanding of the observation and inference aspect of NOS. For example, in his VNOS Questionnaire, Damon states, “when using rock layers, atmospheric data, ice core samples, and fossils there will be a level of unknown because these are all, in our time, relatively static things that we are trying to make dynamic conclusions about” (Damon VNOS Questionnaire). In addition, in the same VNOS Questionnaire, Damon asserts that science “relies on observable and measurable results to form patterns and make predictions” (Damon VNOS Questionnaire). Therefore, it appears that there may be a relationship between an informed understanding of the observation and inference aspect of NOS and a preference for a more scientific explanation of causality for several of the TOPE items. However, this is by no means a predictive relationship.
Interpretive Narrative

A narrative presents Damon’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Damon’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Damon’s Worldview—Nature Interview, a concept map created based on his Worldview—Nature Interview, and his responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Damon read over the narrative and modified it such that he believed it accurately described his conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Damon’s questionnaire responses, interview transcripts, and subsequent concept map:

I think nature and the natural world have been created by God. Therefore, nature is holy, sacred, spiritual, and has a purpose. Because God created the natural world, it is very beautiful and orderly. This order allows it to be knowable and understandable. Being able to learn about the natural world makes it very exciting and interesting. There is so much diversity and complexity in the world! Even when some of this complexity makes things seem confusing or mysterious, that helps to make it interesting.

The order of the natural world allows it to be predictable. We can predict many material things like the flow of a river and some intangible things like gravity and other forces in nature. But human actions can be very unpredictable. The natural world is also very changeable—both in terms of natural forces like continental drift and evolution and in the ways that humans use and interact with nature. In addition, some of the materials and forces in nature can be very powerful. This power can make it seem dangerous and frightening. For example, thunder and lightning may seem frightening to some people and can be dangerous. However, much of the material aspects of nature are not dangerous. In fact, many can be used as resources that help to contribute to the lifestyles we have today. We depend on nature for things like protection, space, food, energy, and water.

Parts of the natural world have been damaged because of the way humans have interacted with it. Even though some aspects of nature have been exploited, I don’t think that it is hopeless. I think that the natural world is restorable; for example, wolves are returning to Michigan. I think that
saying nature is unpredictable, polluted, exploited, unexplainable, and confusing are too strong of words that signify a negative attitude about nature. If you have that attitude about nature, I do not know why you would bother to study and investigate it or learn anything about it.

Science is the study of the natural world that relies on observations and measurable results to form patterns and make predictions. One important defining characteristic of science is that scientific theories can be tested by other scientists. When scientists engage in experimentation, they use creativity and imagination in all aspects of experimentation—from experimental design to data collection to data interpretation.

Scientific phenomena are universal. For example, gravity is gravity everywhere. Science is empirical and deals with evidence and data. However, the practice of science reflects culture. So maybe deciding what is evidence and determining how to interpret the evidence reflects the culture and values of the scientists and context.

Science progresses, and scientific theories can change or be thrown out as new data is obtained or new instrumentation and technologies are developed. Scientific theories try to explain why something occurs. A scientific law simply describes what is happening. Laws allow for prediction and calculation.

Science can also explain how and why many things happen in the world. Many of the observations we make about the world can be explained by cause and effect relationships. I believe that God created the world and is in control of things that happen in the world. Therefore, there are some things that may be too complicated for us to understand because they, for example human brains and thought processes, seem to be more complicated than the sum of their parts. But for the most part, we are able to find scientific explanations for why things happen.

Elizabeth

Demographic Information

Elizabeth is a 47-year-old female. She has 22 years of teaching experience in several different courses including physical science (16 years), biology (10 years), chemistry (4 years), 7th grade science (4 years), 8th grade science (4 years), and 9th grade science (4 years). She has an undergraduate degree in biology and a master’s degree in curriculum and teaching.
**Views of Nature of Science**

Elizabeth’s scores on the VNOS continuum show she has an informed view of the scientific method, theories and laws, empirical, subjective, and tentative aspects of NOS. Her views of the social and cultural and creative aspects of NOS are emerging. Her view of the observation and inference aspect of NOS is naïve. Figure 43 summarizes Elizabeth’s VNOS continuum scores. A radar plot also visually illustrates Elizabeth’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 44 shows a radar plot of Elizabeth’s VNOS continuum scores.

**Tentative.** Elizabeth articulated an informed view of the tentative aspect of NOS,

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**Figure 43.** Elizabeth’s VNOS continuum scores. Numerical scores can be correlated with continuum scores such that 0 = naïve, 1 = emerging, 2 = informed, 3 = informed and articulated in participant’s own words, and 4 = informed and articulated in participant’s own words with examples provided.
and she was able to articulate this view in her own words. For example, Elizabeth explains,

I think that theories do change. I think they change because things are discovered later on, whether because the technology is better or something that we didn't have before that allows us to get more information. Or something doesn't work. Our theory says that something should be discovered and what we find doesn't go along with the theory. Then maybe our theory needs to change. I think that's why theories change. (Elizabeth NOS Follow-Up Interview)

Furthermore, Elizabeth provided examples to support her views regarding the tentative aspect of NOS. She explains,

I think that that theories do change. As better technology develops and we are able to do more things, we can discover more. We can see how matter may act differently in new situations and that can cause us to change our explanations. Dalton believed that the atom was indivisible (the smallest particle of matter). When J.J. Thomson experimented, however, the behavior of the gases indicated that there was something smaller and that
the atom was divisible. From these experiments, the atom was changed to be made up of (-) particles: the Plum Pudding Model. Rutherford and Bohr and Chadwick followed with additional experiments and the model kept changing because of how matter behaved. New theories continue as we learn more and new advances can be made as we understand more. It is important to learn the theories so we understand what is known (or believed) and so we can advance or go beyond where we are now. (Elizabeth VNOS Questionnaire)

Because Elizabeth was able to articulate an informed view of the tentative aspect of NOS and describe that view in her own words with supporting examples, “+++” is her VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Elizabeth articulated an informed view of the subjective aspect of NOS, and she was able to articulate this view in her own words. For example, when asked about scientists deriving different explanations when looking at the same set of data regarding the extinction of dinosaurs, Elizabeth explains,

> The scientists are interpreting the same set of data and coming up with different explanations. Maybe there just isn’t enough information to really be 100% sure. Maybe the information supports both explanations because maybe both happened. Do both groups agree that the dinosaurs became extinct 65 million years ago? At least they’re agreeing on that! As time goes on, maybe further information will be collected that will help by maybe we will never know the answer. If there is one. (Elizabeth VNOS Questionnaire)

Likewise, when discussing whether scientists working on the same question following the same procedures would come to the same conclusions, she explains,

> You’d like to think that they would come to the same conclusions...I would like to think that if they all have the similar background knowledge, they will come to the same conclusions. At least their experiments would turn out to be the same. I don’t know that they would still come to the same conclusion just because there may be more than one explanation that could be offered for the data that they get. I think that you see that happening many times. People read the results of somebody and say, "I don’t think this is what it means." I think that you will not always have them come to the same conclusions. (Elizabeth NOS Follow-Up Interview)
When Elizabeth talked about what she thought science was, she explained, “It’s a particular way of looking at the world that you try to ask the questions and figure out the answers...there may be different explanations for what you observed seeing” (Elizabeth NOS Follow-Up Interview). And later in during the interview, when talking about whether or not she felt that teaching NOS ideas in her classroom was important, Elizabeth explained, “I think it’s important for students to hear about the fact that there are different theories for different things. For students to understand that explanations can be given because of the background of the scientist” (Elizabeth NOS Follow-Up Interview). Therefore, since Elizabeth articulates an informed view, in her own words, of the subjective aspect of NOS, “+++” is her VNOS continuum score.

**Empirical.** Elizabeth articulated an informed view of the empirical aspect of NOS. Throughout her VNOS Questionnaire and NOS Follow-Up Interview responses, Elizabeth comments on the importance of observation and experimentation to science. For example, she states, “I think the development of scientific knowledge does require experiments. Science is not just thinking, but doing. We do science in order to understand the world around us (experiments)” (Elizabeth VNOS Questionnaire). When describing what an experiment is, Elizabeth explains, “it is a way to discover and answer rather than just by reading about it” (Elizabeth NOS Follow-Up Interview).

Elizabeth also cites the importance of being able to repeat experiments and obtain the same results. For example, she explains, “I think scientists need to repeat and repeat their own experiments and get the same results many times before they publish. I think their experiments must be able to be repeated by others” (Elizabeth VNOS Questionnaire). Likewise, she explains,
I think that we can have some knowledge about what happens, but it might just be an opinion...You could say, “this is why.” It might even sound good, but it might not be the actual explanation for it. But to be able to test it with a number of different things and to always come up with the same answer you could have a more likely idea that it is really how it works rather than just saying, “this is what I think.” (Elizabeth NOS Follow-Up Interview)

The acknowledgment that scientific knowledge draws on observations of the natural world indicates Elizabeth has an informed view of the empirical aspect of NOS.

**Creative.** Elizabeth articulated an emerging view of the creative aspect of NOS. In her VNOS Questionnaire responses, Elizabeth seems to articulate an informed view of the creative aspect of NOS in her own words and supports that with examples. For example, Elizabeth states,

I think scientists used creativity and imagination during their investigations. Scientists who think “outside the box” are more likely to discover more things. I think creativity and imagination are used in all parts of investigations. Think of the discovery of penicillin. It was an accident. Fleming could have recoded it as a mistake, and thrown it away. But he didn’t. So many advances occur because the scientists could see the possibilities rather than just follow a set method. Using creativity and imagination makes data deeper and richer. Scientists use creativity and imagination because they can get more than just the expected results. The sky’s the limit. (Elizabeth VNOS Questionnaire)

However, when asked to expand on and clarify her response in the NOS Follow-Up Interview, Elizabeth explains,

I think they do use creativity and imagination during their investigations. I think their creativity can come in with how they planned and design an experiment. I don’t know if it would come in so much with the collection of data. Although, I suppose they could be, well no. Well, different people might collect different data, but it’s probably pretty set depending on what your hypothesis is. But I think that you can be very creative and imaginative when you’re designing an experiment...I think that they might use creativity and imagination their experimental design. But I would think that most of the time they are not being terribly imaginative when they make their conclusions or analysis. (Elizabeth NOS Follow-Up Interview)
Furthermore, she goes on to explain that using creativity and imagination in data analysis is “probably not appropriate. I think that if they did, people would say, ‘they are just being fanciful’ or something like that. Maybe there are places for it, I guess, but most of the time they don’t” (Elizabeth NOS Follow-Up Interview). Since Elizabeth hesitates but does not completely dismiss use of creativity and imagination in aspects of scientific inquiry following data collection, her views regarding the creativity and imagination aspect of NOS are emerging rather than naïve.

**Social and Cultural.** Elizabeth articulated an emerging view of the social and cultural aspect of NOS. In her VNOS Questionnaire, she states, “I think that science is universal but it can be used for political gain...I don’t think the science reflects political values but how quickly it could advance may well be determined by politics” (Elizabeth VNOS Questionnaire). Here, Elizabeth specifically states that although social and cultural factors affect the use and application of science, science itself is universal. This reflects a naïve view of the social and cultural aspect of NOS.

However, her response during the NOS Follow-Up Interview reflects a view of the social and cultural aspect that seems to be moving towards more informed. For example, she explains,

> I guess I would say that science probably reflects the social and cultural values. I think you would like it to be universal, but you go at a question and probably your explanations based on what you already know and what you think...I think that it tends to be that you are going to have your values with you when you make your conclusions and everything else. I think that it can be universally believed, but I think that, at least initially, it will be reflective of what you believe in that context that you are in. I think your conclusions may be different if you were in a different time or a different place. (Elizabeth NOS Follow-Up Interview)
This recognition that the scientific process itself is a human endeavor, influenced by the society and culture in which it is practiced, reflects and informed view of the social and cultural aspect of NOS. Therefore, Elizabeth’s VNOS continuum score is emerging since her views are developing and progressing towards a more informed view.

**Theories and Laws.** Elizabeth articulated an informed view of the theories and laws aspect of NOS, and she was able to articulate this view in her own words. She explains,

> From what I have learned (and teach!) a theory is an explanation of what is observed while a law is the summary of many observations seen in nature. In Physical Science, we tell the kids that all objects are attracted to each other by the force of gravity (known as Newton’s Law of Gravity). But there are many theories (or explanations) on how gravity works. (Elizabeth VNOS Questionnaire)

Elizabeth is able to differentiate between the functional difference of laws and theories: laws describing relationships observed in the natural world, and theories providing the explanations for those relationships. For example, Elizabeth explains,

> There is supposed to be a difference between a scientific theory and a scientific law. A scientific theory is the explanation. And the scientific law is a description. A theory explains, but a law is just the statement. That’s how I would say the difference is. That would be the definition, even though it doesn’t always come through that way. When we talk about the law of gravity, we say, “this is what it is.” We don’t say why. We don’t say why this is what happens. We just say that if you let something go, it will fall. And that’s the law. And the theory would be, “why does that happen?” (Elizabeth NOS Follow-Up Interview)

Because Elizabeth articulates an informed view in her own words, “++” is her VNOS continuum score for the theories and laws aspect of NOS.

**Observation and Inference.** As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough
information regarding participants’ views of the observation and inference aspect of NOS.

Given this limited data, Elizabeth articulated a naïve view of the observation and inference aspect of NOS. When asked to explain her understanding of indirect evidence, she states,

Indirect evidence is evidence that you get without being able to see or touch something. You might do something and see what happens as a result of what you do. And that allows you to draw some conclusions about what you think is happening inside. (Elizabeth NOS Follow-Up Interview)

When asked if this notion of indirect evidence is the same as inference, Elizabeth explains, “I guess that an inference, in my opinion, is something that you make without having as much evidence for. You just have an inference about something—it is not as strongly supported (Elizabeth NOS Follow-Up Interview). This explanation does not really reflect an informed understanding of inference as an interpretation of observation. Rather, it seems to set up a hierarchical notion where inference might be some type of observation for which you simply have less evidence. Therefore, her view of the observation and inference aspect of NOS in considered naïve.

**Scientific Method.** Elizabeth articulated an informed view of the scientific method aspect of NOS. For example, Elizabeth explains,

I think that there are logical steps to follow when trying to discover something. I think it is important that other people can repeat the work so that conclusions can be verified. But I don’t know if there is only one scientific method with steps always in the same order. I think you can start at different places in the process depending on the situation. So to answer the question, I think scientists must follow a scientific method (logical, controlled, etc...) but that it might not look exactly the same each time. (Elizabeth VNOS Questionnaire)

Likewise, Elizabeth states,

I don't know if I want to say the scientific method. I am tending to say there may be many scientific methods. Traditionally, they look at that and they even order the steps. I don't think they have to be in that order. A lot of
times you don't start there. I do think though that there should be some kind of steps that a scientist would follow in terms of trying to come up with some sort of results... I think that you need some sort of process usually. I think that it should be logical. Things happen by mistake, and discoveries are made that happen by mistake and not through a specific process. I still think they were doing science, whether it was through an accident or not. If you are creative person, for example, and not as logical, you might do something that other people would think is kind of strange to do. But you might do that because of your creativity. I would not want to say that there is the scientific method, but there usually is some sort of process they go through. (Elizabeth NOS Follow-Up Questionnaire)

Although Elizabeth believes that science does often, but not always, progress through some sort of process, she is careful to point out that there is not one particular method by which science must progress. This reflects an informed view of the scientific method aspect of NOS.

**Worldview—Nature and the Natural World**

During her Worldview—Nature Interview, Elizabeth discussed nature and the natural world in terms of her specific content areas (biology and chemistry), her religious beliefs, her personal experiences, the aesthetic qualities she sees in nature and the natural world, her interest for nature and the natural world, and her personal concern for care of the natural world.

Elizabeth refers to her content area (biology and chemistry) when she explains, “I think it changes all the time. I think organisms change all the time. I think mutations occur all the time...how the diseases change and mutate” (Elizabeth Worldview—Nature Interview). Likewise, Elizabeth refers to actually teaching chemistry when she adds, “I teach chemistry too, so I know all the different parts that make that up” (Elizabeth Worldview—Nature Interview).
Elizabeth also incorporates her religious beliefs into her articulation of her worldview beliefs regarding nature and the natural world. For example, Elizabeth states,

\[
\text{I can remember one summer when I was in Europe. I stood there in the Alps, and there was hardly anyone around. All I could think of was “My God, How Great Thou Art,” that song...nature makes me feel spiritual and makes me feel that I recognize and see God in nature. (Elizabeth Worldview—Nature Interview)}
\]

Likewise, she explains, “I believe that nature was created by God” (Elizabeth Worldview—Nature Interview).

Elizabeth’s personal experiences and thoughts about aesthetics also shape her beliefs. For example, she recalls, “we were at Pictured Rocks last summer, and it wasn’t the way I remembered it because as a little kid because the top of one of those things is gone” (Elizabeth Worldview—Nature Interview). Likewise, she explains,

\[
\text{Just go to Yellowstone and see, within that one park. Have you ever been there? It’s crazy, so cool, so different. Last summer we went to the Badlands, and how different that is. And then you go to Glacier. And then you think all these different places, and that’s just in this part of the United States. There are so many different things, so I would say it’s definitely diverse. (Elizabeth Worldview—Nature Interview)}
\]

Some of her personal experiences seem to incorporate into her ideas about the aesthetic qualities of nature and the natural world. For example, she explains “if you go to a National Park, for example, and look at all this and say, ‘oh, this is so beautiful’” (Elizabeth Worldview—Nature Interview).

Elizabeth seems to have an interest for nature and the natural world. For example, she explains,

\[
\text{Nature is exciting. I would say that is definitely true. Because, thinking in terms of weather-related nature. In terms of earthquakes and storms. But also thinking in terms of how living organisms interact with each other. I think that can be very exciting. And we make it exciting. When we go to}
\]


different places and see things and say, “oh, this is really cool and exciting.”
I’d say that nature is exciting. (Elizabeth Worldview—Nature Interview)

Likewise, she states, “and I think that’s part of what makes being a scientist exciting.
Because you can’t always predict what is going to happen” (Elizabeth Worldview—Nature Interview).

Finally, Elizabeth also communicates a personal concern for the care of the natural world. For example, she states, “being able to recognize what we were doing wrong and harmful to the environment and being able to stop producing things that were being harmful” (Elizabeth Worldview—Nature Interview). Likewise, she explains, “I am concerned about pollution and the damage it does to nature. Yes, I am. I am kind of afraid sometimes when you hear about the stuff that goes on” (Elizabeth Worldview—Nature Interview). She then incorporates a need to learn about nature and the natural world as she explains, “but a lot of the different parts of nature are things that we’ve used and exploited...we need to understand and know about it so that we can, perhaps, save some part of nature” (Elizabeth Worldview—Nature Interview).

**Worldview—Causality**

Assertions relating to causality relied on Elizabeth’s TOPE responses and her explanations regarding her responses. Elizabeth picked the more scientific explanation for 10 of the 17 TOPE items, and the less scientific explanation for 7 of the 17 TOPE items: Items #5, 7, 8, 10, 13, 14, and 17. Therefore, her overall TOPE score is below the average score for the group of participants ($M = 11.75$). In fact, Elizabeth’s TOPE score of 10 is the lowest TOPE score for the participants. For the items where Elizabeth picked the more scientific
explanation, her reasoning for her choice seems to reflect a scientific way of thinking about the world. For example, her reasoning for TOPE Item #9 states,

I guess I’m thinking like a scientist on this one and want there to be a scientific explanation for why the bouncing chicken bones work. It’s not that I think pre-modern man is naïve and unintelligent but that there is a reason for why watching the bones work. (Elizabeth TOPE Item #9)

Figure 45 contains TOPE Item #9. In addition, on TOPE Item #11 she states, “nutrients are needed for growth, and it makes scientific sense to me that shaking may make these nutrients more available to the roots” (Elizabeth TOPE Item #11). Figure 46 contains TOPE Item #11.

For several of the TOPE items where Elizabeth picked the less scientific explanation,

| A startling discovery has recently been made amongst a pre-modern group of people in a remote region of the Amazon Basin. An anthropologist living with these people for a year noted that the council of elders had a perfect record on predicting rainy days. Out of 365 days there were 109 days on which rain began to fall. All of these days were correctly predicted two to four days in advance. For the same period of time the government meteorological forecasts were much less accurate. The elders based their predictions upon the pattern made by dried chicken bones which they would cast a specific number of times each day. The scientist was impressed with the accuracy but skeptical that the bones had much to do with it. He got the elders to cooperate in a number of experiments by which he hoped to determine the real nature of their predictions. None of his hypotheses were confirmed, all were rejected. In the end he was convinced that the predictions must indeed rest upon the chicken bones. Later the anthropologist reported his findings at the symposium; and although his peers agreed with his conclusions they disagreed in their reasons:
| 1. Pre-modern people although pre-modern are still clever. They skillfully put to use the collective observations and knowledge of their ancestors, as in this case. Modern people are surprised by their achievements only because they think of the pre-modern man as naïve and unintelligent.
| 2. First of all the anthropologist's studies were rationally designed and carefully conducted. Secondly, his findings are corroborated by the work of other anthropologists amongst other types of people. Thirdly, chemists have recently found that dry bones absorb moisture from the air and that the amount of “bounciness” in the bone depends on how much moisture has been absorbed.
| Which side do you find more acceptable? Explain.

Figure 45. TOPE Item #9.
When plant seeds are grown in small pots it is possible to quicken their growth rate by periodically shaking the pots. This "shaking effect" is poorly understood but there are two schools of thought on the matter:

1. The roots of plants use up first the nutrients in the soil which are closest. The result is that the amount of soil nutrients increases with distance from the roots. Shaking stirs up the soil and helps bring richer but distant soil into contact with the roots.

2. All living things benefit from an occasional but gentle stirring up of their environment, and even of themselves. It gets the juices, fluids and chemicals moving and flowing. It provides fresh air and removes the stale. It encourages, one might say, the processes of life.

Which explanation would you be more willing to accept? Explain.

Figure 46. TOPE Item #11.

she refers to her religious beliefs in her response. For example, Elizabeth states,

I would say the man’s soul, rather than his spirit is alive. As a Christian, I believe that a person’s physical body will die but that his soul will live on – either going to heaven or hell. I don’t know what these places will be like, but I believe they exist. Part of me likes to think that people who have ‘died’ and come back to life have had an experience with the afterlife – with God. (Elizabeth TOPE Item #7)

Figure 47 contains TOPE Item #7. Likewise, on TOPE Item #14, Elizabeth states, “in my opinion, God created humans and He created them with these abilities. Our ‘humanity’ makes us different from all the other of God’s creations, including chimpanzees. We are created in God’s image and we are His special creation” (Elizabeth TOPE Item #14). Figure 48 contains TOPE Item #14.

However, she also references her religious beliefs for several TOPE items where she picked the more scientific explanation. For example, for TOPE Item #2, Elizabeth states, “I believe God created this world, and I’m not convinced that there are other civilizations out there. It is easier for me to believe that some other physical bodies exist which would affect the radio wave activity” (Elizabeth TOPE Item #2). Figure 49 contains TOPE Item #2.
Therefore, Elizabeth’s religious beliefs do not appear to affect her understanding of causality such that she would be more likely to pick explanations that are less scientific.

Several of Elizabeth’s TOPE responses also directly reflect her concepts of NOS, particularly her conceptions of the tentative and subjective aspects of NOS. For example, in

In the past when a man's heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man's heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.

2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more willing to accept? Explain.

Figure 47. TOPE Item #7.

People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.

Which explanation would you be more willing to accept? Explain.

Figure 48. TOPE Item #14.
Recently astronomers have observed an increase in radio wave activity of particular frequency from a particular sector in the sky. This observation has caused a stir and a great deal of speculation as to its explanations. So far there are two explanations that the astronomers are arguing most about:

1. Man has often doubted that he was alone in this vast universe. These radio waves might well be radio signals from some far civilization upon which we have stumbled or indeed they may even be meant for us.
2. There are many physical bodies in the heavens which emit radio waves. These emissions fluctuate and chances are these new emissions will be found to fall within the regular patterns of chance fluctuation.

Which explanation would you be more willing to accept? Explain.

*Figure 49. TOPE Item #2.*

Certain planetary bodies appear to deviate slightly from their calculated position in space. The deviation is extremely small. Everyone working in this field agrees:

a) That the deviation exists, and
b) That Relativity Theory offers the most likely explanation.

When asked why they supported this explanation workers gave different reasons:

1. It is difficult to make accurate measurements and existing experimental evidence lends only weak support for the theory. Nevertheless, the evidence gives better support to this theory than to any other.
2. The explanation was published by one of the most distinguished scientists of the 20th century. There is no doubt that he knows more than anyone else in the world about this particular phenomenon.

Which explanation would you be more likely to support? Explain.

*Figure 50. TOPE Item #16.*

Elizabeth’s response to TOPE Item #16, she states,

I don’t think relying on one of the most distinguished scientists is a good idea. At the present time, if the evidence gives better support to this theory, then that is a good theory to support. If, in the future, other evidence comes along to reject this theory, then views can change. I would rather look at evidence than believe in just one knowledgeable scientist. (Elizabeth TOPE Item #16)

Figure 50 contains TOPE Item #16. Additionally, in part of her response to TOPE Item #17 she states, “although it may be true that there could be a better chance for success using theory-guided research (at least most of the time), there will usually be a well-thought out,
theory-driven reason for most research” (Elizabeth TOPE Item #17). Figure 51 contains TOPE Item #17. Likewise, in her responses to the VNOS Questionnaire and the NOS Follow-Up Interview, Elizabeth’s responses indicated she had an informed understanding of both the tentative and subjective aspects of NOS. For example, regarding the tentative aspect of NOS, Elizabeth states,

I think that theories do change. I think they change because things are discovered later on, whether because the technology is better or something that we didn’t have before that allows us to get more information. Or something doesn’t work. Our theory says that something should be discovered, and what we find doesn’t go along with the theory. Then maybe our theory needs to change. I think that’s why theories change. (Elizabeth NOS Follow-Up Interview)

Likewise, she also explains, “there may not be one set answer. There may be different explanations for what you observed seeing” (Elizabeth NOS Follow-Up Interview). Regarding Elizabeth’s informed aspect of the subjective aspect of NOS, she states,

Just because there may be more than one explanation that could be offered for the data that they get. I think that you see that happening many times.

A physicist at a well-known university was conducting a unique set of experiments. He was interested in the effect of electrical discharges on the growth rates of a particular type of tree. The methodology was simple. He administered electrical shocks to one set of trees but not to second. Over a period of several months he measured and compared the growth rates of the two groups. The scientist's work caused a stir amongst his colleagues because he admittedly had no theoretical framework for his research. There were two basic opinions about this kind of experimentation:

1. The highly theoretical nature of physics provides an ample number of research problems for experimental work. Theory guided research is more efficient because there is a greater chance of success. This man has picked an idea out of thin air and pursued it for no other reason than idle curiosity.
2. This man should not be criticized for his unique albeit different research problem. All too often progress in many fields is thwarted by over-conservatism and rigid adherence to theory. Creativity and independence should be encouraged so that more discoveries can be made and the understanding of nature increased.

Which opinion would you be more willing to accept? Explain.

*Figure 51. TOPE Item #17.*
People read the results of somebody and say, "I don't think this is what it means." I think that you will not always have them come to the same conclusions. (Elizabeth NOS Follow-Up Interview)

It appears that Elizabeth’s reasoning for a preference for a more scientific explanation of causality for some of her TOPE responses may be correlated with her informed understanding of the tentative and subjective aspects of NOS.

*Interpretive Narrative*

A narrative presents Elizabeth’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Elizabeth’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Elizabeth’s Worldview—Nature Interview, a concept map created based on her Worldview—Nature Interview, and her responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Elizabeth read over the narrative and modified it such that she believed it accurately described her conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Elizabeth’s questionnaire responses, interview transcripts, and subsequent concept map:

Nature is both living and non-living, and it is made of matter and material. The natural world is very diverse—but in terms of living and non-living things. For example, you can be amazed at the variety of living organisms on earth and impressed by the complexity of places like Yellowstone, the Badlands, and Glacier National Parks. Nature and the natural world are very orderly; therefore, it is knowable and can be understood. However, not everything can be completely understood or predicted. This *unpredictability* can add excitement and mystery to nature. Sometimes, when we do not understand something about nature, we can be confused and possibly misuse things in nature. Therefore, it is important that we learn about nature so that we can try to have positive interactions with nature.
Nature is not just there; rather, God created it for a purpose. However, not everything that happens in the world is God’s purpose. For example, humans have a variety of negative interactions with nature that can lead to exploitation of resources, pollution, and parts of nature becoming endangered. However, hopefully nature is restorable. We can see examples of this in things like the ozone layer coming back and our actions to respond to global warming and its effects. Nature is holy because God created it. Therefore, we are called to try to take care of nature and protect it.

Nature can inspire spiritual experience for me—I can see God and His work in nature. I know that God created nature; therefore, I am filled with awe and wonder when I interact with different parts of nature. Sometimes experiences with nature can be very peaceful for me. However, I do not think that nature itself is peaceful. Rather, nature can be very dangerous and powerful. For example, look at the power of things like the Grand Canyon and Mt. St. Helens. Nature is also wild and can seem frightening. Things like the ocean, mountains, and the weather can sometimes be very frightening. But even then, I think that nature is very exciting.

Science is both a way of learning and a body of knowledge. Science is empirical and uses experimentation as a means for discovery. This experimentation requires a series of logical steps; however, this series of steps may vary depending on the type of experiment. Scientists also use creativity and imagination in their experiments. In fact, using creativity and imagination can make the data deeper and richer. However, creativity and imagination are probably used most often in the design and planning of an experiment.

Science, the body of knowledge, is universal. However, social and cultural values sometimes influence the process of science. The conclusions that scientists draw often reflect the context in which the scientists are working. Science also progresses. As technology develops, advances, and improves, we will be able to discover more. In some cases where scientists disagree, maybe more information and more data collection will help them agree. However, there may be cases where scientists never really agree because they might interpret data differently. A scientific theory is an explanation of observations where a scientific law summarizes patterns in nature.

Science can also explain how and why many things happen in the world. When we are looking for the cause for something, we can usually try to find a reason supported by evidence and logical scientific explanation. For example, if we have a theory supported by evidence, then we should use that theory unless other evidence comes along that causes us to reject that theory. I think that there are some situations that we cannot understand and explain. I believe that God designed and created the world such that some things are so complex, and we just do not have the ability to figure it all out.
Demographic Information

Frank is a 32-year-old male. He has an undergraduate degree in chemistry and biology and a master’s degree in educational leadership with a minor focus in science. He has been teaching for 7 years in several different subject areas including regular biology (5 years), advanced placement biology (5 years), accelerated biology (1 year), chemistry (4 years), life science (1 year), criminalistics (½ year), and honors physical science (2 years).

Views of Nature of Science

Frank’s scores on the VNOS continuum show he has an informed view of the theories and laws, social and cultural, empirical, subjective, and tentative aspects of NOS. His views of the observation and inference and scientific method aspects of NOS are emerging. His view of the creative aspect of NOS is naïve. Figure 52 summarizes Frank’s VNOS continuum scores. A radar plot also visually illustrates Frank’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 53 shows a radar plot of Frank’s VNOS continuum scores.

Tentative. Frank articulated an informed view of the tentative aspect of NOS. He was able to articulate this informed view in his own words and provide examples. For example, Frank explains,

Scientific theories change because new experiments often reveal new scientific knowledge. This may often be due to new, more advanced scientific equipment. If this new knowledge contradicts the existing scientific theory in any way, the old theory must be revised or thrown out. (Frank VNOS Questionnaire)

Likewise, Frank explains,
Theories change because part of being a scientist, and part of being human is that we are always curious and questioning things. And you have new evidence that comes in to play. Or you may have new data. You may have new evidence, and as a result, you set up an experiment to test it. That may give you more data. If the data is not supporting the current theory, then the theory has to change an account for it. It would probably take more than one experiment to do that. I don’t think that most scientists believe that we have figured everything out. Is it kind of the definition of a theory is that it’s not proven? I thought theories were never proven, just explanations for what you think is happening. I think they do change. I think they should change. Some of them just might change a little bit, and some might get totally chopped. (Frank NOS Follow-Up Interview)

Not only is Frank able to articulate an informed view of the tentative aspect of NOS in his own words, but he also provides an example as he explains,

Sometimes new evidence may contradict the current model and then adjustments are made so that the model includes all evidence. Take the model of the atom. Dalton thought it was solid, then the plum pudding model, then electrons and Bohr’s model and then the electron cloud. The
model has changed due to new evidence, which is a good thing. (Frank VNOS Questionnaire)

Frank goes on to articulate a more informed view of the tentative aspect of NOS as he explains,

In science, if you said we wouldn’t accept anything until this was absolutely proven beyond a doubt, that wouldn’t work. There’s probably more stuff that’s not proven without a doubt in science than there are things that are proven. You just need to take it all in. I think that’s part of science. I think it’s a work in progress. (Frank NOS Follow-Up Interview)

Frank appears to recognize that science changes as new evidence emerges, and that science is always subject to change. His views regarding the tentative aspect of NOS are informed, articulated in his own words, and illustrated with examples; thus, “+++” his VNOS continuum score for the tentative aspect of NOS.
Subjective. Frank articulated an informed view of the subjective aspect of NOS, and he was able to articulate this informed view in his own words. Frank explains, “although we can carefully design and carry out experiments, we are still limited by our ability to analyze the data. This is probably why scientific articles are peer-reviewed—so that alternate explanations may be pointed out” (Frank VNOS Questionnaire). His response when asked, “If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions?,” illustrates his informed view of the subjective aspect of NOS when he states,

It's the same thing as being humans and thinking differently. I think that they might have different biases coming in, different backgrounds, and other things...even if you assume they had the same data, I don't think you can say for sure that they would come to the same conclusions. Especially this way. If they have a different bias or a different background, the data collected might even be different. (Frank NOS Follow-Up Interview)

This reflects an informed view of the subjective aspect of NOS since it recognizes that different conclusions based on the same data are possible since biases, background, and other variables may affect the development of explanations for different people. Because Frank recognizes and articulates, in his own words, the subjectivity of science, “+++” is his VNOS continuum score for the subjective aspect of NOS.

Empirical. Frank articulated an informed view of the empirical aspect of NOS. For example, Frank explains, “science usually deals with studying the material world. Although science can be more abstract, often it deals with more concrete evidence that can be explored, investigated, tested, etc... Science provides a unique opportunity to discover new knowledge” (Frank VNOS Questionnaire). Likewise, Frank states,

I think that part of it is, at least aspects of science are more testable than the other disciplines. Obviously we have theories and things like that in
biology and other areas that have not been proven, but to a large extent, you can go and investigate, see, and set up an experiment. You can look at things under microscopes and telescopes...in science you actually go out and explore and investigate a little bit more. (Frank NOS Follow-Up Interview)

When asked whether the development of scientific knowledge requires experiments, Frank responds,

I think it does require experiments because in order to get the new knowledge, you have to go and look for it. Typically, when you see something, your next step is to try to figure out what is going on there, why this is happening. In order to attribute that to something specific, I think that you have to use an experiment. (Frank NOS Follow-Up Interview)

However, as Frank continues to responds, he explains,

Maybe I should change my answer and say that science doesn't necessarily require experiments. I remember about Darwin. He had observation, observation, observation... and then interpretation. And that leads to the idea of natural selection and those kinds of things. I guess I would be hesitant to call that an experiment. He is making observations and trying to weave a conclusion based on that. (Frank NOS Follow-Up Interview)

Throughout these responses, Frank demonstrates an informed view of the empirical aspect of NOS—he explains that scientific knowledge and experiments based on and using that knowledge are based on and derived from observations of the natural world. Since he is able to explain this informed view in his own words, “++” is his VNOS continuum score for the empirical aspect of NOS.

*Creative.* Frank articulated a naïve view of the creative aspect of NOS. He begins one of his VNOS Questionnaire responses with something that sounds like it might reflect an informed view. For example, he explains, “I think that scientists do (and should) use their creativity and imagination during their investigation” (Frank VNOS Questionnaire). Likewise, in his NOS Follow-Up Interview, Frank explains,
I think that you need to have some creativity. I would say that it's probably used more in the planning stages, and even coming up with your original question. In order to be really looking for new things are trying to expand the scientific knowledge, you have to be creative when you think about what you want to investigate. As far as coming up with an experiment, there might not be just a straightforward way about getting your data. It seems like that might take some creativity and imagination to get through some hurdles and try to get it controlled and to get to the heart of the answer. (Frank NOS Follow-Up Interview)

However, in both the VNOS Questionnaire and during the NOS Follow-Up Interview, Frank clearly asserts that there is a point at which creativity is no longer appropriate. For example, Frank states,

Although creativity is good in these areas, I think that creativity can be dangerous when it comes to analyzing the data. I believe that most of the time, the data obtained should clearly either confirm or refute the hypothesis. I don’t see why creativity would be needed to manipulate this data. In fact, the only time this creativity may be useful is in advertising where a company needs to spin the data in a way that supports their product or service. (Frank VNOS Questionnaire)

Not only does Frank feel that creativity can be dangerous when analyzing data, he feels that using creativity during data analysis can lead to the unethical use of data. This negative view and failure to see how creativity can be used, without being manipulative, in all aspects of scientific inquiry is why Frank’s understanding of the creative aspect of NOS is categorized as naïve.

**Social and Cultural.** Frank articulated an informed view of the social and cultural aspect of NOS. In addition, he was able to articulate this understanding in his own words and provide supporting examples. In his VNOS Questionnaire, Frank states,

I believe that science does reflect social and cultural values. I think that most scientists try to make science universal but I don’t think that it is really possible to complete extract our biases from our science. The biggest issue is that we are often not aware of the biases that we hold. If we do not
recognize them, then how can we avoid allowing them to affect our experimentation and analysis of the data? (Frank VNOS Questionnaire)

Likewise, Frank explains,

I do think that science reflects social and cultural values. I think it is hard to separate yourself from that. Everyone is living in this world. It's hard not to be affected by what your society says. Despite them trying to make science as universal as possible, I still think that a scientist here and scientists elsewhere, based on their backgrounds...if you were raised in a different place with different values and different things are stressed to you, it seems like that has to play a role in how you interpret things. Ultimately, in science, when you get to that stage of analyzing your data, it seems like a lot of times, whatever your background is might play a factor in that. Can I think of an example? Maybe with stem cells? (Frank NOS Follow-Up Interview)

Frank tries to expand on this example as he explains,

I’m not sure that this is a good example but how about the issue of embryonic stem cell research. Many scientists and governments believe that this is a great idea. Others feel just as strongly that this is an area that should not be explored. What cause this difference? In part, it is the culture that surrounds the scientists. I think similar patterns can be seen in many other areas such as GM foods, biotechnology, evolution, etc... (Frank VNOS Questionnaire)

An informed view of the social and cultural aspect of NOS articulates the idea that science is a human endeavor influenced by the society and culture in which it is practiced. Frank communicates this informed understanding in his own words and provides supporting examples; thus, “+++” is his VNOS continuum score for the social and cultural aspect of NOS.

Theories and Laws. Frank articulates an informed view of the theories and laws aspect of NOS, and he is able to articulate this understanding in his own words. Frank simply states the difference when he explains,

The difference between a theory and law is that a theory includes an explanation of why things are happening the way that they are. In addition, a theory may never be proven true because it is always possible that future
evidence will prove it wrong. A law merely states what happens without offering an explanation why. (Frank VNOS Questionnaire)

Frank goes on to describe what a law is as he states, “it is not an explanation. It’s just a description: ‘this is what happens.’ You drop something, and it goes down because of gravity. Not really explaining it” (Frank NOS Follow-Up Interview). Likewise, he elaborates on his understanding of a theory as he explains,

I always think of a theory as the best explanation to the data that we currently have. So you have a whole bunch of data compiled by lots of different people, and here he just says, “here’s what we say is happening. And here is an explanation of why we think this happens.” And I don't think it's something that is ever really proven. And I think that is something that is subject to change as different data comes along. (Frank NOS Follow-Up Interview)

Furthermore, Frank uses an analogy to explain his understanding of theories and laws aspect of NOS,

One of the examples that I like to use with my students is about sports and box scores. You read the paper today to see what happened with the Tigers and you get a play-by-play of if they lost or not. You get a play-by-play on what happened: “They gave up a lot of runs, because the shortstop missed a ball. They gave up a grand slam, and this happened, and this happened, etc...” Whereas a law is just like the box score. It just says: Tigers: 0, Twins: 11...So I guess I see the difference as that of the theory explains, and a law just describes. (Frank NOS Follow-Up Interview)

Frank has an informed view of the theories and laws aspect of NOS. This informed view recognizes the distinct and functional differences between theories and laws. Therefore, “++” is his VNOS continuum score for the theories and laws aspect of NOS.

Observation and Inference. As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough information regarding participants’ views of the observation and inference aspect of NOS.
Given this limited data, Frank articulated an emerging view of the observation and inference aspect of NOS. As most of the other participants, Frank talks about indirect evidence as he refers to observation and inference. For example, as Frank talks about how certain scientists are about the way dinosaurs moved, he explains,

    I guess once you've guessed on how it looks and you look at the bones, you can probably make some predictions. And maybe even related to the teeth and the other question. But if it has sharp teeth, you can guess that it can be a meat eater. Then maybe you can make the assumption that it moves a little bit faster. But again it's taking indirect evidence of the bones, and constructing the body, once they have the body can figure out things like the center of gravity and things like that and make a prediction from that about how they moved. (Frank NOS Follow-Up Interview)

Although Frank does not explicitly address the relationship and difference between observation and inference, he does allude to the idea that scientific knowledge involves both observation and inference. Therefore, he articulates an emerging view of the observation and inference aspect of NOS.

**Scientific Method.** Frank articulated an emerging view of the scientific method aspect of NOS. Frank’s response to VNOS Questionnaire item relating to the scientific method is interesting. Frank completed the VNOS Questionnaire electronically and sent in his responses. Therefore, this gave him an opportunity to change and edit his responses as he completed the questionnaire. However, for this question, he appears to have typed out a response, then added a strikethrough (strikethrough) to the answer, and continued with a related response. In the strikethrough section of his response, Frank explains,

    I believe that there does not have to be just one scientific method. As long as there is a systematic and organized way to answer the question or solve the problem and as long as the method used is reproducible, it will work just fine. (Frank VNOS Questionnaire)

Following that statement that he adds a strikethrough to, he continues,
Now I’m confused. I thought that this was my answer but I couldn’t really come up with what the other methods would be so maybe my answer is really “yes.” I guess I’ll just say that regardless of the method, the experiment must be very well thought out. The results must be attributed to a specific factor, and the experiment must be reproducible by other scientists. (Frank VNOS Questionnaire)

At the beginning of his response, Frank seems to recognize the idea that there is no single scientific method. However, when he fails to be able to provide an example, he seems to change his mind.

In the NOS Follow-Up Interview, Frank elaborated on his earlier responses in a similar fashion. For example, Frank explains,

I don't know that you necessarily have to have all the steps. Do you have to have a hypothesis? Probably not. But you do have to have some sort of question or thing that you're going for. I had trouble coming up with an example of if you don't have an experiment... If by scientific method, do you mean like a high school textbook, where you have to do this, then this, then this...? For that, I would say no. So I guess requiring those steps would be “the scientific method.” In that case, I would say no. I guess there are many scientific methods, but they are all kind of the same. (Frank NOS Follow-Up Interview)

Although Frank does seem to have an underlying understanding that there is no single scientific method, the trouble he encounters trying to provide an example to illustrate this idea causes him to return to the notion of a single scientific method. However, he does not state that there is just one single scientific method since he explains, “the scientific method probably not. But a close relative” (Frank NOS Follow-Up Interview). Doing this, Frank articulates an emerging view of the scientific method aspect of NOS.

**Worldview—Nature and the Natural World**

During his Worldview—Nature Interview, Frank discussed nature and the natural world in terms of his scientific understanding of the world, his specific content areas
(biology and chemistry), his religious beliefs, his personal experiences, the aesthetic qualities he sees in nature and the natural world, his interest for nature and the natural world, and his personal concern for care of the natural world.

As articulates his worldview beliefs regarding nature and the natural world, he talks about his scientific understanding of the world. For example, he explains,

> You can study how living things are interacting with each other...We can build models about things like weather patterns...You look at scientists going out into nature are studying the population of things, of a certain animal, and documenting all the things like how they behave and that seems like it's learning about nature. Things that you can directly observe. It seems like there are lots of different ways to learn about nature. It all depends on which aspects of nature you are going to be studying. Some of it is just making good predictions and guessing. It's just a little more testable. (Frank Worldview—Nature Interview)

Likewise, he states, “I guess that scientists try to understand things or to make sense of things” (Frank Worldview—Nature Interview). Frank also refers to his science content area (biology and chemistry). For example, he states,

> I guess the first thing that pops into my head is with biochemistry and molecules and starting from the ground up. The whole organization of cells, tissues, etc... How orderly that is. And dealing with ecology and how you find order in the food webs and primary producers and consumers and things like that. (Frank Worldview—Nature Interview)

Similarly, he explains, “I think of chemistry with entropy and a level of chaos and disorder that is supposedly increasing” (Frank Worldview—Nature Interview).

Another aspect referenced in Frank’s Worldview—Nature Interview is his religious beliefs. For example, Frank explains, “I think of general revelation and special revelation. And going out and enjoying subsets, and going out West and seeing mountains and things like that. And just getting a feel for how God created everything” (Frank Worldview—Nature Interview). Likewise, he states,
I think that sometimes it’s hard to look at beautiful things, whether it is forests, oceans, sunsets, and things like that and not just get a sense of how this can’t just be a random thing. There has to be a Creator. I think that is seen in Scripture too—general revelation and things like that. (Frank Worldview—Nature Interview)

Frank also claims, “by learning more about nature, we learn more about God who created nature” (Frank Worldview—Nature Interview).

Frank also references the aesthetic qualities of nature and the natural world. For example, he explains, “I guess it doesn’t have to be beautiful. But often times, if it is in its natural state, I think it is beautiful. Whether it’s a mountain or desert or rainforest” (Frank Worldview—Nature Interview). Likewise, he asserts, “I definitely see beauty in nature. All the different aspects of nature. All the different places you can go and visit: oceans, forests, mountains, and things like that. I don’t know how you can’t see beauty in nature” (Frank Worldview—Nature Interview).

Frank’s references to the aesthetic qualities of nature and the natural world lead to him talking about his personal experiences with nature and the natural world. For example, he explains,

I guess nature can be pleasant. I think about backpacking on Isle Royale, and it rained for forty-eight hours straight. That wasn’t very pleasant. But if I wasn’t stuck in the rain...I think for the most part though, I think I have a pleasant emotional response. Just being able to get away from the busyness of things and enjoy nature. (Frank Worldview—Nature Interview)

Frank also articulates an interest for nature and the natural world. For example, he explains, “nature is something that can be studied so that we can learn more about it. I think we should study it because I think we should always try to learn more about it” (Frank Worldview—Nature Interview). This interest may lead to a sense of personal concern for the care of the natural world that he illustrates when he states,
I believe nature needs to be protected. I would say for the most part that’s true. I just think of all the places that we are losing nature and resources. And trying to protect trees, and trying to control pollution, and keeping our water pure, and things like that. At the very least, set aside areas that can’t be developed. (Frank Worldview—Nature Interview)

**Worldview—Causality**

Assertions relating to causality relied on Frank’s TOPE responses and his explanations regarding his responses. Frank picked the more scientific explanation for 13 of the 17 TOPE items, and the less scientific explanation for 4 of the 17 TOPE items: Items #5, 9, 13, and 17. Therefore, his overall TOPE score is above the average score for the group of participants (\(M = 11.75\)). In fact, Frank’s overall TOPE score is the highest TOPE score for the participants. For the items where Frank picked the more scientific explanation, his reasoning for his choice seems to reflect a scientific way of thinking about the world. For example, his reasoning for TOPE Item #8 states,

> I do agree that it is very hard to test or prove that these traditional techniques are actually working because it is hard to follow an approach like the scientific method when conducting these “experiments.” With western medicine, we can test one single variable by setting up controlled experiments. (Frank TOPE Item #8)

Figure 54 contains TOPE Item #8. In addition, in his response to TOPE Item #1, Frank explains,

> I would be more willing to accept #1. I think that this is because it seems like it is an explanation that could easily be tested. #2 is a bit “out there” and it would be hard to prove these psychic emanations scientifically. (Frank TOPE Item #1)

Figure 55 contains TOPE Item #1. Frank’s scientific view of the world causes him to want to gather evidence and scientifically test phenomenon we find in the world.
In many areas of the world today the health of the people is looked after by traditional and herbal medicine practitioners. These traditional physicians practice a healing art based on generations of accumulated knowledge. In spite of this, the modern study of medicine does not include any areas of this traditional knowledge. Recently doctors concerned about this issue have divided into pro and con groups:

1. The study of modern medicine is the study of western medicine. This should tip us off to the real reason behind the resistance to the scientific study of traditional herbal medicine. It is pure and simply western chauvinism. From the scientific point of view there is no reason for not carefully researching well-documented traditional cures. The findings would benefit all of mankind; and in addition there would be a greater appreciation of the traditions of non-western peoples.

2. Modern experimental medicine has been successful largely because it is directed by rational theory. The theoretical structure of a science tells the investigator which avenues of experiments are most likely to be profitable, thus avoiding many dead ends. Since there is no such structure in traditional medicine a researcher would be left to follow dozens, even hundreds of nebulous accounts of "cures that work." Such ad hoc experimenting is wasteful and inefficient. It is for this same reason that "home cures" that so many families use are not pursued by researchers.

Which position would you be more willing to accept? Explain.

*Figure 54. TOPE Item #8.*

Reports from a recent space flight indicate a new material has been identified in outer space. Although insensitive to the presence of ordinary matter, when approached by a human being it glows brightly in a variety of colors.

1. The new material is composed of atoms which are sensitive to the heat radiation emitted from human beings. This radiation excites the planetary electrons of the material’s atoms. When these electrons return to their ground state they emit light radiation which is determined by the distance between one atom and the heat.

2. It has long been suspected from other evidence that human beings give rise to psychic emanations, but the main difficulty has always been the development of a suitable detector for this influence. This new material appears to be an ideal detector for it is sensitive to human proximity as well as operating over a wide range of personality types.

Which explanation would you be more willing to accept? Explain.

*Figure 55. TOPE Item #1.*

On TOPE Item #5, Frank actually chose the less scientific explanation. However, in his response to the explanation he states,
#2 is interesting and seems a bit more scientific but I am going with #1 on this one. Mostly because #2 seems way too complex (although that is not a very good reason). I think that our brain is very complicated and that we will never fully understand how it functions. Therefore, I like #1. (Frank TOPE Item #5)

Figure 56 contains TOPE Item #5. Therefore, it appears that even in some instances where Frank picks an explanation that is less scientific, his reasoning for his response reflects a scientific way of thinking about the world.

For TOPE Item #14, Frank refers to his religious beliefs in his response. For example,

Frank states,

I don’t see how you can study “humanity” so I will go with #1. Although I’m not sure I would call their thoughts and emotions as “simple,” I think they are more simple than humans. Therefore, #1 seems to work. To more away from 1 and 2, I think that God has given humans this complex gift of speech. (Frank TOPE Item #14)

Figure 57 contains TOPE Item #14. However, Franks chose the more scientific explanation for this TOPE item. Therefore, Frank’s religious beliefs do not appear to affect his

Occasionally when entering a room for the first time one gets the distinct impression that he has been there before. This impression can be very strong and disturbing, and all the more because one is sure that he has not ever seen the room before. There seems to be two reasonable explanations for this phenomenon:

1. This is an example of déjà vu which is something almost all of us experience from time to time. It is remembering a place you had never been to before or an object or person you have never seen before. This phenomenon is a reminder of the vast complexity of the human mind, a complexity of which we understand very little. What we understand least is the capacity of the mind to perceive things outside the range of our basic physical senses.

2. The human brain is a complex electro-chemical computer. Although for the most part it functions faultlessly there are occasional lapses. The above is such a case. After the first glimpse of the room there is an instantaneous functional lapse and recovery. The lapse causes the initial glimpse to be separated from the current perception of the room. The result is that the initial glimpse becomes like a memory. One is deceived into thinking that he has seen the room before.

Which explanation would you be more willing to accept? Explain.

Figure 56. TOPE Item #5.
People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.

Which explanation would you be more willing to accept? Explain.

Figure 57. TOPE Item #14.

understandings of causality such that he would be more likely to pick explanations that are less scientific.

One of Frank’s TOPE responses also directly reflects his conceptions of NOS, particularly his conception of the tentative and subjective aspects of NOS. For example, in Frank’s response to TOPE Item #16, he states,

I think anytime complex math is used to predict nature, there will always be small deviations. In addition, even if the evidence weakly supports the theory, if there is no other evidence that severely contradicts this theory and if no other theory is more supported, then I think you must go with this until new evidence arises. (Frank TOPE Item #16)

Figure 58 contains TOPE Item #16. Likewise, in his responses to the VNOS Questionnaire and NOS Follow-Up Interview, Frank’s responses indicated he had an informed understanding of the tentative and subjective aspects of NOS. For example, Frank explains that scientists “will continue to discover new evidence which will result in the current model being revised” (Frank VNOS Questionnaire). He goes on to state, “if this new knowledge contradicts the
existing scientific theory in any way, the old theory must be revised or thrown out” (Frank VNOS Questionnaire). It appears there may be a relationship between an informed understanding of the tentative and subjective aspects of NOS and a preference for a more scientific explanation of causality on some of the TOPE items. However, this is by no means a predictive relationship.

**Interpretive Narrative**

A narrative presents Frank’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Frank’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Frank’s Worldview—Nature Interview, a concept map created based on his Worldview—Nature Interview, and his responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Frank read over the narrative and modified it such that he believed it accurately described his conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Frank’s questionnaire responses, interview transcripts, and subsequent concept map:

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**Figure 58. TOPE Item #16.**

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Certain planetary bodies appear to deviate slightly from their calculated position in space. The deviation is extremely small. Everyone working in this field agrees:

- a) That the deviation exists, and
- b) That Relativity Theory offers the most likely explanation.

When asked why they supported this explanation workers gave different reasons:

1. It is difficult to make accurate measurements and existing experimental evidence lends only weak support for the theory. Nevertheless, the evidence gives better support to this theory than to any other.
2. The explanation was published by one of the most distinguished scientists of the 20th century. There is no doubt that he knows more than anyone else in the world about this particular phenomenon.

Which explanation would you be more likely to support? Explain.
I see nature as being both spiritual and material. Since the natural world was created by God, it is spiritual, sacred, and holy. I can see God at work in nature, and learning about nature helps me learn more about God. Because God created the natural world, there is a purpose for nature and it is not “just there.”

I can see incredible beauty in nature due to its complexity and order. I don’t think that we will ever be able to fully understand the natural world and all its workings; however, I do think that the natural world is knowable and, for the most part, explainable. That makes it predictable and testable. There are some parts that may be confusing or unexplainable, and that may seem mysterious. Sometimes, that mystery may make parts of the natural world frightening—thunderstorms, tornadoes, etc… In addition, it can seem chaotic when looking at the larger picture. However, I do think there is order in the natural world. We can see this order more clearly when we look at individual systems or smaller parts of the whole.

Nature and the natural world is material and matter—both living and non-living. This material world is always changing, and we can see this in phenomenon such as evolution and continental drift. Humans also interact with the material world as we use resources. This resource use can lead to exploitation, endangered species, and pollution. However, I do not think the natural world is doomed. We need to take care of nature, protect it, and do what we can restore it.

Science is an organized and systematic method of studying the world around us. Science is empirical and deals with the material world and evidence—things that can be explored, investigated, and tested. The fact that science is testable helps to set it apart from other disciplines. Scientists go about this testing by conducting controlled experiments that are logical and organized. Creativity and imagination are just during appropriate steps of an experiment—design and planning. However, creativity should not be used when interpreting and analyzing the data.

Scientists are humans. This means that even though a group of scientists may all have the same data, there is a chance that the data will be interpreted differently by different scientists. Likewise, even though many scientists try to make science universal, there is no way to completely extract biases from science.

Science also progresses. Scientific theories change as new experiments reveal new scientific knowledge. A scientific theory is an explanation of why things are happening in a certain manner. These explanations can change and undergo revision when new knowledge and evidence comes about. A scientific law merely states what happens without offering an explanation as to why it happens.

Science can explain how and why many things happen in the world. When we are looking for a cause for something, we can usually try to look for the reason that can be tested or that supports the scientific evidence we may find. If an explanation is more scientific than the other, I would tend to
choose that explanation. Furthermore, even if the evidence we see only weakly supports a theory, if there is no other evidence that severely contradicts that theory and no other theory is supported, then we need to go with the first theory until new evidence arises. However, there are some things that are just so complex that we will never be able to explain them.

**Grace**

**Demographic Information**

Grace is a 33-year-old female. She has 10 years of teaching experience in several different courses including physical science (5 years), chemistry (9 years), and test preparation (2 years). She has an undergraduate degree in chemistry and a master’s degree in science education.

**Views of Nature of Science**

Grace’s scores on the VNOS continuum show she has an informed view of the observation and inference, theories and laws, social and cultural, creative, empirical, and tentative aspects of NOS. Her view of the scientific method aspect of NOS is emerging. Her view of the subjective aspect of NOS is naïve. Figure 59 summarizes Grace’s VNOS continuum scores. A radar plot also visually illustrates Grace’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 60 shows a radar plot of Grace’s VNOS continuum scores.

**Tentative.** Grace articulated an informed view of the tentative aspect of NOS. She was able to articulate this view in her own words and provide supporting examples. For example, Grace states,

Scientific theories change with the discovery of new knowledge. For example, the model of the atom, plate tectonics, etc... We bother to learn the latest theory because it is useful in making sense of the world and lots
of theories haven’t been changed or haven’t changed much—so to know them is to have a good foundation (be scientifically literate). This way a person will be able to understand/evaluate proposed changes to theories with relative ease. (Grace VNOS Questionnaire)

Comparable to many of the other participants, Grace provides the example of the development of knowledge of the atom to illustrate the tentative aspect of NOS. She explains,

\[ \text{Theories change because of new evidence that is brought out by new experiments that we didn’t have access to before. But the atom, the atom was a philosophical idea back in the Greek times. And then John Dalton, 2000 years later, came up with the basic, rudimentary experiments that proved there were little particles. But he had no idea of the structure inside of them. And then over time, more and more evidence came about—the cathode-ray tube, Rutherford's experiments, and Bohr’s work with the atom—to give us a more intricate view of what's going on. But we still don’t know every little detail. I would imagine 20 years from now, we will know} \]
even more about it because of more technology and people that keep working on it. (Grace NOS Follow-Up Interview)

However, Grace is also able to provide another example to illustrate the tentative aspect of NOS. Using an example from geology, she explains,

Yes, for example, when I was cleaning out my classroom, I found so many books that were outdated and had information that we don’t hold any more. I remember in my geology class in college learning about how they used to think mountains were formed before they had the plate tectonics theory, and how they were all these bizarre explanations that different camps would subscribe to. It was very fragmented. And then they had this breakthrough of plate tectonics, which was such a unifying theory. It just changed the way that geologists looked at almost everything. There goes all those textbooks. Yes, the knowledge that we have is going to be changed. I can’t tell you which knowledge, but I think that in 20 years the textbooks will look different. If anything, they will look different because we keep learning more. (Grace NOS Follow-Up Interview)
Grace articulates the notion that everything in science is subject to change. Therefore, since she articulated this in her own words and provided supporting examples, “+++” is her VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Grace articulated a naïve view of the subjective aspect of NOS. Grace does allude to the idea that scientific knowledge is theory-laden when she explains,

> I think that hypotheses kind of guide the initial experiment that eventually lead to those. You know, with the atomic theory of the atom. Those people had to have an idea what was going to be going on. Or they wouldn't even have a clue about where to start looking. I think that's one of the beginning parts of it. (Grace NOS Follow-Up Interview)

However, when responding to the question regarding the role of hypotheses in developing theories and laws in her VNOS Questionnaire, Grace states, “perhaps a hypothesis is simply a way to alert a scientist to his/her prejudices so that they will not influence the outcome of the experiment” (Grace VNOS Questionnaire).

In addition, Grace also articulates the idea that data and data interpretation can be free of subjectivity. For example, in her response to the question, “If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions?,” Grace states,

> They should come to the same conclusions if they do not make mistakes. If they have the same set up, and the same working environment, and the same “x, y, and z,” in science you count on them to come to the same conclusion. If they don't, then you know that something is wrong somewhere. You have to go back and find out why. (Grace NOS Follow-Up Interview)

It is this idea that scientists and valid experiments should and can be free of bias and subjectivity that categorizes Grace’s ideas regarding the subjective aspect of NOS as naïve.
**Empirical.** Grace articulated an informed view of the empirical aspect of NOS. In addition, she was able to articulate her understanding in her own words. For example, Grace explains,

Science is the study of the world around us using observable phenomenon. It’s different than other areas of study because we can measure variable, define tangible substances, and design experiments. (Grace VNOS Questionnaire)

Likewise, in her NOS Follow-Up Interview, she states,

Science is the study of the world around us and how it works. It encompasses everything that we can see, and touch, and feel, and experiment with. And things that we can’t touch, like things that are far away in outer space, but we could still experiment on them. I think that science is anything we can experiment on. (Grace NOS Follow-Up Interview)

It is important to note how Grace defines experiment. In her response to a question regarding a person looking at animal teeth and concluding relational aspects between teeth structure and food source, Grace explains,

I think that this is an experiment. I think that he was gathering data. Here is this animal, and this animal, and here's what they eat. And that is similar, and then he looks at their teeth and the different types of animals. I think he is gathering some data, he is answering the question, he is coming to some conclusions based on the data. So yes, I think this is an experiment. (Grace NOS Follow-Up Interview)

Grace’s definition of experiment appears to encompass observation as well. She recognizes the dependence that the development of scientific knowledge has on experimentation, observation, and the empirical aspect of NOS. Therefore, since Grace has an informed view of the empirical aspect of NOS articulated in her own words, “++” is her VNOS continuum score.
**Creative.** Grace articulated an informed view of the creative aspect of NOS. In addition, she was able to articulate her understanding in her own words and provide supporting examples. For example, Grace states,

> Scientists are creative when they plan an experiment. Sometimes it is quite difficult to isolate a variable, and they need to be creative. Or perhaps their data set showed the experiment failed. They need creativity on the redesign. Creativity can also be necessary when collecting data. Some subjects may not be cooperative (think pediatric research); trying to get a child to do as directed may take creativity. Interpreting the data takes a creative mind when the results aren’t what you expected and you have to imagine what is going on at a molecular level so that you can explain your results. (Grace VNOS Questionnaire)

Likewise, in her NOS Follow-Up Interview, Grace explains,

> Yes, for sure scientists use creativity and imagination during their investigations. I think that they use it in every stage. It varies depending on the experiment. So you have imagination and creativity when you come up a question that you’re going to research. You need to be creative in planning how you are going to get your information and design your experiment. Some things are not easy to do and some data is not easy to get. You ask, I want to get this data, how am I going to get it? And even data collection can be a challenge. I think that when things are not easy and obvious, you need to be creative. So if there is data that is hard to collect... I’m sure was hard for people to figure out how much gasses weigh way back then. They had to be creative in figuring that out. And then to interpret the data. Going back to the example I used before with Rutherford getting the bounce backs from his gold foil experiment, he had to imagine what was going on there. He could not see it and say, "oh, I just saw them crash." There is a lot of imagination and creativity. And it’s in every part. (Grace NOS Follow-Up Interview)

Grace effectively articulates the idea that creativity and imagination important and used in all aspects of inquiry. She also supports her ideas with a variety of examples; thus, “+++” is her VNOS continuum score for the creative aspect of NOS.
Social and Cultural. Grace articulated an informed view of the social and cultural aspect of NOS. In addition, she was able to articulate her understanding in her own words and provide supporting examples. For example, Grace states,

Science does reflect the culture and values of the place it is practiced. It starts when scientists choose a project to work on. We (in the US) could have pushed alternative energy harder years ago, but we didn’t for a multitude of reasons. Drug companies try to develop drugs that won’t only help people but make them money. Real science is done either for political reason or monetary ones. Even researchers at universities win grants from foundations that have ties to these (political/business). (Grace VNOS Questionnaire)

Similarly, in her NOS Follow-Up Interview, Grace explains,

I do think that science is social and cultural. You have people that, no matter how objective they want to be, are a product of their social climate in their culture. That colors what kinds of questions you’re going to ask, and what kind of experiments you want to carry out. There are probably one million experiments that are not being done right now because nobody has cared enough to ask those questions. If there is a big flu outbreak coming up, then people are going to push for a vaccine for that and more research on that. And we have cancer research that is going into the types of cancer that are more prominent. We put our resources where a society sees a need for them. There are some places where there is just pure research. Even in that case, the people are still products of their culture. (Grace NOS Follow-Up Interview)

Grace illustrates the inextricably embeddedness of social and cultural aspects in science since science is a human endeavor. This informed view is articulated in her own words and supported with examples; therefore, “+++” is Grace’s VNOS continuum score for the social and cultural aspect of NOS.

Theories and Laws. Grace articulated an informed view of the theories and laws aspect of NOS and was able to articulate her understanding in her own words. For example, Grace states, “as I understand it, a theory is something that explains the world around us, how things work. And the law is not something that explains how, it just tells you what it
does. So there is a difference” (Grace NOS Follow-Up Interview). Her response reflects the informed understanding of the functional difference between theories and laws.

Grace also illustrates her understanding of the difference between theories and laws with examples. She explains,

There is the atomic theory of the atom, which kind of explains how the atom works. Whereas there is the law of gravity. That does not explain how gravity works, it just tells you, “there is gravity, things fall down.” (Grace NOS Follow-Up Interview)

Her example and explanation of a theory show that she understands theories to be explanations for natural phenomena. Whereas her definition and example of a law illustrate the function of laws as descriptive. Therefore, “+++” is her VNOS continuum score for the theories and laws aspect of NOS.

Observation and Inference. As mentioned previously, the scores for the observation and inference aspect of NOS were lower than other aspects of NOS. One reason for this may be that neither the VNOS Questionnaire nor NOS Follow-Up Interview elicited enough information regarding participants’ views of the observation and inference aspect of NOS. Given this limited data, Grace articulated an informed view of the observation and inference aspect of NOS. For example, as Grace responds to the question, “If scientists have never seen these things (such as details of the inside of an atom), what kind of information is this knowledge based on? [i.e. How do they know what they know about these things?]”, she states, “this is based on indirect evidence. (Like Rutherford bouncing alpha particles off the nucleus.) We can’t see them, but there is evidence that they are there” (Grace VNOS Questionnaire). Furthermore, when explaining her understanding of the difference between observation and inference, Grace explains,
Well, I guess that you state it in such a way that you are saying, “This is the experiments. These are the results. The results show that there is something inside of this box that is round”...I think the inference might be like taking it a step farther and saying, "I think it is a ball." So maybe there is a subtle difference between those two. (Grace NOS Follow-Up Interview)

Grace also talks about the application and use of inference as an interpretation of observations. For example, when responding to a series of questions regarding how scientists know that dinosaurs existed, how they looked, and how they moved even though they have never actually seen a live dinosaur, Grace explains,

We use the idea that if something dies today and decays, it will leave its bones behind. Then you can put the pieces together into a skeleton and basically reconstruct what the thing looks like. So I think that is what they are basing it on...I do not know how certain they are about things like skin. They must have taken today’s knowledge of reptiles and extrapolated that knowledge onto a dinosaur...Maybe they are pretty certain about how they moved based on how their bones fit together. You can predict how something is going to work based on their joints. (Grace NOS Follow-Up Interview)

Although Grace does not specifically use the term inference in her responses (one of the questions contained the term), Grace appears to understand the application of observations and inferences in science. Therefore, she has an informed view of the observation and inference aspect of NOS.

Scientific Method. Grace articulated an emerging view of the scientific method aspect of NOS. For example, Grace explains,

So much of the thought process that goes with a team of scientists is informal. I think it’s rare that a scientist strictly follows the scientific method. Rather, it is a guide to help you “cover the bases” when thinking through a scientific issue. To do good science, scientists need to make sure they design good experiments, collect accurate data, and properly interpret the data. But to say this has to always happen in that order is inaccurate. There is always backtracking, “tweaking,” etc... These methods are still scientific because they lead to a body of knowledge that can (and will) be validated by other scientists. (Grace VNOS Questionnaire)
Furthermore, when asked about “the scientific method” in the NOS Follow-Up Interview, Grace responds,

If you told me that for the scientific method, you have to do these steps in order, I would disagree. But if you said, if you’re a scientist, will you do the steps at some point in your experiment? I would say yes. It’s not a perfect cycle. It depends on what happens along the way as to what steps you will do next. Sometimes, things don’t always go as planned. So you might come up with a new question along the way before you get your results. And you might decide that is a more important question to follow. So you have this little sidebar that goes on. So as long as you are being systematic, you will probably do these things. You should probably have a logical reason for why you are doing the next step. Not just "I feel like doing this." (Grace NOS Follow-Up Interview)

As mentioned previously, Grace’s definition of experiment also includes the notion of observation (referring to the observational investigation with teeth as an experiment).

However, when specifically asked about experiments, Grace states,

An experiment is a carefully controlled/planned process designed to answer a question. It will include only one variable at a time, so that the cause of the results will be obvious. Experiments only are valid when there is measurable data that can be collected. (Grace VNOS Questionnaire)

This definition of experiment refers to a carefully controlled and planned process. However, Grace explained earlier that there might not be a particular order of steps to this process, there might be “tweaking” of the process, and being systematic and logical were more important than following a prescribed series of steps. Therefore, Grace articulates an emerging view of the scientific method aspect of NOS.

Worldview—Nature and the Natural World

During her Worldview—Nature Interview, Grace discussed nature and the natural world in terms of her scientific understanding of the world, her specific content areas (chemistry), her religious beliefs, her personal experiences, the aesthetic qualities she sees
in nature and the natural world, her interest for nature and the natural world, and her personal concern for care of the natural world. Grace alludes to her scientific understanding of the world when she explains,

I think nature is understandable in a lot of ways. That is why we do science. Otherwise, what is the point? We have learned a lot. And every time we learn something, we have more questions...and the world is constantly changing, so we have to constantly try to keep up with it. So we are never going to completely understand it, but I hope that we can have a pretty decent understanding of it. (Grace Worldview—Nature Interview)

Likewise, she stresses an empirical view of nature and the natural world when she states, “I do think of nature as being the tangible stuff: things you can touch” (Grace Worldview—Nature Interview).

Grace also refers to her specific science content area (chemistry). For example, when talking about whether or not she feels nature and the natural world are orderly, she explains, “it’s not so orderly in the sense that everything seeks to spread out. And one of those laws of thermodynamics that says that everything is ever expanding” (Grace Worldview—Nature Interview). Likewise, she states, “even studying chemistry for however many years. How those little atoms fit together? And then there’s always some exception to the rule. It is definitely complex and complicated” (Grace Worldview—Nature Interview).

As Grace talks about her worldview beliefs about nature and the natural world, she references to her religious beliefs. For example, she states, “This is my personal belief. I believe that God spoke the world into existence, so God was all there ever was in the beginning” (Grace Worldview—Nature Interview). In addition, she explains, “I think that God is behind nature, and His purpose. And He can use nature for His purposes” (Grace Worldview—Nature Interview). She sees a connection between nature and the natural
world that she expresses when she explains, “I see in nature the work of God. Yes. The
beauty, the craftsmanship, the intricate details” (Grace Worldview—Nature Interview).

Grace’s personal experiences also influence her beliefs about nature and the natural
world. For example, she recalls,

We were in a tent camping once when straight-line winds came through. The
trees were falling around us and crashing on trucks. We couldn’t drive
home the next morning because there were too many roads closed. That
was frightening. And that’s part of nature. But that doesn’t happen very
often. I am not often frightened of nature. (Grace Worldview—Nature
Interview)

Likewise, she speaks about more everyday experiences when she explains, “and when I’m
gardening, and I’m thinking about plants. I live in the woods, and I have a lot of critters and
creatures and bizarre looking bugs that come my way” (Grace Worldview—Nature
Interview). Some of her personal experiences with nature have also influenced her beliefs
regarding the aesthetic qualities of nature and the natural world. For example, she explains,
“I think that it is beautiful. With all the colors, the variety of textures, shapes, etc...definitely
with the variety of senses that you get” (Grace Worldview—Nature Interview). Not only
does she see positive aesthetic values in nature, but she also sees things in nature that she
does not think are aesthetically pleasing. For example, she explains, “There are a lot of
things in nature that I don’t think are beautiful too. I think there are certain plants and
animals that are ugly. You just look at them and think, ‘oh no, you are not pretty’” (Grace
Worldview—Nature Interview).

Grace has a personal interest for nature and the natural world. She explains,

Nature is exciting. Yes. If you think about how complicated it is and all these
other words that we are talking about. Some people don’t get excited about
it. I don’t know why. But I think that understanding and learning about it
and seeing the great variety makes it exciting. (Grace Worldview—Nature Interview)

This interest has also led to a personal concern for the care of the natural world. For example, she explains,

I’m concerned about pollution and the damage it does to nature. This is why I recycle. So that there is less of that in the landfill. And as a chemistry teacher, I was very conscious not to just dump chemicals down the drain. (Grace Worldview—Nature Interview)

She explains some of her reasons for her personal concern when she states, “If we don’t protect it, then it gets trampled all over. No one’s looking out for it, it can’t speak up for itself...it doesn’t have a voice” (Grace Worldview—Nature Interview). Grace also integrates both her religious beliefs and her personal concern for the care of nature and the natural world. For example, she states, “Because it is a product of God’s work, it is something that should be taken care of and held in high esteem and not abused” (Grace Worldview—Nature Interview).

**Worldview—Causality**

Assertions relating to causality relied on Grace’s TOPE responses and her explanations regarding her responses. Grace picked the more scientific explanation for 12 of the 17 TOPE items, and the less scientific explanation for 5 of the 17 TOPE items: Items #5, 7, 8, 14, and 17. Therefore, her overall TOPE score is slightly above the average score for the group of participants ($M = 11.75$). For the items where Grace picked the more scientific explanation, her reasoning for her choice seems to reflect a scientific way of thinking about the world. For example, her reasoning for TOPE Item #1 states,

I tend toward #1 because that is the exact lesson I taught my students about why they can see light/colors. It is logical and understandable and makes
sense. The other seems non-scientific and sci-fi. I would want to test this new substance with other sorts of heat radiation. (Grace TOPE Item #1)

Figure 61 contains TOPE Item #1. In addition, in response to TOPE Item #10, Grace states, “magnetic fields exert a force on magnetic objects. If it is true that the pea seed chromosome is magnetic, then explanation #1 is most viable. Explanation #2 seems to be the same explanation without the scientific grounding” (Grace TOPE Item #10). This response reflects Grace’s scientific understanding of how the world works. Figure 62 contains TOPE Item #10.

On TOPE Item #7, Grace actually chose the less scientific explanation. Figure 63

Reports from a recent space flight indicate a new material has been identified in outer space. Although insensitive to the presence of ordinary matter, when approached by a human being it glows brightly in a variety of colors.
1. The new material is composed of atoms which are sensitive to the heat radiation emitted from human beings. This radiation excites the planetary electrons of the material’s atoms. When these electrons return to their ground state they emit light radiation which is determined by the distance between one atom and the heat.
2. It has long been suspected from other evidence that human beings give rise to psychic emanations, but the main difficulty has always been the development of a suitable detector for this influence. This new material appears to be an ideal detector for it is sensitive to human proximity as well as operating over a wide range of personality types.

Which explanation would you be more willing to accept? Explain.

Figure 61. TOPE Item #1.

Pea seeds when passed through a magnetic field germinate faster than seeds which are not passed through a magnetic field. There appears to be two logical explanations for this:
1. The magnetic field has an effect on the pea seed chromosomes. This results in faster cell division due to the pre-alignment of the chromosomes by the magnetic field. The seeds therefore germinate quicker.
2. After fertilization there is a principle of life which begins to drive the growth process. At an early stage that principle can be stimulated and quickened by many outside forces such as a magnetic field.

Which explanation would you be more willing to accept? Explain.

Figure 62. TOPE Item #10.
contains TOPE Item #7. However, in her response to the explanation she states, “the Bible teaches that we go to heaven...the body may have stopped working but the spirit lives on. The first explanation makes sense, and maybe this explanation scientifically explains what is happening, but I still believe #2” (Grace TOPE Item #7). Therefore, it appears that even in some instances where Grace picks an explanation that is less scientific, her reasoning for her response in some way reflects a scientific way of thinking about the world.

Although Grace’s response to TOPE Item #7 reveals a scientific understanding of how the world works, it also demonstrates how Grace refers to her religious beliefs in several of her TOPE responses. These religious beliefs seemed to have a greater influence on Grace’s understanding of causality for TOPE Item #7. TOPE Item #14 is another example of how Grace’s religious beliefs affect her understanding of causality. Figure 64 contains TOPE Item #14. In her explanation, Grace states,

In the past when a man's heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man's heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.

2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more willing to accept? Explain.

*Figure 63. TOPE Item #7.*
People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.

Which explanation would you be more willing to accept? Explain.

Figure 64. TOPE Item #14.

God created people as a special entity. Perhaps we can explain thoughts and emotions in scientific terms, but the depth of what a human experiences goes way beyond what a chimp would. We do have a great capacity for speech and language that sets us above all other animals and it will remain so. (Grace TOPE Item #14)

One of Grace’s TOPE responses also directly reflects her conceptions of NOS, particularly her conception of the empirical aspect of NOS. For example, in Grace’s response to TOPE Item #4, she states, “I do not believe that you die of meanness, although it may have physical consequences on your body because of the stress it creates. Most likely she died due to the chemicals she poisoned her body with” (Grace TOPE Item #4). Figure 65 contains TOPE Item #4. Likewise, in her responses to the VNOS Questionnaire and NOS Follow-Up Interview, Betty’s responses indicated she had an informed understanding of the empirical aspect of NOS. For example, Grace states, “Science is the study of the world around us using observable phenomenon. It’s different than other areas of study because we can measure variable, define tangible substances, and design experiments” (Grace VNOS Questionnaire). This may show a relationship between an informed understanding of the
empirical aspect of NOS and a preference for a more scientific explanation of causality for some TOPE items.

**Interpretive Narrative**

A narrative presents Grace’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Grace’s responses to the VNOS Questionnaire and NOS Follow-Up Interview, transcripts from Grace’s Worldview—Nature Interview, a concept map created based on her worldview, and her responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Grace read over the narrative and modified it such that she believed it accurately described her conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Grace’s questionnaire responses, interview transcripts, and subsequent concept map:

Nature and the natural world have been created by God. Because it was created by God, it reflects some God’s qualities: spiritual, sacred, and holy. I don’t think that nature is, in and of itself, sacred and worthy to be worshiped, but it reflects those qualities from God. I believe that God created the natural world with intricate detail, variety, and complexity. That complexity makes it exciting to learn about nature and try to understand...
how it works. God created it with order and patterns that we can study such as the changing of the seasons. This orderliness also makes the natural world explainable and knowable. However, sometimes the complexity can make the natural world seem confusing and difficult to understand. But I think that we should strive to learn as much as we can about nature so that we can learn to effectively take care of it. God created nature with a purpose; it is not just there. Therefore, we can study nature and see God’s purpose and His craftsmanship.

I think that, overall, the natural world is constantly changing. There are some elements that do not change or that we cannot change. For example, we can’t stop a volcano from erupting or stop something that is radioactive from being radioactive. However, nature is changing. Some of the change that we see in nature is due to human actions. Humans have used nature and the natural resources we get from nature to the extent that we have caused damage to nature. Some of this damage has led to extinctions, pollution (such as Superfund sites, water contamination, and acid rain). We have exploited nature (such as poaching and mining) and caused things and places, like the Redwoods, to be endangered. However, even though humans have caused damage to the natural world, I do not think it is doomed. We are working to try to restore nature such as trying to restore local watersheds.

The natural world includes both matter/material objects and energy/forces. Sometimes the material and forces of nature can be very powerful. This power can be seen in things like thunderstorms, earthquakes, floods, and hurricanes. Therefore, nature can be both dangerous and frightening, depending on the situation.

Science is the study of the world around us. It is a process of discovery and inquiry, not merely a simple list of facts or vocabulary. It is different from other areas of study because it involves measuring variables, dealing with tangible substances, and experiments. Scientific experiments require good design, accurate data collection, and proper data interpretation; however, there is not one particular “method” that scientists need to use in order to do a good experiment.

Scientists can use creativity and imagination when planning and designing an experiment, when collecting data, and when interpreting data. Science reflects the culture and values in which it is practiced. No matter how objective scientists want to be, they are a product of their social climate. Therefore, the questions they ask and the experiments they conduct are influenced by their culture and values.

Scientific theories are useful because they help us make sense of the world. However, as we discover new knowledge and evidence, our theories can change. Our data is often limited, so having more data can help us make more sense of the world and refine our theories. A scientific law simply just says what happens without an explanation as to why.
Science can also explain how and why many things happen in the world. When we look for a cause for something, we can usually find evidence and experimental data that will support a scientific explanation. If an explanation is more scientific than the other, I would tend to choose that explanation. These scientific explanations would be logical, understandable, and make sense. I believe God is very powerful and is in control. And sometimes I might want to choose an explanation for something that might be less scientific because it fits with my beliefs about God and how He works. But for the most part, we are able to find scientific explanations for why things happen.

**Ian**

**Demographic Information**

Ian is a 65-year-old male. He has an undergraduate degree in physics and a master’s degree in physics. He has been teaching for 41 years in several different subject areas including 8th grade science (11 years), 7th grade science (10 years), 9th grade science (33 years), physics (30 years), 9th grade Bible (10 years), and astronomy (13 years).

**Views of Nature of Science**

Ian’s scores on the VNOS continuum show he has an informed view of the creative, empirical, and tentative aspects of NOS. His views of the subjective, social and cultural, and observation and inference aspects of NOS are emerging. His views of the scientific method and theories and laws aspects of NOS are naïve. Figure 66 summarizes Ian’s VNOS continuum scores. A radar plot also visually illustrates Ian’s scores on the VNOS continuum. A radar plot that is wide and broad illustrates informed, well articulated, and effectively supported conceptions of NOS. Figure 67 shows a radar plot of Ian’s VNOS continuum scores.

**Tentative.** Ian articulated an informed view of the tentative aspect of NOS articulated his understanding in his own words, and provided examples. For example, he
explains, “yes, theories change...as the steps in the scientific method recycle new things may be discovered which cause us to refine our theory...attempts to understand the atom began with theories which were constantly revised over time” (Ian VNOS Questionnaire). Likewise, in his NOS Follow-Up Interview, Ian explains,

Theories change because you could always get deeper and deeper into things. In order to make the theory more complete, it changes as more and more knowledge is found. There is never an end to questions. I don’t think there is ever an end to the questions. So you get new questions, you gather more data, and get more observations, more experimentations, more explanations, more explanations, and it’s a vicious cycle. So in that sense, the theory becomes more elaborate. An example would be with the atomic theory with the atom. You have the nucleus. And they break the nucleus apart, and you find these little particles. And then you smash the little particles, and you find other things. It keeps getting more and more complex. So the theory is constantly revised and enhanced. That’s included in the idea of the theory changing. It’s not like the theory is completely found to be false. It’s not going to a totally new theory. By change, I see it as
Ian recognizes the tentativeness of scientific knowledge with new observations and reinterpretation of existing observations. Since he articulates this in his own words and provides examples, “+++” is his VNOS continuum score for the tentative aspect of NOS.

**Subjective.** Ian’s responses to the VNOS Questionnaire and NOS Follow-Up Interview vary in terms of his view of the subjective aspect of NOS. Several of his responses illustrated a naïve view of the subjective aspect of NOS. When asked about if scientists using the same procedures could come to the same conclusions, Ian explains,
They might see that the data is all of a certain type. And then no matter which scientist looks at the data, if all the data is of the same type, it would certainly be evident no matter which group of scientist looks at it. So, I think it's fairly likely they will come to the same conclusion. (Ian NOS Follow-Up Interview)

Then, when asked if these same scientists, using different procedures, would come to the same conclusions, Ian explains,

If the data is the same, I would think they would come to the same conclusions. They would have the same conclusions about the data if the data was the same. Once you get the data, no matter how you got the data, the data is the data. No matter how you get the data. You can come to the same conclusions. For example, we are sitting at the table here. If you cook up a meal and you bring the food to me through the door behind me and set it on the table. Or if you bring the food to me from the door on the side and set it on the table. If I'm sitting here and look at the food, I can reach the same conclusion that this is good food. Or that this food consists of an ear of corn, mashed potatoes, and Salisbury steak. The conclusions that I would reach about the data they would be the same. If they have the same data, pretty likely will come to the same conclusions, no matter how they got the data. (Ian NOS Follow-Up Interview)

However, some of Ian’s other responses articulate a more informed view of the subjective aspect of NOS where scientific knowledge and inquiry are influenced by the prior knowledge, beliefs, theoretical commitments, experiences, etc... of the investigators. For example, he explains,

So you have your observation, and now you have two different explanations. So how is it possible to have two different explanations? Maybe the question should be, "why would you only ever expect one explanation?" Maybe it's unreasonable to expect just one explanation for something. (Ian NOS Follow-Up Interview)

Therefore, since Ian has responses demonstrating both a naïve and informed view of the subjective aspect of NOS, Ian’s overall view of the subjective aspect of NOS is emerging.

**Empirical.** Ian articulated an informed view of the empirical aspect of NOS. He was able to articulate his understanding in his own words and provide supporting examples. Ian
articulates the idea that knowledge about the scientific world derives from observations as he explains,

To gain knowledge of a physical nature, for example the acceleration due to gravity. This quantity can be determined by actually dropping objects and recording where they are at specific time intervals. The data so obtained can then be analyzed and then acceleration determined. (Ian VNOS Questionnaire)

Ian continues to talk about the empirical aspect of NOS and defines the empirical qualities of science that make it different from other disciplines. In his VNOS Questionnaire response, he states,

What makes science different from other disciplines is that science deals with measurable quantities. Unless something is measurable, science has no way of dealing with it in a meaningful way. That’s not to say that things which aren’t measurable aren’t real. For example, love and justice (and God) are real but they do not have a length you can measure, no mass, no volume. Thus, love and justice (and God) are not topics you will find in a physics textbook. (Ian VNOS Questionnaire)

Likewise, in his NOS Follow-Up Interview, Ian explains,

Science deals with measurable things. Disciplines like religion deal with things that you cannot measure. Science deals with measurable quantities. You have to be able to measure it makes sense of it and for it to be meaningful. Mass, length, and time are measurable quantities. The mass, length, and time quantities are combined to give the other quantities in physics. For example, length and time: if you take length divided by time, you get the concept of speed. And if you take length divided by time divided by time, then you get the quantity of acceleration. If you take mass times the length divided by time divided by time, then you have mass times acceleration, which gives you force. So physics is built upon measurable quantities: mass, length, and time. And then you combine those quantities to get other concepts. Whereas in religion, for example, there is no mass involved. (Ian NOS Follow-Up Interview)

Ian’s view regarding the empirical aspect of NOS are informed, articulated in his own words, and illustrated with examples; thus “+++” is his VNOS continuum score for the empirical aspect of NOS.
**Creative.** Ian articulated an informed view of the creative aspect of NOS. He was able to articulate his understanding in his own words and provide supporting examples. For example, in his NOS Follow-Up Interview, Ian explains,

They would use creativity and imagination in their explanations for sure. And you would use creativity to make observations. There are very creative ways to make observations. For example, I can look at the sun with my naked eye and say, “the sun is yellow.” But, if I am creative, I will let the light go through a diffraction grating and then I will look through it again and I will say, “I have a spectral lines here”...Your creativity will help you with your observations. Your creativity will help you with your explanations. I think that Einstein said something about how imagination is more important than something or other. So your creativity and your imagination will help in your explanations. And creativity and imagination will also help in your experimentations. If you are very creative, you will think up clever ways to test and check things out...I would include collecting and analyzing data and experimentation. So it’s okay to use creativity and imagination in all the stages of the experimentation phase. (Ian NOS Follow-Up Interview)

Likewise, in his VNOS Questionnaire, Ian states,

Of course they use their creativity and imagination! This is what makes science so exciting. God gives people different skills and abilities. Whenever an Einstein or Hawking or Newton or Hubble comes along, they look at things in a while new way and bingo! There comes another scientific “breakthrough.” Imagination/creativity can occur at any of the three steps in the Scientific Method. Step 1 Observation—Someone “sees” something in a new way no one has seen before. For example, Galileo saw Venus in phases. 
Step 2 Explanation—Someone “explains” something in a new way no one else ever did. For example, Copernicus said earth orbits the sun. 
Step 3 Experimentation—Someone “tries” something no one has ever tried before. For example, Galileo dropped different masses and observed all fall at same rate. (Ian VNOS Questionnaire)

Even though his views regarding the scientific method aspect of NOS may be naïve (discussed in a later section), he acknowledges that creativity and imagination in all aspects of scientific inquiry. Since he also provides examples, “+++” is his VNOS continuum score for the creative aspect of NOS.
Social and Cultural. Ian articulated an emerging view of the social and cultural aspect of NOS. For example, he explains how he feels that social and cultural aspects do not influence the body of knowledge aspect of science,

I do not think that science is based on cultural values or social values. Science is science. Science is supposed to be where you are not prejudiced in one way or the other. For example, I may be a happy that the law of gravitation is an inverse square, I would kind of prefer that it’s an inverse cube. But the theory of the experiments show me that it’s an inverse square. Or if I’m dealing with a culture that does not value mathematics and the people are not into algebra of those kind of things, things are still going to accelerate towards the Earth’s surface with the same acceleration regardless of your cultural values. They say in the Dominican Republic and in Spanish culture that it is a "hot" culture where relationships are very important. They say the United States is "cold" culture where people like to maintain their distance, and you do not have other family relatives living with you. If somebody drops a fork or something, it’s going to hit the floor with the same acceleration in both cultures. (Ian NOS Follow-Up Interview)

However, in his NOS Follow-Up Interview, Ian explains that he thinks that the practice of science could reflect political, social, and cultural values. He explains,

Pure science is universal! The acceleration due to gravity is the same in the United States as it is in China. Both countries have different cultures and values but the acceleration due to gravity is still 9.8 m/s². The practice of certain types of science might reflect social/cultural values, however. For example, doing an abortion no doubt requires some knowledge of science but might not be embraced by certain people. (Ian VNOS Questionnaire)

Therefore, Ian demonstrates an emerging view of the social and cultural aspect of NOS.

Theories and Laws. Ian articulated a naïve view of the theories and laws aspect of NOS. For example, Ian states,

A scientific law is a theory that has stood the test of time. It is more believable. A scientific law is more prestigious and highly thought of than a scientific theory. It has a high status. For example, in physics we have the Law of the Conservation of Energy and the Law of the Conservation of Momentum. These laws are accepted without questions. In physics, we also have the Wave Theory of Light. This gives a way for thinking about light which may or may not be true depending on the experiment. For example,
there is an experiment called Young’s Experiment where the results can only be understood if you assume the wave theory—that light is a wave. Then there is an experiment called the Photoelectric Effect where the results can only be understood if you assume light is not a wave but instead a particle.
(Ian VNOS Questionnaire)

Not only does Ian explain his idea of how a theory can become a law over time (a hierarchical view), he also supports his beliefs with examples. For example, Ian explains,

They always say a law has been around for a long time. A theory is generally accepted, but a law has been around. There's more credence given to a law than to a theory. A theory is a step up from a hypothesis. But a law is a step up from theory. Like the law of gravitation. Some people describe that as Newton's theory of gravitation. I'm not saying that the theory has to be around for 50 years, and then in the 51st year we will call it a law. I think that the theory and the law are kind of loosely switched one for the other. But a scientific law is something that is generally considered to be true by virtually the whole scientific world. It's a matter of more time. A law has been around longer. There is less argument about laws. I don't know if they would consider something like evolution, well there are different kind of evolution, the evolution of animals or something like that. There is more controversy with that, so they call it the theory of evolution. But some people consider that to be a law, I guess. So the laws the highest you can get. (Ian NOS Follow-Up Interview)

Ian's ideas and examples regarding the nature of theories and laws reflect a naïve understanding of a hierarchical relationship between theories and laws.

Observation and Inference. Ian articulated an emerging view of the observation and inference aspect of NOS. In fact, Ian appeared to lack a clear working definition of observation and inference and their differences. For example, when asked about observation and inference during his NOS Follow-Up Interview, Ian states,

It depends on how you define inference. I never use that word. An inference means to infer. To be honest with you, I'm not really sure know what that means. Is that the same as deduce? Is an inference the same as a deduction? Is an inference something that you have this knowledge, and then you kind of take a leap of faith? I think it's more than a leap of faith. You have these things that you know are true, so you... I would prefer the word deduce and deduction. (Ian NOS Follow-Up Interview)
However, other responses in his VNOS Questionnaire and NOS Follow-Up Interview demonstrate an emerging view of the observation and inference aspect of NOS (even in the absence of the terms observation and inference). For example, in response to the question regarding whether or not explanations and descriptions of thing scientists have not seen are scientific, Ian responds,

Yes, these explanations are scientific. Because the explanations are based on observations. And even though they have not seen the inside of the atom, you can still conclude there are atoms based on observations. It’s not just that we think that it would be really cool to think of things made up of little particles. There are reasons for thinking that. (Ian NOS Follow-Up Interview)

Likewise, when asked what type of information the knowledge about things scientists have never seen is based on, Ian explains, “The information is based on theory. For example, the temperature inside the sun. Scientists have never seen this. It’s based on scientific law that they know are true. And then they extrapolate those laws” (Ian NOS Follow-Up Interview).

Although Ian’s used of the terms theory and law seems to obscure his intended meaning, an emerging view of the observation and inference aspect of NOS is reflected in his responses.

**Scientific Method.** Ian demonstrated naïve view of the scientific method aspect of NOS. For example, when asked about the “scientific method” being described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results, Ian explains,

I think scientists must follow the scientific method. That’s a definite no-brainer—yes. They must follow the scientific method because it’s a scientific method. If you are going to be a scientist that is the method that you follow in order to qualify as a scientist. The scientific method is a method followed by scientists to discover knowledge: observation, explanation, experimentation. Or as you put it in a more complicated fashion here: Hypothesis, identifying variables, designing experiments, collecting data,
and reporting results. I prefer this: A scientist has to observe something. And then they say, "hey, look at that." Then they make an explanation where they say, "I bet I know why that happened." That’s sort of their hypothesis. But then they do more than that. They check it out. They check out that it covers the “identifying variables, designing an experiment, collecting data, reporting results.” So when I have the three steps: observation, explanation, experimentation, I am actually including the observation which you have neglected. Even though you have more steps, yours is incomplete. And mine with three steps, is complete. (Ian NOS Follow-Up Interview)

Repeatedly throughout his VNOS Questionnaire and NOS Follow-Up Interview, Ian referred to the scientific method as a specific series of steps to follow when doing science. He asserts, “This method must be followed (to do things scientifically)!!” (Ian VNOS Questionnaire). Even as he defines science in his VNOS Questionnaire, he explains that science is both a body of knowledge and a way of attaining knowledge that “refers to the method and activity of science which is also called The Scientific Method” (Ian VNOS Questionnaire). Therefore, Ian articulates a naïve view of the scientific method aspect of NOS.

Worldview—Nature and the Natural World

During his Worldview—Nature Interview, Ian discussed nature and the natural world in terms of his scientific understanding of the world, his specific content areas (physics and astronomy), his religious beliefs, his personal experiences, the aesthetic qualities he sees in nature and the natural world, his interest for nature and the natural world, and his personal concern for care of the natural world. Ian articulates a scientific understanding of the world when he explains,

The natural world is something that is tangible, touchable, and seeable. You can work with it. You can do experiments with it. You can find orderly processes involved with it. It is possible for human beings to write equations and come up with theories on how things work. It’s tangible. It’s
measureable. That’s an even better word! Nature involves things that are measurable. (Ian Worldview—Nature Interview)

Likewise, he goes on to explain,

Just because something is not measureable doesn’t mean it’s not real. Science deals with measureable quantities. But just because something is not measureable doesn’t mean it’s not real. Like love is real. And justice. The way I define reality is broader than just measureable things. (Ian Worldview—Nature Interview)

Ian talks about his specific content area (physics and astronomy) when he talks about his worldview beliefs about nature and the natural world. For example, he states,

If you think of the planet and all the gravity is coming from this one, and coming from that one, and coming from the sun. An asteroid comes by and tugs on the moon…I think of nuclear power. And Niagara Falls. Physics defines power as the work that something can do divided by the time it takes to do it. So even gravity could be considered a powerful force, if you let it do a lot of work or something. (Ian Worldview—Nature Interview)

Ian also integrates ideas and concepts from his specific content area (physics and astronomy) and his interest in nature and the natural world as he explains,

I think looking at the Hubble telescope pictures that have been taken is exciting. I got the Sky & Telescope magazine a few days ago, and it has a DVD of pictures from Mars from the rover. I think it’s exciting to see that. (Ian Worldview—Nature Interview)

Ian also integrates his religious beliefs into his discussion of nature and the natural world. For example, he explains, “I see in nature the work of God. That’s for sure...try to explain the universe and the millions of galaxies without God. That’s a no-brainer” (Ian Worldview—Nature Interview). In addition, he states,

If you talk about purpose, then you can attach a Creator to it. And there is some catechism that says, “What is our purpose? To enjoy God and worship Him forever.” I think that God created the universe for us to enjoy and so that would be our purpose. And to glorify Him. (Ian Worldview—Nature Interview)
Ian also integrates his personal experiences into his beliefs regarding nature and the natural world. For example, Ian recalls,

Nature could be frightening. Have you even see Quimet Canyon? Going around Lake Superior? The place where you can pull of, it’s called Quimet Canyon. There are not any fences up around there, at least not the last time we were there. There is a sign that says, “Parents, hold on to your children.” You go up there, and it’s huge, straight down drop. And in that sense, it’s frightening. So nature can be frightening. (Ian Worldview—Nature Interview)

Ian’ personal experiences appear to relate to his ideas regarding the aesthetic qualities of nature and the natural world. For example, Ian explains, “I think nature is incredibly beautiful. The variety of biology, the colors, even the Hubble telescope shows a lot of beautiful things” (Ian Worldview—Nature Interview). Likewise, he states, “I see beauty in nature. I agree with that. I would see beauty in a spiral galaxy. It’s beautiful. And some double stars are beautiful, you know, the different colors. I’ve always liked astronomy” (Ian Worldview—Nature Interview). Finally, Ian also articulates a personal concern for the care of the natural world. For example, he states,

I’m concerned about it, but maybe not as concerned as I should be. When we do physics, we don’t talk about pollution all that much. Maybe it’s an easier thing to do in chemistry and biology. We talk a little bit about nuclear waste. But I just haven’t been thinking that much about it. Maybe it’s a shortcoming of mine. (Ian Worldview—Nature Interview)

**Worldview—Causality**

Assertions relating to causality relied on Ian’s TOPE responses and his explanations regarding his responses. Ian picked the more scientific explanation for 12 of the 17 TOPE items, and the less scientific explanation for 5 of the 17 TOPE items: Items #1, 8, 14, 16, and 17. Therefore, his overall TOPE score is slightly above the average score for the group of participants ($M = 11.75$). For the items where Ian picked the more scientific explanation, his
reasoning for his choice seems to reflect a scientific way of thinking about the world. For example, his reasoning for TOPE Item #15 states,

This is a natural explanation that makes sense (no pun intended- see next sentence). Animals have greater awareness thru their senses. Explanation #1 implies people had this ability at one time but I don’t think there is any evidence of that. (Ian TOPE Item #15)

Figure 68 contains TOPE Item #15. In addition, in his response to TOPE Item #12, Ian explains,

Number 2 would be the preferred choice. This gives a natural explanation which I prefer. (Actually, seems like I’ve got it in my mind that bird migration has something to do with sensing the earth’s magnetic field also, but I might be wrong on that.) Choice #1 talks about “natural” and “unnatural.” What is “natural” in choice #1 might have its explanation in the information given in #2. (Ian TOPE Item #12)

Figure 69 contains TOPE Item #12. Ian even refers to himself as a scientist when he states, “the scientist in me views this explanation as logical” (Ian TOPE Item #7). Figure 70 contains TOPE Item #7.

On TOPE Item #1, Ian actually chose the less scientific explanation. However, in his response to the explanation he states, “Based on the information I’d pick explanation #2 although it sounds ‘less scientific’” (Ian TOPE Item #1). Figure 71 contains TOPE Item #1.

The goal that geologists have long had is to acquire enough knowledge about earthquakes so that they can be anticipated hours or even days in advance. Now it has been discovered that many animals can do just that. The geologists are still unsure about just how a particular animal senses a quake coming but there are two theories:

1. There are many things in the environment that animals sense such as danger or changes in the weather. This is an ability that modern people have lost due to their remoteness from nature and reliance upon technology.
2. It has now been learned that there are slight almost imperceptible pre-tremors that come hours, sometimes days before a major quake. These pre-tremors are noticed by animals, particularly grazing animals, which then become quite nervous. Which of the above explanations would you be more willing to accept? Explain.

Figure 68. TOPE Item #15.
Therefore, it appears that even in some instances where Ian picks an explanation that is less scientific, his reasoning for his response reflects a scientific way of thinking about the world.

For one TOPE item where Ian picked the less scientific explanation, he refers to his religious beliefs in his response. For example, Ian states,
Reports from a recent space flight indicate a new material has been identified in outer space. Although insensitive to the presence of ordinary matter, when approached by a human being it glows brightly in a variety of colors.

1. The new material is composed of atoms which are sensitive to the heat radiation emitted from human beings. This radiation excites the planetary electrons of the material’s atoms. When these electrons return to their ground state they emit light radiation which is determined by the distance between one atom and the heat.

2. It has long been suspected from other evidence that human beings give rise to psychic emanations, but the main difficulty has always been the development of a suitable detector for this influence. This new material appears to be an ideal detector for it is sensitive to human proximity as well as operating over a wide range of personality types.

Which explanation would you be more willing to accept? Explain.

Figure 7. TOPE Item #1.

Actually, I like #2. The thing I like about #2 is that in #2 there is the feel of something “special” (indicated by the word “humanity”) about human beings. Taken one step further, the idea of where the “humanity” comes from can lead to the idea of God and other religious ideas (example—“image-bearers of God”) which I would endorse. Explanation #1 is a completely naturalistic explanation which I feel falls short of explaining “humanity.” (Ian TOPE Item #14)

Figure 72 contains TOPE Item #14. However, he also mentions the religious beliefs in another TOPE response where he picked the more scientific explanation. For example, Ian states,

Explanation #1 makes sense. Explanation #2 is confusing to me. #1 is like a “divide and conquer” idea...although I don’t think it will give the ultimate “Why does it exist?” explanation which I think gets into a more religious/philosophical realm. (Ian TOPE Item #13)

Figure 73 contains TOPE Item #13. Therefore, it appears that Ian’s religious beliefs do not significantly affect his understanding of causality such that he would be more likely to pick explanations that are less scientific for most TOPE items.

Several of Ian’s TOPE responses also directly reflect his conceptions of NOS, particularly his conception of the empirical aspect of NOS. For example, in Ian’s response to
People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.

2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.

Which explanation would you be more willing to accept? Explain.

*Figure 72. TOPE Item #14.*

Is it logically possible for a system to explain itself? It appears to be a tautological dilemma since to explain itself a system can only explain the system in terms of itself. For instance is it possible to know how the brain really works since any theory put forward is a product of the human brain? The dilemma seems very discouraging yet scientists are undeterred.

1. The key to understanding any system, no matter how complicated, is in its parts which are necessarily less complicated than the whole. By examining and experimenting with the parts we eventually will learn enough about the whole brain to enable us to restore all neurological disorders.

2. Science has enjoyed great progress in understanding natural phenomena and scientists as a result have come to take progress as a scientific right. They have lost sight of the fact that all human endeavors including progress are limited and unending progress is not to be expected. If neuro-scientists were to remember that then their present viewpoint on the human brain would certainly be more humble.

Which of the above positions would you be more willing to accept? Explain.

*Figure 73. TOPE Item #13.*

TOPE Item #3, Ian states, “I’d be more willing to accept #2. A natural explanation is to be preferred than to think so “magic” is being done. Actually, the “magic” the magician does in #1 might be explained by #2” (Ian TOPE Item #3). Figure 74 contains TOPE Item #3. In addition, Ian states, “Number 2 would be the preferred choice. This gives a natural explanation which I prefer” (Ian TOPE Item #12). Figure 69 contains TOPE Item #12 (see
Likewise, his responses to the VNOS Questionnaire and NOS Follow-Up Interview indicated he had an informed understanding of the empirical aspect of NOS. For example, Ian states, “what makes science different from other disciplines is that science deals with measurable quantities. Unless something is measurable, science has no way of dealing with it in a meaningful way” (Ian VNOS Questionnaire). In addition, Ian states,

Science deals with measurable things. Disciplines like religion deal with things that you cannot measure. Science deals with measurable quantities. You have to be able to measure it makes sense of it and for it to be meaningful. Mass, length, and time are measurable quantities. (Ian NOS Follow-Up Interview)

It appears there may be a relationship between an informed understanding of the empirical aspect of NOS and a preference for more scientific explanations of causality on some TOPE items. However, this is by no means a predictive relationship.

Interpretive Narrative

A narrative presents Ian’s views of NOS, worldview beliefs relating to nature and the natural world, and worldview beliefs relating to causality. Ian’s responses to the VNOS...
Questionnaire and NOS Follow-Up Interview, transcripts from Ian’s Worldview—Nature Interview, a concept map created based on his worldview, and his responses to the TOPE items helped form this narrative. Following the initial creation of the narrative, Ian read over the narrative and modified it such that he believed it accurately described his conceptions of NOS, beliefs regarding nature and the natural world, and beliefs regarding causality. The following is the first person interpretive narrative created from Ian’s questionnaire responses, interview transcripts, and subsequent concept map:

The natural world is the material world that is made of matter. This material world includes both living and non-living things. On a large scale, most of the material world is non-living. This non-living world is solid and reliable—not just a figment of our imagination. It is measurable, and this is what science deals with. It is also unchangeable to the extent that things like atoms still exist even if their form changes—the conservation of matter. Although much of the material world is non-living, there is also a living component. This is the “smaller scale” components and can be changed. For example, living things change as they age. This living component can become polluted and might be considered doomed; therefore, it should be protected.

Not only does a material world exist, but a spiritual world also exists. Nature is not a part of this spiritual world, but being in, interacting with, and studying nature can inspire thoughts about and experiences with the spiritual world. Unlike the material world, the spiritual world is not measureable; therefore, science does not deal with the spiritual world. My ideas about the spiritual world have been shaped by my religious beliefs—my belief that God exists and created the world/nature. God alone is worthy to be worshiped and is holy, not the natural world. In addition, my religious convictions also cause me to believe that the natural, material world is restorable. I believe that God created the world, the world has fallen because of sin, God has come to redeem the world, and God will renew and restore the world.

The natural world is knowable, and we are able to understand how it works. If we learn a lot, we can explain it. We are able to explain it because there is an order to the natural world which allows us to be able to predict things, even though it is very complex. Although the natural world may seem chaotic, if we look at it on a larger scale, we can find some order in the midst of the apparent chaos. If we don’t know enough about nature, that is when it becomes mysterious and confusing. This confusion and mystery sometimes lead to frightening experiences.
I believe that nature is beautiful. This beauty that I find in nature comes from the diversity I see in nature, the peaceful experiences I have in nature (enjoying a sunny day, going camping, listening to the birds sing), and seeing the power in nature in things such as forces like gravity at work in places like Niagara Falls. These experiences also allow me to feel that nature and the natural world are exciting.

Science is both a body of knowledge regarding the physical universe and a way of attaining knowledge. Science is different from other disciplines because it deals with measurable quantities. This way of attaining knowledge is a method and activity known as the scientific method. This method can be summarized in three steps: observation, explanation, and experimentation. It is critical that these three steps are followed in order to do something scientifically. Scientists can use their creativity and imagination in all three of these steps. And although experimentation is required for attaining a lot of knowledge, some of our knowledge is theoretical.

Pure science is universal. For example, acceleration due to gravity is the same in the United States as it is in China. And if you’re a Republican or Democrat and you fall down the stairs, you are going to hit the ground with the same amount of force. If a number of scientists are looking at the same data, it is very likely they will come to the same conclusions. However, the practice of science might reflect social and cultural values. That is, the types of science and scientific experiments that are done and are allowed to be done is reflective of the society in which you live.

Science also progresses. Scientific theories change as we make new discoveries and are able to revise and refine our theories. More experimentation could yield more data which would help develop our theories. A scientific law is a theory that has stood the test of time and it is more believable. A scientific law is a “step up” from a scientific theory, and there is less argument about a law than a theory.

Science can also explain how and why many things happen in the world. A scientific explanation is logical and supported by evidence. And scientific explanations tend to support a cause-and-effect relationship. If one explanation is more scientific than the other, I would tend to choose that explanation. However, I believe that sometimes there are events and actions that lead to the idea of God. When we talk about God, sometimes completely naturalistic explanations fall short. But, for the most part, we are able to find scientific explanations for why things happen.

**Summary**

This chapter provides the results of the elicitation and examination of eight high school science teachers’ conceptions of NOS and worldview beliefs as revealed in written
questionnaires and personal interviews. The VNOS Questionnaire and NOS Follow-Up Interview addressed the following aspects of NOS: (1) tentative and subject to change, (2) subjective and theory-laden, (3) empirical, (4) product of human imagination and creativity, (5) social and culturally embedded, (6) relationship between theories and laws, (7) distinction between observation and inference, and (8) the myth of the scientific method.

The Worldview—Nature Interview asked to "think aloud" while they sorted cards and sentences containing terms and statements regarding nature and the natural world. The TOPE questionnaire asked participants to choose between two explanations of an event (one explanation being more scientific than the other). Participants picked one explanation and explained why they made that particular choice.

Taken as a whole, participants’ views of the aspects of NOS typically ranged from emerging to informed. Following the analysis of the VNOS Questionnaire and a NOS Follow-Up Interview, each participant received a score on a VNOS continuum scale based on his or her responses. Average NOS scores for each individual aspect of NOS (tentative, subjective, empirical, creative and social, theories and laws, observation and inference, and scientific method) indicated participants had views of the various aspects of NOS ranging from emerging to informed. This is not necessarily consistent with previous research findings that indicated that science teachers typically have a naïve understanding of NOS (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1999; and Nott & Wellington, 1998). However, these studies did not use the type of continuum description that this study uses to describe the teachers’ conceptions of NOS. Therefore, previous studies may have indicated a teacher’s conceptions of NOS as naïve where this study would identify that teacher’s conceptions of NOS as emerging. Nevertheless, it does appear that
teachers in this study may have more informed conceptions of NOS than teachers in previous studies. Quotes illustrating participants’ conceptions of NOS and the rationale for placement on the NOS continuum to aid understanding of how data were analyzed and how they may compare to previous studies are earlier in this chapter. Furthermore, Chapter V discusses this finding in more detail.

During the Worldview—Nature Interviews, all participants talked about their belief that God created the natural world. In addition, most participants communicated a scientific understanding of nature and the natural world. A number of participants talked about the emotions evoked while experiencing nature and the natural world. Overall, participants seemed to have a mixture of spiritual, scientific, and relational organizing structures of their perceptions of nature and the natural world.

As indicated by their responses and explanations for the TOPE items, the participants appear to have a mostly scientific understanding of causality. Out of the 17 TOPE items, the average number of more scientific explanations picked was 11.75 with a high score of 13 and low score of 10. Interestingly, in several of the accompanying elaborations of less scientific explanations, several participants indicated that they knew they were choosing an explanation that was less scientific. However, they felt that the less scientific explanation had some aspect to it that led them to feel more comfortable choosing the less scientific explanation over the more scientific explanation. A discussion of the significance and implications of these relationships and other findings in this study is in the following chapter.
CHAPTER V

DISCUSSION AND IMPLICATIONS

This research examined the conceptions of NOS in relationship to several components of worldview that science teachers at Christian schools hold. The following chapter provides an analysis of the significance of the results with respect to the research questions. The chapter contains four sections. The first section provides an analysis of the results. The second section discusses the limitations of the research. The third section discusses implications of the study, and the final section provides recommendations for future research.

Analysis

Before analyzing the results of the study and determining its significance and implications, it is important to recall the motivating framework and research questions that guided this study. According to the American Religious Identification Survey (ARIS 2008), approximately 80% of the population of the United States self-identifies as religious (Kosmin & Keysar, 2009). According to the National Center for Education Statistics, approximately four million children in the United States attend a religiously sponsored or affiliated school (Broughman et al., 2011). Concerning science education, an understanding of aspects of NOS is important to developing scientifically literacy, and this scientific literacy is an essential goal for science education (AAAS, 1990; Lederman, 1992; NRC, 1996). There is disagreement amongst philosophers, educators, and scientists regarding the compatibility of science education and religious education (Collins, 2006; Ecklund, 2010; Haarsma, 2004;...
Keys, 2004; Mahner & Bunge, 1996; Martin, 1997; Ruse, 2010; Settle, 1996; Wolters, 1985, and others).

Where do those assertions leave us? Are science education and religious education compatible or incompatible? Can a student enrolled in an institution claiming to provide a Christian education receive an adequate science education such that they can become scientifically literate? In order to find a place from which to start looking for answers to these questions, this study focused on teachers at a Christian education institution (secondary school setting). These teachers were very homogeneous in terms of their undergraduate training (six of eight at the same institution), religious beliefs, and church affiliations. Looking at this small, homogeneous population of science teachers, three main research questions were identified:

1. What conceptions of NOS do science teachers at Christian schools hold?

2. What worldview beliefs, specifically two components of worldview, the conceptualization of Nature and causality, do science teachers at Christian schools hold?

3. Is there a relationship between worldview and conceptions of NOS for science teachers at Christian schools?

These questions point back to the larger question of the compatibility of science education and religious education in that in order to teach science adequately and help students develop scientific literacy, teachers themselves need to be scientifically literate (which includes having informed conceptions of NOS). The following subsections address each of these questions separately.
Conceptions of NOS for Science Teachers at Christian Schools

Teachers in this study communicated understandings of NOS that ranged from uninformed to informed in various aspects (see Chapter 4, Table 10, pg. 120). These participants did not articulate noticeably less informed view of NOS than other science teachers in previous studies (Abd-El-Khalick & Lederman, 2000b; Akerson, Morrison, & Roth McDuffie, 2006; Carey & Stauss, 1968; Gallagher, 1991; Lederman, 1992, 1999; Nott & Wellington, 1998; Pomeroy, 1993; and others). In addition, several previous studies (all utilizing a very similar VNOS assessment instrument) have reported conceptions of NOS for teachers that can be compared to teachers in this study (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004).

Tentative

Seven of the eight (88%) of the participants in this study articulated an informed view of the tentative aspect of NOS. However, several previous studies (all utilizing a very similar VNOS assessment instrument) have reported much lower percentages of teacher participants with informed views of the tentative aspect of NOS prior to some type of instructional intervention (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 12 illustrates the percentages of participants with informed views of the tentative aspect of NOS in previous studies (using a similar VNOS assessment instrument). However, these studies did not use the type of continuum description that this study uses to describe the teachers’ conceptions of NOS. Therefore, previous studies may have indicated a teacher’s conceptions of NOS as naïve where this study would identify that teacher’s conceptions of
Nevertheless, it does appear that teachers in this study may have more informed conceptions of the tentative aspect of NOS than teachers in previous studies. When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 88\% informed result obtained is much higher than the pre-instructional results of other studies.

Since this group of participants is very homogeneous in terms of their undergraduate training, their current experiences of professional development, their departmental training, the textbooks they use in various courses, etc..., it would be
interesting to investigate this more. What about these teachers, their training, their experiences, their beliefs, etc... leads them to articulate more informed conceptions of the tentative aspect of NOS? This is a particularly interesting question in light of criticisms made to religious, specifically Christian, education (Mahner & Bunge, 1996; Martin, 1997). Martin asserts that the tentative aspect of NOS is in conflict with Christian beliefs. For example, he explains,

On the one hand, one goal of science education is to give students factual knowledge. However, this knowledge is sometimes in conflict with the dogmas of Christianity. Moreover, even when there is not actual conflict, there exists the potential for conflict in the sense that new scientific information can always come to light that challenges Christian belief. On the other hand, another goal of science education is to teach students to have the propensity to be sensitive to evidence: to hold beliefs tentatively in light of evidence and to reject these beliefs in the light of new evidence if rejection is warranted by this evidence. But this propensity conflicts with one way in which beliefs are often taught in Christian education: namely as fundamental dogmas, rather than as subject to revision in the light of the evidence. (p. 240)

The results of this study appear to be in conflict with Martin’s assertions. At the very least, Martin’s assertions conflict with the view of the tentative aspect of NOS articulated by these participants. One further question for research would be why? What about these participants leads them to articulate these more informed views of the tentative aspect of NOS? Is it something related to their worldview, specifically religious, beliefs (which would provide opposition to the arguments presented by those such as Martin (1997) and Mahner & Bunge (1996)? Or is it something else entirely?

Perhaps, these participants are, as Settle (1996) explains, “taking the ancient ‘two books’ idea seriously. Since both nature and scripture have the same ‘author’, we should
expect consistency between them” (p. 128). For example, in his Worldview—Nature Interview, Frank alludes to this “two books” idea as he explains,

I think of general revelation and special revelation. And going out and enjoying sunsets, and going out West and seen mountains and things like that. And just getting a feel for how God created everything. How you can see its beauty and all that...I think that sometimes it's hard to look at beautiful things, whether it is forests, oceans, sunsets, and things like that and not just get a sense of how this can't just be a random thing. There has to be a Creator. I think that is seen in Scripture too [and] general revelation and things like that. (Frank Worldview—Nature Interview)

The consistency that Settle describes can be found if both “books” are approached with a tentative attitude. That is, new evidence calls for the reexamination and reinterpretation of both science (the natural world) and Scriptures. Therefore, understandings of both science and Scriptures can change and are tentative.

Subjective

Three of the eight (38%) of the participants in this study articulated an informed view of the subjective aspect of NOS. This finding is consistent with several previous studies (all utilizing a very similar VNOS assessment instrument) (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 13 illustrates the percentages of participants with informed views of the subjective aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 38% informed result obtained is consistent with the pre-instructional results of other studies.
Empirical

All of the eight (100%) of the participants in this study articulated an informed view of the empirical aspect of NOS. However, several previous studies (all utilizing a very similar VNOS assessment instrument) have reported lower percentages of teacher participants with informed views of the empirical aspect of NOS prior to some type of instructional intervention (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 14 illustrates the percentages of participants with informed views of the empirical aspect of

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<tr>
<th>Study</th>
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<td>Abd-El-Khalick (2005)(^a)</td>
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<tr>
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<td>Philosophy of Science course group</td>
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<td>Abd-El-Khalick &amp; Akerson (2004)(^b)</td>
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<tr>
<td>Preservice Teachers</td>
<td>47</td>
</tr>
<tr>
<td>Akerson, Abd-El-Khalick, &amp; Lederman (2004)(^c)</td>
<td></td>
</tr>
<tr>
<td>Undergraduate Pre-Instruction</td>
<td>32</td>
</tr>
<tr>
<td>Undergraduate Post-Instruction</td>
<td>52</td>
</tr>
<tr>
<td>Graduate Pre-Instruction</td>
<td>44</td>
</tr>
<tr>
<td>Graduate Post-Instruction</td>
<td>52</td>
</tr>
<tr>
<td>Current Study</td>
<td>38</td>
</tr>
</tbody>
</table>

\(^a\)Conceptions of NOS assessed post-instruction in a Methods and POS Course

\(^b\)Conceptions of NOS assessed both pre- and post-instructional intervention

\(^c\)Findings separated for student level and both pre- and post-instructional intervention
When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 100% informed result obtained is much higher than the other pre-instructional results of other studies. Since this group of participants is very homogeneous in terms of their undergraduate training, their current experiences of professional development, their departmental training, the textbooks they use in various courses, religious beliefs, etc..., it would be interesting to investigate this further.
One possible contributing factor to this more informed view of the empirical aspect of NOS maybe related to participants’ worldview beliefs, specifically their religious beliefs. In addition, since these participants are all teachers at a Christian school, perhaps they more effectively articulate the empirical aspect of NOS in order to distinguish it from other disciplines. For example, in his Worldview—Nature Interview, Ian alludes to the empirical aspect of NOS as he explains,

The natural world is something that is tangible, touchable, and seeable. You can work with it. You can do experiments with it. You can find orderly processes involved with it. It is possible for human beings to write equations and come up with theories on how things work. It’s tangible. It’s measurable. That’s an even better word! Nature involves things that are measurable. (Ian Worldview—Nature Interview)

Likewise, in his VNOS Questionnaire response, he attempts to articulate his understanding of the qualities of science that distinguish it from other disciplines as he explains,

What makes science different from other disciplines is that science deals with measurable quantities. Unless something is measurable science has no way of dealing with it in a meaningful way. That’s not to say that things which aren’t measurable aren’t real. For example, love and justice (and God) are real but they do not have a length you can measure, no mass, no volume. Thus, love and justice (and God) are not topics you will find in a physics textbook. (Ian VNOS Questionnaire)

Therefore, perhaps as participants try to integrate their worldview beliefs regarding faith with their understandings and conceptions of NOS, they are better able to articulate and informed conception of the empirical aspect of NOS.

**Creative**

Four of the eight (50%) of the participants in this study articulated an informed view of the creative aspect of NOS. However, several previous studies (all utilizing a very similar VNOS assessment instrument) have reported lower percentages of teacher participants with
informed views of the creative aspect of NOS prior to some type of instructional intervention (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 15 illustrates the percentages of participants with informed views of the creative aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 50% informed result obtained is higher than the other pre-instructional results of other studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Percentage Informed</th>
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<tbody>
<tr>
<td>Abd-El-Khalick (2005)^a</td>
<td></td>
</tr>
<tr>
<td>Methods course group</td>
<td>30.4</td>
</tr>
<tr>
<td>Philosophy of Science course group</td>
<td>60.7</td>
</tr>
<tr>
<td>Abd-El-Khalick &amp; Akerson (2004)^b</td>
<td></td>
</tr>
<tr>
<td>Pre-Instruction</td>
<td>18</td>
</tr>
<tr>
<td>Post-Instruction</td>
<td>86</td>
</tr>
<tr>
<td>Students in History of Science Courses</td>
<td>15</td>
</tr>
<tr>
<td>Preservice Teachers</td>
<td>14</td>
</tr>
<tr>
<td>Akerson, Abd-El-Khalick, &amp; Lederman (2004)^d</td>
<td></td>
</tr>
<tr>
<td>Undergraduate Pre-Instruction</td>
<td>24</td>
</tr>
<tr>
<td>Undergraduate Post-Instruction</td>
<td>80</td>
</tr>
<tr>
<td>Graduate Pre-Instruction</td>
<td>16</td>
</tr>
<tr>
<td>Graduate Post-Instruction</td>
<td>40</td>
</tr>
<tr>
<td>Current Study</td>
<td>50</td>
</tr>
</tbody>
</table>

^a Conceptions of NOS assessed post-instruction in a Methods and POS Course  
^b Conceptions of NOS assessed both pre- and post-instructional intervention  
^c Findings separated for student level and both pre- and post-instructional intervention
Since this group of participants is very homogeneous in terms of their undergraduate training, their current experiences of professional development, their departmental training, the textbooks they use in various courses, etc..., it would be interesting to investigate this more. Nothing in particular about the participants’ Worldview—Nature Interview or TOPE Questionnaire responses indicated any special propensity to have a more informed understanding of the theories and laws aspect of NOS. Therefore, probing into teachers’ understanding of this particular aspect of NOS would be quite interesting.

**Social & Cultural**

Three of the eight (38%) of the participants in this study articulated an informed view of the theories and laws aspect of NOS. This finding is consistent with several previous studies (all utilizing a very similar VNOS assessment instrument) (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 16 illustrates the percentages of participants with informed views of the social and cultural aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 38% informed result obtained is consistent with the pre-instructional results of other studies.

**Theories & Laws**

Six of the eight (75%) of the participants in this study articulated an informed view of the theories and laws aspect of NOS. However, several previous studies (all utilizing a very similar VNOS assessment instrument) have reported much lower percentages of teacher
participants with informed views of the theories and laws aspect of NOS (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 17 illustrates the percentages of participants with informed views of the theories and laws aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. Therefore, the 75% informed result obtained is much higher than the other pre-instructional
results of other studies. Since this group of participants is very homogeneous in terms of
their undergraduate training, their current experiences of professional development, their
departmental training, the textbooks they use in various courses, etc..., it would be
interesting to investigate this more. Nothing in particular about the participants’
Worldview—Nature Interview or TOPE Questionnaire responses indicated any special propensity to have a more informed understanding of the theories and laws aspect of NOS.

One possible reason for this more informed conception of the theories and laws aspect of NOS may be how these Christian school science teachers approach teaching “controversial” topics such as evolution. Understanding the difference between theories and laws may be related to these teachers’ religious beliefs and how they try to find compatibility between science and religion by understanding the empirical nature of both theories and laws and that both are subject to change. That is, perhaps in order to find more compatibility between science and their religious beliefs, these teachers have developed a more informed view of theories and laws that allows these teachers to than an absolutist view of science that laws are proven and only theories are subject to change. Therefore, probing into teachers’ understanding of this particular aspect of NOS would be quite interesting.

**Observation & Inference**

Two of the eight (25%) of the participants in this study articulated an informed view of the observation and inference aspect of NOS. Several previous studies (all utilizing a very similar VNOS assessment instrument) have reported similar or higher percentages of teacher participants with informed views of the observation and inference aspect of NOS prior to some type of instructional intervention (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 18 illustrates the percentages of participants with informed views of the observation and inference aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that
The participants in this study did not receive any type of interventional instruction. Therefore, the 25% informed result appears to be consistent with or lower than the other pre-instructional results of other studies. One of the major obstacles for determining whether participants in this study had informed views of the observation and inference aspect of NOS was simply lack of data from which to draw conclusions about participants.
view. Therefore, the researcher was hesitant to classify a participant’s views regarding the observation and inference aspect of NOS as informed due to lack of supporting responses, ideas, examples, and quotes from participants. One suggestion for further study, discussed more in a later section, would be, if using a similar VNOS assessment instrument, to add more prompts to elicit more view regarding the observation and inference aspect of NOS.

**Scientific Method**

Two of the eight (25%) of the participants in this study articulated an informed view of the scientific method aspect of NOS. Of the four studies utilizing a similar VNOS assessment instrument, only two reported results specifically related to the scientific method aspect of NOS. These two studies seem to report slightly lower percentages of teacher participants with informed views of the scientific method aspect of NOS prior to some type of instructional intervention (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). Table 19 illustrates the percentages of participants with informed views of the scientific method aspect of NOS in previous studies (using a similar VNOS assessment instrument). When comparing the results, it is also important to note that the participants in this study did not receive any type of interventional instruction. However, based on the lack of data for comparison, it appears that the 25% informed result obtained is somewhat consistent with the other pre-instructional results of other studies.

As illustrated, participants articulated understandings of NOS that ranged from uninformed to informed in various aspects of NOS. As a group, participants However, several previous studies (utilizing a very similar VNOS assessment instrument) have reported lower percentages of teacher participants with informed views of various aspects of NOS
Table 19

Percentage of Participants with Informed Conceptions of the Scientific Method Aspect of NOS

<table>
<thead>
<tr>
<th>Study</th>
<th>Percentage Informed</th>
</tr>
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<tbody>
<tr>
<td>Abd-El-Khalick (2005)(^a)</td>
<td></td>
</tr>
<tr>
<td>Methods course group</td>
<td>-</td>
</tr>
<tr>
<td>Philosophy of Science course group</td>
<td>-</td>
</tr>
<tr>
<td>Abd-El-Khalick &amp; Akerson (2004)(^b)</td>
<td></td>
</tr>
<tr>
<td>Pre-Instruction</td>
<td>14</td>
</tr>
<tr>
<td>Post-Instruction</td>
<td>68</td>
</tr>
<tr>
<td>Abd-El-Khalick &amp; Lederman (2000)(^c)</td>
<td></td>
</tr>
<tr>
<td>Myth of “The Scientific Method”: Without prompts(^d)</td>
<td>-</td>
</tr>
<tr>
<td>Students in History of Science Courses</td>
<td>-</td>
</tr>
<tr>
<td>Preservice Teachers</td>
<td>-</td>
</tr>
<tr>
<td>Myth of “The Scientific Method”: When specifically asked</td>
<td></td>
</tr>
<tr>
<td>Students in History of Science Courses</td>
<td>15</td>
</tr>
<tr>
<td>Preservice Teachers</td>
<td>86</td>
</tr>
<tr>
<td>Akerson, Abd-El-Khalick, &amp; Lederman (2004)(^e)</td>
<td></td>
</tr>
<tr>
<td>Undergraduate Pre-Instruction</td>
<td>-</td>
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<tr>
<td>Undergraduate Post-Instruction</td>
<td>-</td>
</tr>
<tr>
<td>Graduate Pre-Instruction</td>
<td>-</td>
</tr>
<tr>
<td>Graduate Post-Instruction</td>
<td>-</td>
</tr>
<tr>
<td>Current Study</td>
<td>25</td>
</tr>
</tbody>
</table>

\(^a\)No results reported for this aspect of NOS
\(^b\)Conceptions of NOS assessed both pre- and post-instructional intervention
\(^c\)Patterns and themes within aspects of NOS separately reported
\(^d\)Recorded here just as reported in study
\(^e\)No results reported for this aspect of NOS

(Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). One can postulate several reasons for the higher level of informed conceptions of various aspects of NOS. One likely reason for this result is that this was a unique group of teachers than compared with previous studies and that the sample size was small.
Another reason for the increased levels of informed conceptions of aspect of NOS could be that since the researcher was a colleague, participants may also have been motivated to provide what they perceived as “correct” answers. That is, participant responses may have not completely reflected the actual beliefs and conceptions held by participants. Rather, they may have been simply an attempt by the participants to articulate what they had previously learned was the “correct” or more informed conception of aspects of NOS. As will be discussed further in the Limitations section, this personal relationship between the participants and researcher may have influenced the results.

**Worldview Beliefs of Science Teachers at Christian Schools**

This study provides information on teacher worldview beliefs regarding nature and the natural world and causality. Worldview beliefs are very complex. They can, as these participants articulated, incorporate and meld religious and scientific understandings. Worldview beliefs regarding nature and causality reflect religious beliefs. For these participants, faith did not appear to interfere with their ability to think scientifically in regards to their worldview beliefs regarding nature and causality. Rather, participants incorporated their faith beliefs into a scientifically compatible worldview regarding nature and causality that is not much different from other teachers.

**Worldview—Nature**

Each participant participated in a Worldview—Nature Interview in order to articulate his or her worldview beliefs regarding nature and the natural world. Participants discussed nature and the natural world in terms of their scientific understanding of the world, their specific content areas (physics, biology, chemistry, and/or astronomy), their religious beliefs, their personal experiences, the aesthetic qualities they sees in nature and
the natural world, their interest for nature and the natural world, and their personal concern for care of the natural world. During the discussion these participants articulated, incorporated, and melded religious and scientific understandings. For these participants, faith did not appear to interfere with their ability to think scientifically in regards to their worldview beliefs regarding nature and the natural world. Rather, participants were able to incorporate faith into a scientifically compatible worldview regarding nature and the natural world.

*Worldview—Causality*

Overall, the participants in this study demonstrated a fairly scientific view of causality. That is, participants tended to choose the more scientific explanation for the TOPE items. For particular TOPE items where one or more participants picked the less scientific explanation, the participant(s) had explanations for those choices based on their morals, concepts of justice, religious beliefs, and explained interpretation of the question. Interestingly, in several of the accompanying elaborations of less scientific explanations, several participants indicated that they knew they were choosing an explanation that was less scientific. However, they felt that the less scientific explanation had some aspect to it that led them to feel more comfortable choosing the less scientific explanation over the more scientific explanation.

In a previous study, Bell and Lederman (2003) also found a similar lack of correlation between understandings of NOS and, in their study, decision making on science and technology issues. In addition, they found that participants made decisions based on personal values, morals and ethics, and social concerns rather than simply on their understandings of NOS. In a study that addressed the role of conceptions of NOS in decision
making for high school students, Lederman & O’Malley (1990) concluded that high school students did not appear to base their decision making on the their understandings of the tentative aspect of NOS. Therefore, the results of this study appear to be consistent with previous studies examining the relationship between decision making and conceptions of NOS.

As illustrated in the participant responses to the TOPE items, both the religious views and scientific training of the participant affected how the participant responded to the TOPE items. For instance, several participants referred to specific content knowledge in their response such as illustrated in one of Elizabeth’s responses,

> Since certain electrons can be excited by electricity and do give off light when they return to ground state, it seems more logical to me that this could be the case for this new material. Would this substance glow if exposed to organisms other than human beings? (Elizabeth TOPE Item #1)

In addition, a number of participants referred to specific notions regarding their Christian faith such as illustrated in another of Elizabeth’s responses, “in my opinion, God created humans and He created them with these abilities. Our ‘humanity’ makes us different from all the other of God’s creations, including chimpanzees. We are created in God’s image and we are His special creation” (Elizabeth TOPE Item #14). This reference to both scientific training/content knowledge and religious beliefs is not unexpected. The TOPE gathers information about what a person believes about the nature of causation. Therefore, it makes sense that both a person’s religious beliefs and their scientific training might affect what they believe regarding the nature of causation.

One very interesting finding is that there were TOPE items for which a participant would indicate that one item was the more scientifically compatible explanation; however,
they explained that they would prefer the less scientifically compatible explanation for religious reason. For example, in response to the TOPE item regarding explanation for claims of afterlife experiences (for which the first explanation is the more scientifically compatible explanation), Grace states, “the Bible teaches that we go to heaven...the body may have stopped working but the spirit lives on. The first explanation makes sense, and maybe this explanation scientifically explains what is happening, but I still believe #2” (Grace TOPE Item #7). Likewise, in his response to the TOPE item regarding human-like characteristics of chimpanzees (for which the first explanation is the more scientifically compatible explanation), Ian explains,

Actually, I like #2. The thing I like about #2 is that in #2 there is the feel of something “special” (indicated by the word “humanity”) about human beings. Taken one step further, the idea of where the “humanity” comes from can lead to the idea of God and other religious ideas (example—“image-bearers of God”) which I would endorse. Explanation #1 is a completely naturalistic explanation which I feel falls short of explaining “humanity.” (Ian TOPE Item #14)

Given these TOPE results, it appears that participants in this study have complex views on the nature of causation. Their scientific training makes them aware of the value of the more scientifically compatible explanation. Likewise, their religious views appear to persuade them to prefer, when they have to choose, the less scientifically compatible explanation for a TOPE item. However, it appears that participants are somewhat hesitant to make that choice unless forced to do so. As a result, they attempt to synthesize the less scientific and more scientific explanation into a complex view of causation which is not satisfied with an either/or choice between the two. For example, Carl states,

Both explanations seem hard to test but I will settle for #2 because I am unsure that the thoughts and emotions of a chimpanzee are simple but I do believe there is something special about humans, something that God has
given us and if the experimenters want to refer to this as humanity then
that will work for me. (Carl TOPE Item #)

Sometimes this synthesis appears to come easily. For example, in her response to
the TOPE item regarding afterlife experiences, Grace explains,

The Bible teaches that we go to heaven...the body may have stopped
working but the spirit lives on. The first explanation makes sense, and
maybe this explanation scientifically explains what is happening, but I still
believe #2. (Grace TOPE Item #7)

Likewise, in response to the TOPE item regarding conducting research without a theoretical
framework, Damon explains,

I think that many first steps in scientific discovery were made by people who
either purposely did something no one had thought to do before or were
trying to “toe the line” but got an unexpected result. Historically many of
them were also criticized for their work also but some of it ended up being
very important and led to a broadening of the current theories or a shift to a
new theory. I think that this man, while maybe a little nutty, may also be a
genius for looking for a connection between areas that were thought to be
distinct – electricity and plant growth. Creation is tied together so there’s no
telling how many connections there might be that we just have not thought
to look for. It is sometimes the experiment that looks foolish that turns out
to be the one that allows a leap forward. (Damon TOPE Item #14)

In his reasoning for picking the less scientific explanation, Damon cites some very
scientifically compatible ideas (tentative and creative aspects of NOS). In addition, he also
alludes to his religious beliefs about the natural world when referring to it as “Creation.”

Sometimes this synthesis appears to come with great difficulty and incompletely.
For example, in response to TOPE item #2 regarding astronomers observation of increased
radio waves, Allen picks the less scientific explanation and states, “although it is true that
many physical bodies emit radio waves (all the suns do), there is a possibility there is a far
off civilization. To say no would limit what God is capable of doing” (Allen TOPE Item #2).
Here, he alludes to the idea that one option may be the more scientific explanation;
however, he will choose the less scientific explanation simply because he does not want to impose limits on what God can do.

**Relationship between Worldview and Conceptions of NOS for Science Teachers at Christian Schools**

The analysis of the data indicated some “internal” connections and relationships between worldview beliefs and conceptions of NOS for individual participants. For example, participants frequently mentioned aspects of their faith in the Worldview—Nature Interview, TOPE responses, VNOS Questionnaire responses, and NOS Follow-Up Interviews. In addition, scientific explanations and reasoning also appeared in the worldview nature interviews, TOPE responses, VNOS Questionnaire responses, and NOS Follow-Up Interviews.

Furthermore, there were several interesting findings from the participants’ conceptions of NOS that may show some connection to their worldview beliefs as articulated in their Worldview—Nature Interview and TOPE responses. As mentioned earlier in this chapter, the participants in this study articulated more informed conceptions of the tentative, empirical, and theories and laws aspect of NOS than reported in previous studies (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). In addition, participants in this present study articulated a complex synthesis of more and less scientifically compatible explanations for causality that, at times, evoked both their conceptions of NOS and their religious beliefs.

**Tentative Aspect of NOS**

The participants articulated more informed conceptions of the tentative aspect NOS than participants in several previous studies which utilized very similar VNOS
assessment instruments (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). As suggested earlier, perhaps this is connected to a religious belief related to the idea of two books where, since both nature and scripture have the same author (God), we should expect consistency between them (Settle, 1996). Therefore, new evidence related to both the natural world and scripture should be consistently reexamined and reinterpreted. This idea, articulated by several participants, supports the tentative aspect of NOS.

Not only is this more informed conception of the tentative aspect of NOS interesting, but it also serves to refute the criticisms of religious, specifically Christian, education which claim that religious education and science education are incompatible (Mahner & Bunge, 1996; Martin, 1997). Furthermore, Martin (1997) asserts that Christian education is specifically in conflict with the tentative aspect of NOS. However, the articulated worldview beliefs and conceptions of NOS of the participants in this study refute Martin’s claims.

**Empirical Aspect of NOS**

The participants articulated more informed conceptions of the empirical aspect of NOS than participants in several previous studies that utilized very similar VNOS assessment instruments (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). As suggested earlier, perhaps this connects with participants’ religious beliefs in that they are able to articulate more effectively the empirical aspect of NOS in order to distinguish it from other disciplines. This might allow participants to compartmentalize aspects of their worldview—scientific aspects from religious aspects.
However, it appears that participants do not compartmentalize and segregate their religious beliefs from their scientific understandings; rather, they synthesis and integrate their religious beliefs into their scientific understanding of the natural world. For example, Ian explains,

The natural world is something that is tangible. Touchable, seeable, you can work with it, you can do experiments with it, you can find orderly processes involved with it. It possible for human beings to write equations and come up with theories on how things work. It's tangible. That's a good word. It's measurable. That's an even better word! Nature involves things that are measurable. I like that. Things that aren't measurable can be just as real, but they're not in nature. Like love, justice, and the spiritual realm. This is real, but not part of nature. It's not measurable. Love isn’t measurable either in the sense that you can’t put it on a scale and say I got 5 g of love here. (Ian Worldview—Nature Interview)

This more informed conception of the empirical aspect of NOS is not only interesting, but it also serves to refute criticisms of religious, specifically Christian, education which claim that religious education and science education are incompatible (Mahner & Bunge, 1996; Martin, 1997).

**Theories and Laws Aspect of NOS**

The participants articulated more informed conceptions of the theories and laws aspect of NOS than participants in several previous studies that utilized very similar VNOS assessment instruments (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). As discussed earlier, the data did not identify any particular connections between these more informed conceptions of the theories and laws aspect of NOS and other worldview beliefs. Perhaps, since this group of participants is very homogeneous in terms of their undergraduate training, their current experience of professional development, their
departmental training, the textbooks they use in various courses, etc., it would be interesting to look at these areas and see if there might be something that would lead these teachers to develop more informed conceptions of the theories and laws aspect of NOS. In addition, it would be interesting to look at how they understand and approach teaching a topic such as evolution where misconceptions regarding the nature of theories have led to confusion and debate and where studies have found explicitly teaching the nature of and differences between scientific theory and scientific law and other aspects of NOS can help to dispel misconceptions about evolution (Lombrozo, Thanukos, & Weisberg, 2008; Nehm & Schonfeld, 2007; Oliveira, Cook, & Buck, 2011; Scharmann, Smith, James, & Jensen, 2005; Schulteis, 2010, and others).

**Synthesis of Explanations for Causality**

As a part of their TOPE responses, participants have complex beliefs about the natural of causation. That is, they were able to identify and synthesize a more scientifically compatible explanations for causality with religious views that would cause them to pick a less scientifically compatible explanation for causality (even when they recognize this is a less scientifically compatible explanation). Their scientific training makes them aware of the value of the more scientifically compatible explanation. Likewise, their religious views appear to persuade them to prefer, when they have to choose, the less scientifically compatible explanation for a TOPE item. However, it appears that participants are somewhat hesitant to make that choice unless forced to do so. Bell and Lederman’s (2003) study reports a similar result when examining teachers’ understandings of NOS and decision making: understandings of NOS did not affect decision making. As a result, they attempt to synthesize the less scientific and more scientific explanation into a complex view of
causation which is not satisfied with an either/or choice between the two. This ability to recognize and synthesize various explanations for causality is not only interesting, but leads to several questions for further research addressed in a subsequent section.

Overall, the results reveal several very interesting possible connections between worldview beliefs and NOS. These include the tentative, empirical, and theories and laws aspects of NOS, explanations for causality, and integration of religious beliefs into a scientifically compatible worldview. However, no specific causal relationships between worldview beliefs and conceptions of NOS appeared among the participants. This is consistent with Liu and Lederman’s (2007) study looking at worldview and conceptions of NOS for Taiwanese students.

One interesting conclusion drawn from these results is that perhaps the concept of worldview needs to be redefined once again. This study collected data regarding worldview beliefs regarding nature and the natural world and causality and data regarding conceptions of NOS. Data analysis then reported results for each area and attempted to find connections between them. However, perhaps the concept of worldview needs to be broadened farther. Rather than looking to see if a person has a scientific or religious worldview, perhaps it would be better to refer to a scientifically compatible or religiously compatible worldview. Although perhaps a small semantic change, it supports the idea that there is not one particular scientific worldview or religious worldview. As demonstrated by the participants in this study, it is quite possible to have both a scientifically compatible and a religiously compatible worldview—even if a person does not exclusively provide uniform responses and explanations for either of those types of worldviews. Since a person’s worldview is unique in the way that it functions to shape how a person sees the world—the “lens”
through which he or she sees the world, her or his worldview may contain complex nuances, competing aspects that are not necessarily compatible, and other intriguing interconnections.

**Limitations**

One limitation encountered as a part of this study was the recruitment of participants. Due to the highly in depth nature of the study, the number of participants in the study needed to remain small (fewer than ten participants). Although eight participants may be sufficient as articulated by Lee (2000) for an exploratory study such as this to make key assertions and identify major patterns, it is expected that a larger number of participants would yield data and assertions that may be more comprehensive and allow more confidence in regards to similarities and differences found among the participants. Therefore, the results of this study cannot be generalized beyond the sample of teachers included in the study. However, the results could serve as a reference for larger studies investigating worldview beliefs and conceptions of NOS of science teachers who teach at Christian schools.

In addition, the researcher anticipated that, because of the amount of time required to complete the questionnaires and interviews, recruitment of participants might be difficult. Therefore, the design of the study was complimentary to worldview beliefs project already in progress at the targeted school. All participants willingly completed the questionnaires and interviews when requested. Several even commented that they enjoyed the process. In addition, the teachers received an honorarium as compensation for their time.
Since recruitment of teachers was not random, several of the teachers may have felt coerced to participate in the study. However, because the school at which these teachers teach has committed to the topic of the study, the teachers may have been willing to complete the study as a part of their professional development at their school. In addition, although teachers were encouraged by the principal and curriculum coordinator to participate in the activities associated with the study, these teachers could have, at any time, refused to participate in the study.

Although there are several negative effects of this type of recruitment strategy, there are also several possible positive effects of this type of recruitment strategy. First, by having a principal and curriculum coordinator who support the study ask their teachers to participate, more teachers may have been willing to participate in the study. Second, because teachers were already involved in a worldview beliefs project already in progress at their school, they may have been more willing to participate in the study since the topic of the study may have sounded more familiar.

Due to the personal nature of worldview and conceptions of NOS, the process of completing the questionnaires and interviews may have caused the participants in the study to reflect on their worldview beliefs and conceptions of NOS to a greater degree than they may have if they had not participated in the study. Although this further reflection may have caused some level of discomfort (i.e., frustration with a perceived “wrong answer” or lack of knowledge), it should not have had any permanent detrimental effects on the participants.

In fact, one of the major strengths of the study is the quality and completeness of the data obtained. Because the study only involved eight teachers, the researcher spent a significant amount of time with each participant to ensure that the data obtained from the
participant was complete. Furthermore, investing a great deal of time with a small number of participants may have allowed the participants to feel more comfortable and open during the interview sessions. Therefore, the participants’ responses may have been more open and telling as to the actual beliefs held by the participants. Finally, because the school at which the participants teach is interested in the study, the participants themselves may have had more of an internal interest in the topic and been more willing to participate in the study than if the teachers had been recruited in a more random fashion.

The researcher in this study was a colleague of the participants. Therefore, one possible reason for the increased levels of informed conceptions of aspect of NOS could be that, since the researcher was a colleague, participants may also have been motivated to provide what they perceived as “correct” answers. That is, participant responses may have not completely reflected the actual beliefs and conceptions held by participants. Rather, they may have been simply an attempt by the participants to articulate what they had previously learned was the “correct” or more informed conception of aspects of NOS. Future studies could eliminate the possible effect of this personal relationship between the participants and researcher by studying participant populations not personally known by the researcher. Like any other qualitative research, the results are influenced by the main instrument of research—the researcher and her knowledge and interpretation of the data. This is both a strength and limitation to the study and the findings. In addition, this suggests that results cannot be generalized beyond the teachers in this sample.

Implications of the Study

The science teachers in this study were able to integrate their faith beliefs into both their worldview beliefs regarding nature/natural world, causality, and conceptions of NOS.
In fact, other than the fact that these science teachers integrated their faith beliefs into some of their responses regarding worldview and NOS, these teachers did not appear to be much different from other science teachers as demonstrated by articulating overall scientifically compatible worldview beliefs regarding nature/natural world and causality and conceptions of NOS that were as or more informed than participants in previous studies. Therefore, it appears it is not necessary to be “devoid” of religious beliefs in order to have a scientifically informed view of the world. Teachers with religious convictions can have very scientifically compatible views of the world in terms of their worldview beliefs regarding nature/natural world, causality, and conceptions of NOS.

This notion of the compatibility of religions and scientific aspects of worldview has been disputed by a variety of philosophers, scientists, and educators (Cunningham, 2010; Dawkins, 2006; Dennett, 1995; Good, 2003; Mahner & Bunge, 1996; Martin, 1997; Suchting, 1994; and others). For instance, Good (2003) explains, “the habits of mind associated with science are not only different that those associated with religion (and especially fundamentalist religion), they are basically incompatible)” (p. 515). Likewise, Mahner & Bunge (1996) assert, “a religious education is detrimental to a scientific one but also...science and religion are incompatible...whoever wishes to form a comprehensive and consistent world view must opt for either a religious or a scientific outlook” (p. 102, 116).

However, the results of this study refute the philosophical criticisms those such as Mahner & Bunge (1996) and Martin (1997) raise against Christian education citing the incompatibility of science education and Christian education. Rather, this study examined a group of science teachers at a Christian school who hold religious convictions while also articulating scientifically compatible views of the world. Perhaps, as Ecklund (2010), in her
study examining the religious attitudes of prominent scientists, articulates, “the
‘insurmountable hostility’ between science and religion is a caricature, a thought-cliché,
perhaps useful as a satire on groupthink, but hardly representative of reality” (p. 5). Ecklund
(2010) goes on to assert,

It is important that we uncover the complex truth about what scientists
practice and believe as well as how they encounter and engage (or
disengage from) religion in their lives, rather than cede the floor to the
hotheads on both sides of this contentious issue. (p. 5)

Not only do the teachers in this study articulate a scientifically compatible view of
the world in terms of their worldview beliefs regarding nature/natural world, causality, and
conceptions of NOS, in several areas of NOS (tentative, empirical, and theories and laws),
they articulate more informed conceptions of NOS than participants in previous studies
utilizing similar VNOS assessment instruments (Abd-El-Khalick, 2005; Abd-El-Khalick &
Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b;
Akerson et al., 2004). Furthermore, they articulate a complex view of causation as they
attempt to synthesize the less scientific and more scientific explanation into a complex view
of causation which is not satisfied with an either/or choice between the two in instances
where their religious views might persuade them to prefer the less scientifically compatible
explanation.

There are several implications for teaching that can be drawn from these results.
One important implication is the recognition that a science teacher can have Christian
religious convictions, scientifically compatible worldview beliefs, conceptions of NOS that a
similar or more informed than other science teachers. This refutes assertions by those such
as Mahner & Bunge (1996) and Martin (1997), that Christian education and science
education are incompatible and that a person must be devoid of religious beliefs in order to have a scientifically informed view of the world.

Second, important interactions and relationships exist between worldview beliefs involving religion and science (narrowed in this study to focus on views of the nature and the natural world and causality). As Reiss (2009) asserts,

A person can have more than one worldview and there are many worldviews other than religious ones but the religious worldview is a powerful and important one for many people. It provides a lens through which the world, including those aspects of the world that science focuses on, can be viewed. (p. 792)

It is important that worldview beliefs (including those regarding religious beliefs) be acknowledged as a part of science instruction (Cobern, 2000b; Matthews, 2009; Reiss, 2009). As Cobern (2000b) explains, avoiding the intersection and potential perceived conflicts between science and religion may lead to a poorer understanding of NOS and increase the chance that science remains irrelevant for some students. Likewise, Fysh & Lucas (1998) assert, “denigrating or ignoring students’ personal religious beliefs in science classrooms is not an intelligent or effective way of dealing with such challenges” (p. 399).

Therefore, acknowledging other aspects of worldview beliefs during science instruction is vital. This does not imply that the science classroom become the place where religious, sociology, psychology, and other cultural instruction takes place. Rather, these other influences for worldview beliefs need to be identified, recognized, and perhaps examined in light of their role and influence in science and science education. Matthews (2009) identifies questions that teachers need to address or of which they should be informed:

Does science have a worldview, and if so, what is it?
What are the components of religious worldviews?
In which ways are religious and scientific worldviews compatible and in which ways are they incompatible?
Where they are incompatible, how are they to be reconciled?
To what extent should examination of worldview matters take place in classrooms?
Should teachers promote knowledge of worldview options or belief in specific worldviews?
What impact does a religious worldview have on motivation to study science, and on the understanding of scientific concepts? (p. 648)

This study partially addresses the questions of the ways in which religious and scientific worldviews compatible or incompatible and the impact a religious worldview might have on the understanding of scientific concepts (conceptions of NOS).

**Recommendations for Future Research**

There have been few studies that have empirically examined worldview beliefs in regards to nature and the natural world and causality and conceptions of NOS to find any possible relationship between these beliefs and conceptions (Liu, 2003). This is particularly the case for the particular subset of participants involved in this study (science teachers at a Christian school who are very homogeneous in terms of religious beliefs, professional training, etc...). Therefore, the validity of this study would be enhanced by additional empirical studies involving similar assessment instruments for worldview beliefs and conceptions of NOS for participants with similar religious beliefs and professional training. In addition, there is a need for more empirical studies looking at religious beliefs and scientifically compatible worldviews. There is a plethora of literature related to the philosophical relationships between science and religion. But few studies empirically examine the religious beliefs, worldview beliefs, and conceptions of NOS of teachers and students.
Since this study involved a small number of participants, the results of this study cannot be generalized beyond the sample of teachers included in the study. However, the results could serve as a reference for larger studies investigating worldview beliefs and conceptions of NOS of science teachers. This would not only simply provide more data, but would also allow for potentially more variety in faith beliefs, worldview beliefs, and conceptions of NOS. For example, studies could look at other Christian school teachers who have similar religious beliefs as the participants in this study but who received a wide variety of professional training experiences. Additionally, studies could examine other teachers who have different religious beliefs from the participants in this study but similar beliefs to each other (i.e. a group of Jewish teachers, a group of atheist teachers, etc...). Furthermore, studies could examine other teachers with similar beliefs to each other who received their training from the same institution. It would be interesting to see if the worldview beliefs and conceptions of NOS for these teachers would show any correlations—both within the groups and possibly between different groups of teachers.

One very interesting finding was that for several aspect of NOS, tentative, empirical, and theories and laws, the participants in this study articulated more informed conceptions of the tentative aspect NOS than participants in several previous studies which utilized very similar VNOS assessment instruments (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & BouJaoude, 1997; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2004). The reasoning for these results is not immediately evident based on the results of this study. Perhaps there is some aspect related to their training, their school environment, the textbooks they employ, or some other aspect that can account for these differences. Since this group of participants is very homogeneous in terms of their undergraduate training,
their current experiences of professional development, their departmental training, the textbooks they use in various courses, etc., it would be interesting to analyze some of those aspects to look for any indicators that might lead to a more informed conception of NOS for various aspects. Furthermore, it would be interesting to ask the teacher participants to reflect on why they provided the particular responses they did and if these teachers could provide any insight into why they articulated more informed conceptions of NOS in terms of the tentative, empirical, and theories and laws aspects of NOS.

The results of this study indicated a complex view of causality articulated by participants. Future studies could examine this complex view of causality in more depth. For example, one could identify a group of participants with similar Christian religious beliefs to the participants in this study. Of these participants, the ones who had as much or more scientific training or interest in science as the participants in this study would likely provide responses to TOPE items similar to the participants in this study (Cobern, 1997). Furthermore, of these future participants, the ones who had less scientific training or interest in science would probably provide responses to TOPE items that more often indicated the less scientific explanation as the preferred choice.

Similarly, one could identify a group of participants with religious views very different from the participants in this study (e.g., non-theistic, atheist, etc.). Of these participants, the ones who had little or no scientific training or interest would be likely to indicate they preferred the less scientific explanation for TOPE items more frequently than participants in this present study. However, participants in this future study who had a great deal of scientific training or interest might be more likely to pick the more scientific explanation than the participants in this present study with a high degree of scientific
training (Cobern, 1997). These types of results would further corroborate the idea of the complex views of causality articulated by the participants in this present study.

This present study examined worldview beliefs and conceptions of NOS as articulated by participants through responses to several questionnaires and interviews. Another interesting way to examine worldview beliefs and conceptions of NOS would be to look at the teaching practices of these teachers. For example, when these teachers are teaching scientific concepts, do they also intentionally teach conceptions of NOS? Previous studies have found no correlation between conceptions of NOS and teaching practices (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse, 1990; Lederman, 1992, 1999; Lederman & Druger, 1985; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; and others). However, this present study focuses on a unique group of teachers in a unique situation (very similar background, training, and religious views). Therefore, it would be valuable to examine the teaching practices of these unique teachers or other teachers in a similar unique situation. In addition, do they self-consciously (or unconsciously) attempt to transmit their own complex views on the nature of causation? Classroom observations, lesson plan and material examination, and student interviews would provide a wide variety of information by which to attempt to address these questions.

Not only would it be enlightening to look at how worldview beliefs and conceptions of NOS are demonstrated during teaching practices, but also to study the students of these teachers. If the teachers in this present study had at least as informed and for some aspects of NOS—tentative, empirical, and theories and laws—more informed conceptions of NOS as teachers in other studies and they integrate these conceptions with their worldview beliefs regarding religious beliefs, understandings of nature and the natural world, and causation,
does this translate into an improved understanding of NOS among their students? That is, will the students of these teachers show the same improvements in conceptions of NOS as their teachers? Previous studies found that even when teachers appeared to articulate adequate understandings of NOS, they were unable to translate these NOS understandings to their classroom practices (Bell et al., 2000; Lederman, 1999). However, since this particular group of teachers appeared to be somewhat different in regards to their understandings of several aspects of NOS (tentative, empirical, and theories and laws) and because they are a unique group of teachers in terms of their background, training, and religious beliefs, it would be interesting to investigate the conceptions of NOS of their students to see how they compare to students in previous studies. In addition, are their students also able to articulate a complex understanding of causality similar to the understandings articulated by these teachers? Alternatively, is the more informed understanding of NOS and complex views of causality something that these teachers can articulate but are unable to translate into practice or convey to students?
APPENDIX A

Demographic Questionnaire

1. Name: ________________________________________________

2. Phone number: ________________________________

3. E-mail address: ________________________________
   (Phone number and/or e-mail address will only be used to contact you for a possible follow-up interview.)

4. Gender (circle one):
   1. Female
   2. Male

5. Your Age: ____________

6. Total years of teaching experience (including this year): ____________

7. I want to find out which school subjects you have taught during your teaching career (this includes subjects you are currently teaching and any other subject you have ever taught during your teaching career). For each different subject you have taught, please list the subject and the number of years that you have taught that subject.

   1. Subject taught: ____________________ Total years teaching this subject: ___
   2. Subject taught: ____________________ Total years teaching this subject: ___
   3. Subject taught: ____________________ Total years teaching this subject: ___
   4. Subject taught: ____________________ Total years teaching this subject: ___

   Continued on following page...
5. Subject taught: ____________________ Total years teaching this subject: ___

6. Subject taught: ____________________ Total years teaching this subject: ___

8. Undergraduate college major(s) (please list):
   1. ________________________________
   2. ________________________________
   3. ________________________________

9. College(s) attended (please list):
   1. ________________________________
   2. ________________________________
   3. ________________________________

10. Highest level of education (circle one):
    1. Bachelors
    2. Bachelors + some graduate
    3. Masters
    4. Masters + additional graduate credits
    5. Ph.D.

11. If you have earned or are currently working on a graduate degree, please indicate the area(s) of your graduate degree(s) or anticipated degree(s). (For example, educational leadership, science education, chemistry, etc...)
    1. ________________________________
    2. ________________________________
    3. ________________________________

Continued on following page...
12. Describe any career experience you may have had before teaching:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

13. Denominational affiliation of church you currently attend (circle one):

1. CRC
2. RCA
3. Lutheran
4. Methodist
5. Baptist
6. Catholic
7. Presbyterian
8. Non-denominational
9. Other (please specify): ________________________________
APPENDIX B

Religious Belief Survey

This survey includes a number of statements related to specific religious beliefs. You will probably find that you agree with some of the statements and disagree with others, to varying extents. Please mark your opinion for each statement, according to the amount of your agreement or disagreement, by using the following scale:

Circle:
-3 if you strongly disagree with the statement,
-2 if you moderately disagree with the statement,
-1 if you slightly disagree with the statement.
0 if you feel exactly and precisely neutral about the statement.
1 if you slightly agree with the statement,
2 if you moderately agree with the statement,
3 if you strongly agree with the statement.

1. God exists as Father, Son, and Holy Spirit.
2. Man is not a special creature made in the image of God; he is simply a recent development in the process of animal evolution.
3. Jesus Christ was the divine Son of God.
4. The Bible is the word of God given to guide man to grace and salvation.
5. Those who feel that God answers prayers are just deceiving themselves.
6. It is ridiculous to believe that Jesus Christ could be both human and divine.
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<tr>
<th></th>
<th>Statement</th>
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<tr>
<td>7</td>
<td>Jesus was born of a virgin.</td>
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<td>8</td>
<td>The Bible may be an important book of moral teachings, but it was no more inspired by God than were many other such books in the history of Man.</td>
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<td>9</td>
<td>The concept of God is an old superstition that is no longer needed to explain things in the modern era.</td>
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<td>10</td>
<td>Christ will return to the earth someday.</td>
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<td>11</td>
<td>Most of the religions in the world have miracle stories in their traditions; but there is no reason to believe any of them are true, including those found in the Bible.</td>
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<td>12</td>
<td>God hears all of our prayers</td>
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<td>13</td>
<td>Jesus Christ may have been a great ethical teacher, as other men have been in history. But he was not the divine Son of God.</td>
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<td>14</td>
<td>God made man of dust in His own image and breathed life into him.</td>
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<td>15</td>
<td>Through the life, death, and resurrection of Jesus, God provided a way for the forgiveness of man’s sins.</td>
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<td>16</td>
<td>Despite what many people believe, there is no such thing as a God who is aware of Man’s actions.</td>
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<td>17</td>
<td>Jesus was crucified, died, and was buried but on the third day He arose from the dead.</td>
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<td>18</td>
<td>In all likelihood there is no such thing as a God-given immortal soul in Man which lives on after death.</td>
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<td>19</td>
<td>If there ever was such a person as Jesus of Nazareth, he is dead now and will never walk the earth again.</td>
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<td>20</td>
<td>Jesus miraculously changed real water into real wine.</td>
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</table>
21. There is a God who is concerned with everyone’s actions.  
22. Jesus’ death on the cross, if it actually occurred, did nothing in and of itself to save Mankind. 
23. There is really no reason to hold to the idea that Jesus was born of a virgin. Jesus’ life showed better than anything else that he was exceptional, so why rely on old mythos that don’t make sense. 
24. The Resurrection proves beyond a doubt that Jesus was the Christ or Messiah of God.

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<th>Moderately Disagree</th>
<th>Slightly Disagree</th>
<th>Neutral</th>
<th>Slightly Agree</th>
<th>Moderately Agree</th>
<th>Strongly Agree</th>
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<td>24</td>
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APPENDIX C

VNOS Questionnaire

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

2. What is an experiment?

3. Does the development of scientific knowledge require experiments?
   • If yes, explain why. Give an example to defend your position.
   • If no, explain why. Give an example to defend your position.

4. The “scientific method” is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?
   ________YES, scientists must follow the scientific method
   ________NO, there are many scientific methods
   • If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
   • If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

5. After scientists have developed a scientific theory (e.g., atomic theory), does the theory ever change?
   • If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   • If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

6. Do you see a role for hypotheses in developing theories and laws? If so, what is that role? If not, why?

7. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

8. There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen “dark matter,” the center of the
earth, or into the nucleus of an atom. Yet we have ideas and even representations of such phenomena (such as diagrams of atoms in science textbooks).

a. If scientists have never seen these things (such as details of the inside of an atom), what kind of information is this knowledge based on? [i.e. How do they know what they know about these things?]

b. How certain do you think scientists are about the structure of the atom?

c. Do you think explanations or descriptions of things scientists have not seen are scientific? Why or why not?

d. Should we, as a public, accept this type of knowledge? Why or why not?

9. 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, suggests 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?

10. 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, and 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.

11. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

- If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
- If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

12. How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others of their claim?
APPENDIX D

NOS Follow-Up Interview Protocol

Hi. Thank you for agreeing to participate in this project. I hope that your participation will help you to reflect on your worldview beliefs and your conceptions of Nature of Science. In addition, you will help me greatly in my research project. I just have a few questions to ask you. Please feel free to elaborate on issues, even ones that I don’t specifically mention.

Before we start, I just want to remind you that there is no “right” or “wrong” answer to these questions. In addition, if at any time you feel you want to discontinue the interview, we can stop. I’ll be taping our conversation because I think we might be talking too fast for me to write everything down. Is that ok? Let’s get started.

1. What do you think are the most important things to emphasize in your teaching? Why?
2. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc...) different from other disciplines of inquiry (e.g., religion, philosophy)?

At this point interviewees will be provided with their questionnaires, be asked to familiarize themselves with their earlier responses, and to comment on and clarify these responses by answering the following questions:

3. What is an experiment?
4. Does the development of scientific knowledge require experiments?
   • If yes, explain why. Give an example to defend your position.
   • If no, explain why. Give an example to defend your position.
5. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.
   a. Do you consider this person’s investigation to be an experiment? Please explain why or why not.
b. Do you consider this person’s investigation to be scientific? Please explain why or why not by describing what it means to do something “scientifically.”

6. The “scientific method” is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

   _______ YES, scientists must follow the scientific method
   _______ NO, there are many scientific methods

   • If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
   • If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

7. After scientists have developed a scientific theory (e.g., atomic theory), does the theory ever change?

   • If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   • If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

8. How does a scientific theory develop/come to be? When can theories change?

9. Do you see a role for hypotheses in developing theories and laws? If so, what is that role? If not, why?

10. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

11. How do scientific laws develop? How do scientific theories develop?

12. There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen “dark matter,” the center of the earth, or into the nucleus of an atom. Yet we have ideas and even representations of such phenomena (such as diagrams of atoms in science textbooks).

   a. If scientists have never seen these things (such as details of the inside of an atom), what kind of information is this knowledge based on? [i.e. How do they know what they know about these things?]
   b. How certain do you think scientists are about the structure of the atom?
   c. Do you think explanations or descriptions of things scientists have not seen are scientific? Why or why not?
   d. Should we, as a public, accept this type of knowledge? Why or why not?

13. What is “indirect evidence?”

14. In science, do you think there is a difference between “data” and “evidence”? Explain your answer.
15. We often hear that scientists have learned something more about dinosaurs, but we don’t have any dinosaurs alive today. Scientists have never actually seen a live dinosaur.  
   a. How do scientists know that dinosaurs really existed?  
   b. How certain are scientists about the way dinosaurs looked?  
   c. How certain are scientists about the way dinosaurs moved?  
   d. What kind of information do you think scientists use to figure out how dinosaurs looked and moved? Do they use the same kind of information or different? Why?

16. It is believed that about 65 million years ago the dinosaurs became extinct. There are two widely supported explanations formulated by scientists to explain the extinction. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second explanation, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction.  
   a. How are these different explanations possible if scientists in both groups have access to and use the same set of data to derive their explanations?  
   b. Do you think anything would help the scientists to agree? If so, what? If not, why not?

17. If several scientists, working separately, ask the same question and follow the same procedures to collect data, do you think they will come to the same conclusions? Explain why or why not.

18. If several scientists, working separately, ask the same question and follow different procedures to collect data, do you think they will come to the same conclusions? Explain why or why not.

19. 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, and 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.

20. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?  
   • If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.  
   • If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.
21. Are creativity and imagination ever used in experimenting, data collection, and data analysis? Is it ever appropriate?

22. How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others of their claim?

23. You learn and teach science and about science in school and in everyday life outside of school. That information (scientific knowledge) comes from scientists. Do you think the scientific knowledge we have today (such as that in a textbook) may change in the future? Explain why or why not and give an example if you can.

24. Do you think that teaching the Nature of Science ideas is important? Why? (Or why not?)

25. Do you teach Nature of Science ideas? If yes, how? Why do you teach Nature of Science ideas in that particular way? (If not, why?)

26. Do you think there are special implications for Christian school teachers in their teaching of Nature of Science ideas?
APPENDIX E

Worldview—Nature: Interview Protocol

This interview protocol is adapted from Cobern (2000a), Cobern (1997), and Cobern, Gibson, & Underwood (1995).

Worldview Interview Sequence #1: The Essence of Nature

The interview will begin with a few introductory comments:

“Hi. Thank you for agreeing to participate in this project. I hope that your participation will help you to reflect on your worldview beliefs and your understandings of Nature of Science ideas. In addition, you will help me greatly in my research project. Please feel free to elaborate on issues, even ones that I don’t specifically mention.”

“Before we start, I just want to remind you that there is no “right” or “wrong” answer to these questions. In addition, if at any time you feel you want to discontinue the interview, we can stop. I’ll be taping our conversation because I think we might be talking too fast for me to write everything down. Is that ok? Let’s get started.”

Subsequently, the interview will proceed as follows:

<table>
<thead>
<tr>
<th>INTERVIEWER DOES</th>
<th>INTERVIEW SAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spread out pictures and let participant look at them.</td>
<td>“I’ve laid some pictures out in front of your, would you just take a moment to look at them?”</td>
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<tr>
<td></td>
<td>Pause</td>
</tr>
<tr>
<td></td>
<td>“How would you define Nature or the Natural world?”</td>
</tr>
<tr>
<td></td>
<td>Pause</td>
</tr>
<tr>
<td></td>
<td>“Is there any difference of are they essentially the same thing?”</td>
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</tbody>
</table>

If a distinction is being made—combine definitions or otherwise resolve.
<table>
<thead>
<tr>
<th>INTERVIEWER DOES</th>
<th>INTERVIEW SAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Would you say that all of these pictures depict <em>nature</em> or are there some that do and some that <em>do not</em>?”</td>
<td></td>
</tr>
<tr>
<td>Put up signs:</td>
<td></td>
</tr>
<tr>
<td><em>NATURE IS</em>...</td>
<td></td>
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<tr>
<td>AND</td>
<td></td>
</tr>
<tr>
<td><em>NATURE IS NOT</em>...</td>
<td></td>
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<tr>
<td>“We are going to go through a series of cards. I’m going to ask you to think about the words and then I’ll ask you to comment about them.”</td>
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<tr>
<td>Divide cards randomly into three groups. Use 1/3 at a time. Lay out 1/3 of the cards.</td>
<td></td>
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<tr>
<td>“Remember, what we are focusing on is what nature is. I want you to divide these cards into two groups. One group of words that you would use when talking about nature and one group that you would not use.”</td>
<td></td>
</tr>
<tr>
<td>Repeat for each 1/3 of cards.</td>
<td></td>
</tr>
<tr>
<td>Take words in the “would use” pile and spread them out in front of interviewee.</td>
<td></td>
</tr>
<tr>
<td>“Some of these words may be about the same thing—do you want to lump any of these words together?”</td>
<td></td>
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<tr>
<td>Turn tape recorder on if it hasn’t been turned on yet.</td>
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<tr>
<td>Wait for participant to pick.</td>
<td></td>
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<tr>
<td>“O.K., let’s talk about these groups. Which of these would you pick out 1st to talk about “what nature is?”</td>
<td></td>
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<tr>
<td>“Fine”</td>
<td></td>
</tr>
<tr>
<td>INTERVIEWER DOES</td>
<td>INTERVIEW SAYS</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Repeat chosen words for tape.</td>
<td>“What do these words have in common? Why have you put these words together?” etc.</td>
</tr>
<tr>
<td>Ask clarification questions if necessary. Avoid “Okay.”</td>
<td>Why are you saying, “Nature is _____”? What do you mean when you say, “Nature is _____”? In what sense would you say, “Nature is _____”? What examples can you give me?</td>
</tr>
<tr>
<td>Ask non-directed questions that invite the interviewee to talk about why the terms were picked and what they mean. Ask for clarification and examples. Ask follow up questions that are appropriate.</td>
<td>All right, we have this group aside now let’s take a look at the rest. Which group would you pull out next?</td>
</tr>
<tr>
<td>Pull 1st group of words aside but keep them visible.</td>
<td>“Why did you pull this group out after this group?”</td>
</tr>
<tr>
<td>Go back through the question series as above. Look for conflicting words. Ask how first group relates to second or if they do.</td>
<td>Can you help me understand this? Why is it that on the one hand (name first of previous groups) and on the other its (name present group)?</td>
</tr>
<tr>
<td>Try for at least 4 groups of “Nature is.” Do all if interviewee is prepared to continue—then go to “Nature is not.”</td>
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Appendix F

Worldview—Causality: Test of Preferred Explanations (TOPE)

Test of Preferred Explanations

ITEM 1
Reports from a recent space flight indicate a new material has been identified in outer space. Although insensitive to the presence of ordinary matter, when approached by a human being it glows brightly in a variety of colors.
1. The new material is composed of atoms which are sensitive to the heat radiation emitted from human beings. This radiation excites the planetary electrons of the material’s atoms. When these electrons return to their ground state they emit light radiation which is determined by the distance between one atom and the heat.
2. It has long been suspected from other evidence that human beings give rise to psychic emanations, but the main difficulty has always been the development of a suitable detector for this influence. This new material appears to be an ideal detector for it is sensitive to human proximity as well as operating over a wide range of personality types.
Which explanation would you be more willing to accept? Explain.

ITEM 2
Recently astronomers have observed an increase in radio wave activity of particular frequency from a particular sector in the sky. This observation has caused a stir and a great deal of speculation as to its explanations. So far there are two explanations that the astronomers are arguing most about:
1. Man has often doubted that he was alone in this vast universe. These radio waves might well be radio signals from some far civilization upon which we have stumbled or indeed they may even be meant for us.
2. There are many physical bodies in the heavens which emit radio waves. These emissions fluctuate and chances are these new emissions will be found to fall within the regular patterns of chance fluctuation.
Which explanation would you be more willing to accept? Explain.

ITEM 3
Some people were observing a demonstration that involved a miniature red train car, a bit of track, and a tunnel. When the demonstrator pushed the train car into the tunnel a blue car came out the opposite side. When the blue car was pushed back into the tunnel
the red car reappeared out the other side. People suspected that there were really two cars, originally the blue one being hidden by the tunnel.

To test this idea they listened carefully when the red car was pushed into the tunnel feeling sure that they would hear it knocking the blue car out the opposite side. Try as they might, they could hear no sound of a collision. The people then fell into two groups over the matter:

1. Some people found the demonstration intriguing and amusing. They considered the demonstrator to be a kind of magician who was proving that the hand really is quicker than the eye.
2. Other people recalled that like-poles of magnets repel each other. So perhaps there were two cars each with a magnet. Like poles faced each other so that one car entering the tunnel drove the other out without ever touching.

Which explanation would you be more willing to accept? Explain.

ITEM 4

There once was a woman who to put it mildly drank a great deal. Every day after work she would begin going from bar to bar until late in the night. Hardly a day would pass that she did not end in a state of intoxication. People said that this was not even the worst of her moral degeneracy, but that she was as well a cruel and spiteful woman. She seemed to delight in unkindness. One morning she did not come to work and later it was learned that she died the night before of a heart attack. Her colleagues at work spent much time that day discussing her fate.

1. As the doctors said she died of a heart attack. She undoubtedly put too much physical strain on her system and her heart finally gave way.
2. She was a young woman who should have had many years ahead of her. She was however decadent and mean, and an untimely death was the consequence.

Which of the above explanations would you be more willing to accept? Explain.

ITEM 5

Occasionally when entering a room for the first time one gets the distinct impression that he has been there before. This impression can be very strong and disturbing, and all the more because one is sure that he has not ever seen the room before. There seems to be two reasonable explanations for this phenomenon:

1. This is an example of déjà vu which is something almost all of us experience from time to time. It is remembering a place you had never been to before or an object or person you have never seen before. This phenomenon is a reminder of the vast complexity of the human mind, a complexity of which we understand very little. What we understand least is the capacity of the mind to perceive things outside the range of our basic physical senses.
2. The human brain is a complex electro-chemical computer. Although for the most part it functions faultlessly there are occasional lapses. The above is such a case.
After the first glimpse of the room there is an instantaneous functional lapse and recovery. The lapse causes the initial glimpse to be separated from the current perception of the room. The result is that the initial glimpse becomes like a memory. One is deceived into thinking that he has seen the room before.

Which explanation would you be more willing to accept? Explain.

ITEM 6

Two men became tired of working for their living so they decided to rob a bank to make themselves rich. They took guns, went to a local bank and demanded all the money. An alert policeman saw what was happening and intervened. The robbers fearing capture fired their guns. In the confusion they managed to escape in a stolen car leaving behind several injured and dying people. By this time the robbers were panic stricken and raced down the road at a very high speed. On a curve the driver lost control of the car and both of them died in a ghastly accident. Amongst the people who read about this incident in the newspapers there seemed to be two feelings about why these robbers died:

1. Why did these men die? We may be glad that they did die being so evil. The "how" however is more simple. Their evil deed was poorly planned. Had they carefully thought it all out ahead of time they either would have abandoned the idea or would have developed a much less reckless plan.

2. Sometimes we look around and see the evil that people get away with, and we think to ourselves, "There is no justice." But often there is justice and here is a good example. These men willfully decided to do evil. Why did these two die? It was the just price of their evil.

Which explanation do you find more acceptable? Explain.

ITEM 7

In the past when a man's heart stopped beating he was declared dead. Now medical doctors have the technology to restart a man's heart if they act quickly enough and thus to bring him back to life. A curious result of this is that we are now receiving interesting reports from these patients who have "died" but have been saved by this new technology. These reports are about the experiences these people have had during the minutes when their hearts were not beating. They claim that during that time they experienced the afterlife, that is the life that many people believe to be waiting for a person after he dies. There have been two reactions to these claims:

1. The dreams of a sleeping man are due to various electro-chemical processes in the brain. When a man's heart stops beating these brain processes do not immediately stop as well. His mind may still be dreaming since it takes time for this electro-chemical activity to cease. If the doctors are able to revive a man's heart, then when he regains consciousness what he remembers are only dreams like any other.

2. We may say that a man has died when his heart stops beating. What we really should say is that his body has died. The spirit of the man still lives just as the
philosophers have so often taught. The reports from these people who have died and then been revived give us the first empirical evidence that the spirit of a man does not die with his body.

Which explanation would you be more willing to accept? Explain.

**ITEM 8**

In many areas of the world today the health of the people is looked after by traditional and herbal medicine practitioners. These traditional physicians practice a healing art based on generations of accumulated knowledge. In spite of this, the modern study of medicine does not include any areas of this traditional knowledge. Recently doctors concerned about this issue have divided into pro and con groups:

1. The study of modern medicine is the study of western medicine. This should tip us off to the real reason behind the resistance to the scientific study of traditional herbal medicine. It is pure and simply western chauvinism. From the scientific point of view there is no reason for not carefully researching well-documented traditional cures. The findings would benefit all of mankind; and in addition there would be a greater appreciation of the traditions of non-western peoples.

2. Modern experimental medicine has been successful largely because it is directed by rational theory. The theoretical structure of a science tells the investigator which avenues of experiments are most likely to be profitable, thus avoiding many dead ends. Since there is no such structure in traditional medicine a researcher would be left to follow dozens, even hundreds of nebulous accounts of "cures that work." Such ad hoc experimenting is wasteful and inefficient. It is for this same reason that "home cures" that so many families use are not pursued by researchers.

Which position would you be more willing to accept? Explain.

**ITEM 9**

A startling discovery has recently been made amongst a pre-modern group of people in a remote region of the Amazon Basin. An anthropologist living with these people for a year noted that the council of elders had a perfect record on predicting rainy days. Out of 365 days there were 109 days on which rain began to fall. All of these days were correctly predicted two to four days in advance. For the same period of time the government meteorological forecasts were much less accurate. The elders based their predictions upon the pattern made by dried chicken bones which they would cast a specific number of times each day. The scientist was impressed with the accuracy but skeptical that the bones had much to do with it. He got the elders to cooperate in a number of experiments by which he hoped to determine the real nature of their predictions. None of his hypotheses were confirmed, all were rejected. In the end he was convinced that the predictions must indeed rest upon the chicken bones. Later the anthropologist reported his findings at the symposium; and although his peers agreed with his conclusions they disagreed in their reasons:
1. Pre-modern people although pre-modern are still clever. They skillfully put to use the collective observations and knowledge of their ancestors, as in this case. Modern people are surprised by their achievements only because they think of the pre-modern man as naïve and unintelligent.

2. First of all the anthropologist's studies were rationally designed and carefully conducted. Secondly, his findings are corroborated by the work of other anthropologists amongst other types of people. Thirdly, chemists have recently found that dry bones absorb moisture from the air and that the amount of "bounciness" in the bone depends on how much moisture has been absorbed.

Which side do you find more acceptable? Explain.

---

**ITEM 10**

Pea seeds when passed through a magnetic field germinate faster than seeds which are not passed through a magnetic field. There appears to be two logical explanations for this:

1. The magnetic field has an effect on the pea seed chromosomes. This results in faster cell division due to the pre-alignment of the chromosomes by the magnetic field. The seeds therefore germinate quicker.
2. After fertilization there is a principle of life which begins to drive the growth process. At an early stage that principle can be stimulated and quickened by many outside forces such as a magnetic field.

Which explanation would you be more willing to accept? Explain.

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**ITEM 11**

When plant seeds are grown in small pots it is possible to quicken their growth rate by periodically shaking the pots. This "shaking effect" is poorly understood but there are two schools of thought on the matter:

1. The roots of plants use up first the nutrients in the soil which are closest. The result is that the amount of soil nutrients increases with distance from the roots. Shaking stirs up the soil and helps bring richer but distant soil into contact with the roots.
2. All living things benefit from an occasional but gentle stirring up of their environment, and even of themselves. It gets the juices, fluids and chemicals moving and flowing. It provides fresh air and removes the stale. It encourages, one might say, the processes of life.

Which explanation would you be more willing to accept? Explain.

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**ITEM 12**

Bird migrations are an interesting phenomenon. For instance some geese can fly thousands and thousands of kilometers from one point on the earth to another never
getting lost. This remarkable feat of navigation is of great interest to biologists and also controversial. There are two much debated explanations:

1. Some biologists view bird navigation as a kind of natural movement. For instance, humans, can both walk and crawl; but they always walk because that is what is natural for them to do. It is possible for geese to fly in the wrong direction but that would be like humans crawling. They do not do it because it is unnatural.
2. Some biologists are quite convinced that wind currents act like Coriolis forces on the birds. The geese are sensitive to very slight variations in wind force and direction. By instinct they react to these variations and thus maintain their course.

Which of the two explanations would you be more willing to accept? Explain.

ITEM 13

Is it logically possible for a system to explain itself? It appears to be a tautological dilemma since to explain itself a system can only explain the system in terms of itself. For instance is it possible to know how the brain really works since any theory put forward is a product of the human brain? The dilemma seems very discouraging yet scientists are undeterred.

1. The key to understanding any system, no matter how complicated, is in its parts which are necessarily less complicated than the whole. By examining and experimenting with the parts we eventually will learn enough about the whole brain to enable us to restore all neurological disorders.
2. Science has enjoyed great progress in understanding natural phenomena and scientists as a result have come to take progress as a scientific right. They have lost sight of the fact that all human endeavors including progress are limited and unending progress is not to be expected. If neuro-scientists were to remember that then their present viewpoint on the human brain would certainly be more humble.

Which of the above positions would you be more willing to accept? Explain.

ITEM 14

People often wonder when confronted by the human-like characteristics of chimpanzees why they have not evolved the ability for language and speech. Opinion on this issue is divided:

1. The thoughts and emotions of a chimp are simple, lacking complexity, and can be communicated to another chimp by simple means, e.g. gestures. On the other hand an elaborate capacity for speech is required by humans because of their equally elaborate structures of thought and emotion. Simple means of communications would just not be sufficient.
2. Appearance can be deceiving as in the case of human-like characteristics of chimpanzees. The primary distinction between other animals and human beings is the "humanity" of man which is composed of such abilities as speech and rational thought. Without "humanity" man would indeed be just another animal.
ITEM 15
The goal that geologists have long had is to acquire enough knowledge about earthquakes so that they can be anticipated hours or even days in advance. Now it has been discovered that many animals can do just that. The geologists are still unsure about just how a particular animal senses a quake coming but there are two theories:
1. There are many things in the environment that animals sense such as danger or changes in the weather. This is an ability that modern people have lost due to their remoteness from nature and reliance upon technology.
2. It has now been learned that there are slight almost imperceptible pre-tremors that come hours, sometimes days before a major quake. These pre-tremors are noticed by animals, particularly grazing animals, which then become quite nervous.
Which of the above explanations would you be more willing to accept? Explain.

ITEM 16
Certain planetary bodies appear to deviate slightly from their calculated position in space. The deviation is extremely small. Everyone working in this field agrees:
   a) That the deviation exists, and
   b) That Relativity Theory offers the most likely explanation.
When asked why they supported this explanation workers gave different reasons:
1. It is difficult to make accurate measurements and existing experimental evidence lends only weak support for the theory. Nevertheless, the evidence gives better support to this theory than to any other.
2. The explanation was published by one of the most distinguished scientists of the 20th century. There is no doubt that he knows more than anyone else in the world about this particular phenomenon.
Which explanation would you be more likely to support? Explain.

ITEM 17
A physicist at a well-known university was conducting a unique set of experiments. He was interested in the effect of electrical discharges on the growth rates of a particular type of tree. The methodology was simple. He administered electrical shocks to one set of trees but not to second. Over a period of several months he measured and compared the growth rates of the two groups. The scientist's work caused a stir amongst his colleagues because he admittedly had no theoretical framework for his research. There were two basic opinions about this kind of experimentation:
1. The highly theoretical nature of physics provides an ample number of research problems for experimental work. Theory guided research is more efficient because
there is a greater chance of success. This man has picked an idea out of thin air and pursued it for no other reason than idle curiosity.

2. This man should not be criticized for his unique albeit different research problem. All too often progress in many fields is thwarted by over-conservatism and rigid adherence to theory. Creativity and independence should be encouraged so that more discoveries can be made and the understanding of nature increased.

Which opinion would you be more willing to accept? Explain.
Sample Code Book for Worldview Interviews

<table>
<thead>
<tr>
<th>Sample Code Words for Worldview—Nature Interviews</th>
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<tbody>
<tr>
<td>Knowable</td>
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<td>Explainable</td>
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<td>Pattern</td>
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<tr>
<td>Reliable</td>
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<td>Unchangeable</td>
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APPENDIX H

Participant Worldview—Nature Concept Maps
APPENDIX I

Human Subjects Institutional Review Board Approval

WESTERN MICHIGAN UNIVERSITY

Date: September 27, 2007

To: Renee Schwartz, Principal Investigator
   William Cobena, Co-Principal Investigator
   Kara Kita, Student Investigator for dissertation

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number: 07-08-20

This letter will serve as confirmation that your research project entitled “An Exploration of Worldview and Conceptions of Nature of Science among Science Teachers at Christian Schools” has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: September 27, 2008
BIBLIOGRAPHY


Rubba, P. A. (1976). *Nature of scientific knowledge scale.* School of Education, Indiana University, Bloomington, IN.


