

Student Conceptions of the Nature of Science

by

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ABSTRACT

Research has shown that students from elementary school to college have major misconceptions about the nature of science. While an appropriate understanding of the nature of science has been an objective of science education for a century, researchers using a variety of instruments, continue to document students' inadequate conceptions of what science is and how it operates as an enterprise. Current research involves methods to improve student understanding of the nature of science.

Students often misunderstand the creative, subjective, empirical, and tentative nature of science. They do not realize the relationship between laws and theories, nor do they understand that science does not follow a prescribed method. Many do not appreciate the influence culture, society, and politics; nor do they have an accurate understanding of the types of questions addressed by science.

This study looks at student understanding of key nature of science (NOS) concepts in order to examine the impact of implementing activities intended to help students better understand the process of science and to see if discussion of key NOS concepts following those activities will result in greater gains in NOS understanding. One class received an "activities only" treatment, while the other participated in the same activities followed by explicit discussion of key NOS themes relating to the activity.

The interventions were implemented for one school year in two high school anatomy and physiology courses composed of juniors and seniors. Student views of the nature of science were measured using the Views of the Nature of

Science – Form C (VNOS-C). Students in both classes demonstrated significant gains in NOS understanding. However, contrary to current research, the addition of explicit discussion did not result in significantly greater gains in NOS understanding. This suggests that perhaps students in higher-level science classes can draw the correlations between NOS related activities and important aspects of “real” science. Or perhaps that a curriculum with a varied approach may expose students to more aspects of science thus improving their NOS understanding.

DEDICATION

This paper is dedicated to my dad, who has always encouraged my educational pursuits and to my students, who join me in the adventure called learning.

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Introduction

Introduction to the Problem

Throughout the history of science education in American schools, teaching students to understand how science works, or the nature of science (NOS) continues to be issue of concern. The past century has seen many reforms, yet science education has been continually criticized for not producing scientifically literate students (Lederman, 2007).

As early as 1907, the Central Association of Science and Mathematics Teachers pushed for focus on a scientific method or process in science curricula (Lederman, 1992). Through the twentieth century and now into the twenty first century, understanding the process of science continues to be included as a key component of science literacy and an important goal of science education (American Association for the Advancement of Science [AAAS], 1989; National Research Council [NRC], 2004; National Science Teachers Association [NSTA], 1982).

NOS was included in the *National Standards for Science Education* (NSES), the project to create national standards as guidelines for science education (NRC, 2004). The NSES list four main goals of science education. Three of the four goals listed for school science relate directly to science literacy and include an understanding of NOS (2004). The related goals are:

To educate students who are able to... use appropriate scientific processes and principles in making personal decisions; engage intelligently in public discourse and debate about matters of scientific and technological

concern; and increase their economic productivity through the use of the knowledge, understanding, and skills for the scientifically literate person in their careers. (NRC, 2004, p. 13).

These goals are tied to an accurate understanding of the nature of science, or are skills the scientifically literate individual possesses.

One goal of teaching NOS is to increase scientific literacy. Scientific literacy can improve as a person matures in science understanding (NRC, 2004). It refers to one's ability to apply scientific skills to personal and civic decisions. A scientifically literate person should be able to ask and answer questions about their life and their world, critically read and evaluate science and other news articles and arguments, and communicate adequately about political issues with scientific roots. Scientifically literate individuals should also be able to appropriately use and apply science concepts, processes, and terms (NRC, 2004).

It is clear that NOS has been and will continue to be an essential aspect of science education. A major goal of science education will continue to be producing scientifically literate students who will enter society with the ability to understand how science works, to make informed decisions, and to use their science related skills to improve their skills in the workplace.

In striving to improve student understanding of NOS, research has repeatedly shown that students have major misconceptions relative to the process of science. (Lederman, 1992, 2007; McComas, 1996; Wenning, 2006). As the government and educators strive to increase the number of students who go on to study science and technology, increase the level of scientific understanding

among non-science students, and improve the public's view of science as an enterprise more emphasis must be placed on this critical component of scientific literacy.

Within the realm of NOS research there has been a great deal of research documenting student and teacher misconceptions, however, much remains to be done by way of development and implementation of effective NOS curricula. Research has outlined core ideas relative to NOS (Lederman, 2007; McComas, 2004) as well as NOS misconceptions held by both students and teachers (Bady, 1979; Lederman, 2007; McComas, 1996; Rubba, 1977). Studies have speculated, but have not necessarily demonstrated the benefits of learning NOS (Driver et al., 1996; Lederman, 2007).

Since the late 1950's a variety of NOS assessments have been published (Bell, 2008). Many NOS assessments, used in a variety of studies, repeatedly document the shortcomings of science education in teaching key NOS concepts (Abd-El-Khalick, 2006; Bell, 2008; Lederman, 1992, 2007). Research shows that students as well as teachers do not adequately understand key NOS concepts.

While shortcomings in NOS understanding are pervasive, research on ways to improve these misunderstandings is available, yet not as abundant. Curriculum that incorporates the history of science, curriculum that emphasizes the process of science over science content, and curriculum that incorporates explicit discussion of NOS concepts have been shown to improve NOS understanding (Klopfer & Cooley, 1963; Kuhn, 1970; Rudge & Howe, 2009; Yager & Wick, 1966). Research has also shown that inquiry related activities

accompanied by explicit NOS discussion demonstrate the greatest gains in NOS understanding for both teachers and students (Abd-El-Khalick & Lederman, 2002; Matkins et al., 2002; Rudge & Howe, 2009).

Researchers have conducted studies on various age groups from elementary school, through high school and college, to in-service teachers. NOS research has been conducted in a variety of content areas (Lederman, 2007). However, no studies were found using high school anatomy students. Research in upper level high school classes is sparse. The objective of this study is to use factors shown to improve NOS understanding in a variety of content areas with a wide range of ages, and apply those principles to teaching NOS in high school anatomy and physiology classes, a higher-level high school science class.

Synopsis of the study

In this study, the author measures student NOS views to investigate whether incorporating activities that address how science works can help improve student understanding of NOS. The study also addresses the effect of including explicit discussion of key NOS tenets following NOS related activities. Lederman's Views on the Nature of Science Assessment, form C (VNOS-C) is the instrument used to measure changes in student conceptions of various NOS concepts (Lederman et al, 2002).

During the 2008-2009 school year, activities were implemented in the authors anatomy and physiology classes that were intended to help students learn anatomy and physiology content as well as to expose them to how science works. One class, 5th hour, simply did the activities, with minimal to no explicit NOS

discussion. The other class, 6th hour, participated in explicit discussion focusing on NOS related questions following each activity. Data from the author's 5th and 6th hour anatomy classes will be statistically analyzed to see if NOS related activities increase student understanding of NOS and to look at whether explicit discussion following those activities will improve NOS understanding to a greater degree.

The results of this study will add to current research on NOS instruction by looking at an age group and content area lacking in NOS related research, high school anatomy and physiology students. This study aims to provide insight into to improving NOS instruction in high school science classrooms.

Statement of questions

This study looks at student understanding of key NOS concepts in order to examine the impact of implementing activities intended to help students better understand the process of science and to see if explicit discussion of key NOS concepts following those activities will result in greater gains in NOS understanding. This study addresses the following questions:

- 1) What is the understanding of NOS among high school students in an anatomy and physiology class?
- 2) Does explicit instruction make a difference in student understanding of NOS?

It is hypothesized that the activities alone will improve students' NOS conceptions. It is also hypothesized that the students who participate in the

activities followed by explicit NOS discussion will demonstrate greater gains in NOS understanding than those who participate in the activities alone.

Significance of the Questions

An appropriate understanding of the field of science is in the state and national science standards. It is also a vital skill that students need to really participate in science and society. This includes an understanding of the processes, values, and scientists that make science happen. Students may not understand all of the content in science, but they should understand how the enterprise works. With this knowledge, they can know the limits of the field. As their understanding of science increases ultimately, students will be skeptical at times. This will make them better consumers of science as it is presented in the media. It is intended that this study will provide further insight into the overarching question: How can we improve NOS instruction in high school science classrooms?

Literature Review

The Nature of Science

The “nature of science” can be difficult to define. As is true with science, our perceptions evolve, thus describing NOS poses a challenge (Alters, 1997; Lederman, 2007). In his 1992 review of literature on the nature of science conceptions, Lederman defines the NOS as referring “to the values and assumptions inherent to the development of scientific knowledge.”

Chambers wrote an entire book that was, “intended to be a simple, clear and elementary introduction to modern views about the nature of science” (1999, p. xi). While he intended to keep his explanations clear and simple, he describes how varying opinions and criticisms come in to play, convoluting the matter. This demonstrates the complexity associated with defining NOS. While slightly different views may exist, in short, NOS refers to the process whereby scientific knowledge is obtained, including the norms, procedures, ethics, and values inherent in the process.

Historians and philosophers of science have teamed with sociologists and psychologists to study scientists doing their work, the products of science, and the interactions within the scientific community (McComas, 2004). Their work is used to help science educators have a more accurate view of NOS. Defining NOS for science teachers, McComas simplified the NOS saying, “The definition and scope of NOS is quite basic; NOS is the sum total of the ‘rules of the game’ leading to knowledge production and the evaluation of truth claims by the natural sciences” (2004, p. 24).

Lederman, Chambers, and McComas each refer to NOS as the values or rules associated with gaining scientific knowledge. While pages could be and have been filled in an attempt to describe or define NOS, it does not have to be complicated. For the purposes of this study, Lederman's definition of NOS is used in this thesis. Again, he says that NOS refers to "the values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992, p. 331).

Components of NOS. While disagreements as to the definition of NOS may exist, there is general agreement on several key components of science. In 2004 Schwartz, investigated the NOS views of 24 experienced scientists in a variety of fields and found that, "on a level of broad generality, scientists' views are as similar within as across groups, demonstrating overall consistency in how scientists view that 16 categories of NOS/NOSI." When it comes to the nature of science, there are key concepts that are generally agreed upon (Abd-El-Khalick & Lederman, 2000; Lederman, 2002 & 2007; McComas & Olsen, 1998). See Table 4 for a brief summary of key NOS components included in a few papers. The NOS ideas in two of these papers will be discussed.

Lederman (2007) outlines six fundamental aspects important to science educators. He states that science is tentative; empirically based; subjective; involves human inference, imagination, and creativity; and is carried out in social and cultural contexts (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). Also important are the nature of laws and theories, as well as the differences between observations and inferences. He describes these tenants as follows:

Among the characteristics of scientific knowledge corresponding to this level of generality (philosophers, historians, and science educators) are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), and subjective (involves personal background, biases, and/or is theory laden); necessarily involves human inference, imagination and creativity (involves the invention of explanations); and is socially and culturally embedded. (Lederman, 2007, p. 833)

Writing to educators, McComas outlines nine key ideas that represent science (2004). He suggests educators use these to guide instruction. The core ideas he discusses are: 1) science requires and is based on empirical evidence; 2) while there are common features of good science, there is no universal “scientific method;” and 3) Scientific knowledge is tentative and subject to change. He continues by 4) drawing the distinction between laws and theories (Laws do not mature into theories.); 5) emphasizing the importance of creativity in science; 6) as well as the subjective nature of science. His final three points include: 7) the influence of history, culture, and society; 8) science and technology are related but different; and lastly 9) science is unable to answer all questions (McComas, 2004).

Table 1

NOS Elements in Literature

Paper	NOS Concepts										
	Tentative	Empirical	Subjective	Creative	Social & Cultural	Laws & Theories	Observations & Inferences	Interdependence of Concepts	No Scientific Method	Science & Technology	Unable to answer all Questions
Lederman (2007)	•	•	•	•	•	•	•				
Shwartz, Lederman, & Crawford (2004)	•	•	•	•	•	•	•	•			
McComas (2004)	•	•	•	•	•	•			•	•	•
Abd-El-Khalick, Bell, & Lederman (1998)	•	•		•		•	•				
Khishfe & Abd-El-Khalick (2002)	•	•		•			•				
Totals	5	5	3	5	3	4	4	1	1	1	1

The Key NOS tenets used in this study come from those discussed by Lederman (2007) and McComas (2004). These include concepts tested on the VNOS-C (Lederman, 2002). They include the tentative, creative, and subjective nature of the discipline. Also addressed in the study is the empirical aspect of science in context of experiments. Lastly, this study also focused on the human aspect of science by addressing the cultural and social context in which science happens. Other key NOS concepts were not used for one of two reasons. Either the concepts did not fit neatly with the anatomy and physiology curriculum or they were left out to limit the focus of the study.

Importance of NOS. Understanding the nature of science has been an important goal of science teaching for over 100 years (American Association for the Advancement of Science [AAAS], 1989; Central Association of Math and Science Teachers, 1907; Lederman, 2007; National Research Council [NRC], 2004; National Science Teachers Association [NSTA], 1982). There have been many revolutions in the history of science education. Content, methods, strategies, textbooks, etc. that ought to be included in science curricula continue to be debated. However, it is agreed that the nature of science must be included as a vital component of science education.

The nature of science is described as a key aspect of scientific literacy (Wenning, 2006). As stated in the introduction of this paper, a scientifically literate person should be able to ask and answer questions about their life and their world; critically read and evaluate science and other news articles and arguments; and communicate adequately about political issues with scientific

roots. “Science literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed” (NRC, 2004, p. 23). Scientifically literate individuals will also be able to accurately and appropriately use science concepts, processes, and terms (NRC, 2004).

Driver (1996) advocated that learning the nature of science reaps utilitarian, democratic, cultural, moral, and science learning benefits. In addition, people at the American Association for the Advancement of Science (AAAS) stated, “The development of an ‘adequate understanding of the nature of science’ or an understanding of ‘science as a way of knowing’ continues to be convincingly advocated as a desired outcome of science instruction” (1989).

Alters (1997) stated that, “(NOS) is a major goal, if not the major goal of science education” (p. 39). However, the inadequacy of our current education system in preparing scientifically literate students, with an accurate and adequate NOS understanding are clear and will be outlined in the following pages. With the established importance of NOS understanding for our students and our deficiencies in conveying an adequate understanding to our students, the need for research on improving NOS instruction is evident. It is vital that science educators improve curriculum and instruction in order to represent science as an enterprise more accurately.

Teaching NOS

In the mid 1950’s there was a realization that the current system of teaching science was failing. This realization was in part due to global

happenings such as World War II and the Russians launch of sputnik. The National Science Foundation (NSF) poured more than \$30 million dollars into research to develop curriculum that would meet the needs of a changing world and improve science education in the United States. The result was new curriculum, courses, and materials including films, tests, and lab equipment.

With these new resources came NOS assessments. As assessments were developed it became clear that science education was not adequately producing scientifically literate citizens. Researchers found the misconceptions are also widespread among science teachers. Researchers and science educators began producing new curriculum and studying factors that contribute to improved science understanding. NOS research over the last few decades includes many studies on teacher and student beliefs as well as curriculum and methods to improve understanding for both groups of individuals (Abd-El-Khalick, 2006; Lederman, 2007). Some of these studies will be discussed in more detail later in this chapter.

Research on students from elementary school to college, as well as with pre-service and in-service teachers has documented improvements in NOS understanding for all age groups. Three reoccurring factors shown to improve NOS understanding are curriculum that incorporates science history, curriculum that focuses on the process of science more than science content such as inquiry activities, and curriculum that implements explicit discussion of the nature of science. The component that seems to make the most difference in improvement

of NOS understanding is explicit discussion. These three methods have been shown to improve NOS understanding using a variety of assessment tools.

Several studies have found that incorporating the history of science into science curriculum can improve NOS understanding because the history of science is abounding with NOS concepts (Kuhn, 1970). When Klopfer and Cooley found that student views on NOS were deeply inadequate (1961), they developed and tested the first curriculum intended to improve NOS, called History of Science Cases for High Schools (HOSC). The researchers proposed that using cases from history would help paint a more complete and accurate view of science. Using 2,808 students in 108 biology, chemistry, and physics classes, they implemented the HOSC program for five months. Pre-test and post-test scores showed the treatment group demonstrated significantly greater improvement on the TOUS (Klopfer & Cooley, 1963). It is interesting to note that this study found that, with this curriculum, the teachers' NOS understanding did not play a role in the student scores. With its large sample size and significant findings, Klopfer and Cooley's study led to a surge in curriculum development intended to focus on inquiry and science skills (Lederman, 1992).

Other studies incorporating the history of science into science curriculum have generally found this to be an effective way of improving NOS understanding. Yager and Wick, looked at NOS scores on the TOUS for a variety of curriculum types. They found that the curriculum that added the historical view of developing science ideas showed the greatest gains (1966). Recent research has yielded the same general results: the history of science can improve

understanding of the nature of science. (Rudge & Howe, 2004, 2009; Mathews, 1994; and Monk & Osborne, 1997, cited in Rudge & Howe, 2009).

While not all curriculum developed in light of Klopfer and Cooley's 1963 study showed increases in NOS understanding (Lederman, 1992), many did. In addition to incorporating the history of science, studies found that inquiry-based curriculum could also improve NOS understanding. Crumb, 1965 using the TOUS as an assessment, found NOS gains with the Physical Science Study Curriculum (PSSC) greater than with traditional physics curricula. The PSSC curriculum emphasizes the process of science, and not just science content.

Another curriculum designed to emphasize the process of science was developed and tested by Aikenhead (1979). High school juniors and seniors took the Science Process Inventory (Welch, 1967) and the Test on the Social Aspects of Science (Korth, 1969) as a pretest and a posttest and showed significant improvement on both (Lederman, 1992)

In addition to using the history of science and inquiry to teach NOS, one factor has stood out in improving NOS understanding. To increase the effect of these two methods, educators should add explicit discussion of NOS to science curriculum in conjunction with these activities. Research has shown that discourse on the nature of science, particularly explicit discussion can improve understanding of NOS for students from elementary to high school as well as science teachers (Abd-El-Khalick & Lederman, 2000; Zeidler and Nichols, 2002).

Working to improve NOS understanding, Khishfe & Abd-El-Khalick (2002), performed a study with 62 sixth graders. The sixth graders were in two

groups that participated in the same inquiry activities. The intervention lasted 2.5 months and used interviews before and after the implementation of the inquiry activities to measure changes in NOS understanding. The researchers found that the inquiry only group did not improve, while the inquiry plus reflection and explicit discussion group demonstrated more informed views of NOS.

Rudge and Howe (2009) incorporated the history of science, using the research process with sickle-cell anemia, into an eighth grade curriculum and demonstrated the importance of including explicit NOS reflection to really improve NOS conceptions. “Throughout the unit students are invited to explicitly and reflectively consider the implications of their reasoning about the disease for their understanding of nature of science issues” (Rudge & Howe, 2009, abstract). They conclude that this explicit and reflective approach is needed to deepen the effect of HOS activities on NOS understanding.

Continuing to document studies through the grade levels Moss (1992) performed a similar study using high school juniors and seniors in an environmental science class. Students were interviewed and their concepts of NOS were described over the duration of a school year. The students participated in inquiry projects with scientists. Moss reported no significant change in NOS. Results of this study support other findings that state that inquiry curriculum with only implicit NOS aspects is not sufficient to improve student NOS understanding (Moss, 1998). The researchers cite Durke (1974) saying, “By merely involving students in science related projects, they will not necessarily develop an improved understanding of NOS” (p. 24).

Matkins et al (2002) did research on pre-service elementary school teachers. Using global warming and global climate change as the context, some of the course were taught incorporating explicit NOS instruction. Seventy-five teachers were surveyed over four semesters. The researchers found that the teachers in classes with an explicit NOS component scored significantly better on their posttest scores than on their pretest (Matkins et al, 2002).

Yet another study used an even older, more experienced group and found similar results. Abd-El-Khalick and Lederman (2000), conducted a study of science teachers and found that NOS concepts need to be discussed explicitly in order to significantly improve science understanding.

Other studies have supported the findings of the studies discussed, showing explicit discussion to be an essential aspect of effective NOS instruction (Lederman, 1999; Schwartz et al, 2002; Lederman et al, 2002; Schwartz & Lederman, 2004). The studies span from elementary to in-service teachers, in a variety of content areas from biology and sickle-cell anemia to earth science and global warming. However, no studies were found using high school students in upper level biology classes such as anatomy and physiology.

Based on the research, the ideal program to improve student conceptions of science would incorporate the history of science, while involving students in inquiry activities, and including an opportunity for explicit reflection on the nature of science relative to the activities in which they have just participated.

Learning NOS (Areas of Misconceptions)

Student perceptions of NOS are inadequate. Research has found a number of common areas of misconception. McComas (1996) delineates ten myths regarding NOS, myths commonly held by students as well as teachers.

They address the following:

- 1) The relationship between or definition of hypotheses, laws, and theories;
- 2) The use of a “scientific method”;
- 3) Evidence leading to sure knowledge or absolute proof;
- 4) The role of creativity in science;
- 5) The ability of science to answer all questions;
- 6) Objectivity of scientists;
- 7) Experiments as the only way to gain scientific knowledge; and
- 8) The role of peer review and honesty in science (McComas, 1996).

These areas of misconception correlate with key NOS concepts discussed at the beginning of this chapter and depicted in table 4. In this research, reference to NOS is reference to these important and often misunderstood aspects of science. This section will discuss these areas of misunderstanding

Research has found that students possess many naïve beliefs relative to how science works. One common misunderstanding pertains to the relationship between hypothesis, theories, and laws. Students often believe that a scientific hypothesis may develop into a theory, which then can mature and become a law when it is “proven true” (Lederman, et al., 2002). This widespread notion of a hierarchical relationship between hypotheses, theories, and laws is incorrect.

McComas even relays an incident where a US president claimed he was not concerned about the theory of evolution because it was “just a theory” (1996). He says, “Those who understand the distinction between laws and theories would never call evolution ‘just a theory!’” (McComas, 2004).

Students and others often do not realize that a theory in science is different from the common usage of the word theory, and that a scientific theory is backed by significant amounts of empirical evidence (McComas, 2003). Laws are “generalizations, principles or patterns in nature and theories are the explanations of those generalizations” (McComas, 1996). A theory does not mature into a law! “Laws and theories are related but individually important kinds of scientific knowledge and both should be considered valuable products of the scientific endeavor” (McComas, 2004).

In 1979, Bady found it common for students to have naïve beliefs relative to hypothesis and theories (Lederman, 2007). Using the NSKS, Rubba and others surveyed high school students and found that the majority of students believed that theories become laws (Rubba, 1977; Rubba & Anderson, 1978; Rubba, Horner, & Smith, 1981; cited in Lederman, 2007).

One could walk into a science classroom today and likely find posters and notes depicting a neat and tidy “scientific method” with certain steps found in an unbreakable order which students must memorize and regurgitate on some test or quiz. Another common myth, sadly perpetuated in many science classrooms, is that there is one universal process, or “Scientific Method,” that must be followed in order to obtain scientific knowledge. “This myth has been a part of the folklore

of school science ever since its proposal by statistician Karl Pearson (1937)” (McComas, 1996).

School science resources may differ in their wording or exact steps, but the steps scientific method generally include: 1) identify a problem, 2) research the problem, 3) develop a hypothesis, 4) make observations, 5) design an experiment, 6) perform the experiment, 7) analyze results, 8) write a conclusion, and 9) communicate results (Falcignos, 2010). While the steps may vary, the idea is misleading. It also perpetuates another myth which is the idea that all scientific knowledge is the result of experimentation. Science philosophers have found that scientists do not use a universal scientific method; however, common skills (discussed below) used are similar to those used in solving any other problem (Carey, 1994; Gibbs & Lawson, 1992; Chalmers; Gjertson, 1989; all cited in McComas, 1996).

Another common myth is that science and its methods provide absolute proof and that evidence accumulated carefully results in sure knowledge. It is impossible to gather all data in time and space to draw absolute conclusions about natural phenomena. Through observation and experimentation, scientists gather information, which they then synthesize and interpret to yield conclusions based on induction. This process results in well-supported theories, which can gain support with added evidence. Therefore, although generally based on significant amounts of data, science cannot provide absolute truth nor can it result in sure knowledge. New evidence can support a scientific idea. New evidence can disprove or falsify a theory. However, contrary to what science learners as well

as many of the public in general believe, evidence cannot prove a scientific idea nor does it generate sure knowledge.

One of the skills vital to the scientific process, discussed above, is creativity. The cookbook labs commonly found in science courses make it hard for students to conceptualize a profession where creativity and imagination are involved at every step. “Even the spark of inspiration that leads from facts to conclusions is an immensely creative act” (McComas, 2004).

Creativity can be involved in nearly every phase of science: making observations, planning and conducting experiments, interpreting results, organizing and gathering data, etc. “Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world” (Lederman, et al., 2002). Zeidler, Walker, Ackett, and Simmons found that the majority of high school students they tested did not appreciate the tentative, subjective, and creative aspects of science (2002, cited in Lederman 2007).

Students perceive science to be procedural and rigid. They imagine older men with crazy hair, glasses, and lab coats pouring chemicals into test tubes (Chambers, 1983). While this may describe some science and scientists, this portrayal and the perceived message students receive, is missing an important and potentially enticing aspect of science. William McComas said, “Studies have shown that otherwise bright students reject science as a career choice simply because they have no opportunity to see the creativity involved” (McComas, 2004). If students participate in science education that exposes true science they

may see how involved creativity and imagination are in the process of science and perhaps science could claim more bright and talented individuals.

As represented throughout this discussion, misunderstandings of what science really is and what science does are pervasive. Another point of confusion pertains to the types of questions science entertains. William McComas cites Karl Popper in an effort to provide an operational definition of science, “Popper believed that only those ideas that are potentially falsifiable are scientific ideas” (McComas, 1996). If this line were clear in the minds of individuals that make up society, some of the current legal arguments, including the push to include “creation science” in biology curriculums, would be nullified (McComas, 1996).

The Supreme Court even turned to Popper’s definition of science. Popper’s idea of “falsifiability” has been used in cases such as *Daubert v. Merrell Dow Pharmaceuticals* to differentiate between science and other means of answering questions (O’Connor, 1995). In another case, and *McClain vs. Arkansas Board of Education*, testimony of the tentative and falsifiable nature of scientific knowledge helped resolve the case. The case dealt with creationism or place (or lack thereof) in science education. Science is intended to explain the “natural,” not the unnatural or metaphysical (McComas, 2004). Thus, the importance of making the role of science clear to students and increasing science literacy is evident. A scientific idea is one that can be tested and proven false. A religious idea, on the other hand, cannot really be tested and proven false. As such science is empirically based and cannot answer all questions.

Another myth is that science is objective and uninfluenced by societal norms or personal bias (Zeidler, et al, 2002; cited in Lederman, 2007). Science is performed within the context of current ideas and theories, which influence and often guide research. In addition, as an enterprise operated by people, science cannot escape the influence of constituting individuals' personal paradigms, including "personal values, agendas, and prior experience (that) dictate what and how scientists conduct their work" (Lederman, et al., 2002). Nor can it escape the influence of society with its culture and politics. In the scoring rubric for the VNOS-C, Lederman and his team of researches describe how science is embedded in society and culture. "Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted" (Lederman, et al., 2002).

Other myths and misunderstandings about science certainly do exist. These are some of the most important and most pervasive as seen as in the media and society as well as in the results of a variety of NOS assessments conducted by various researchers across the globe. In 1961, Klopfer and Cooley developed and administered the TOUS to high school students in the US and found their understanding of science and scientists to be entirely deficient (Lederman, 2007). Mackay administered the TOUS to high school students in Australia and found they lacked understanding of many of the aspects of science discussed above (1971).

These are only a few of the many studies showing that students consistently demonstrate naïve beliefs in all of the areas discussed in the preceding paragraphs in this section (Abd-El-Khalick, 2006; Lederman, 1992; Lederman, 2007). A scientifically literate citizenry must understand the nature of science and scientific knowledge. In order to improve misconceptions educators must aim the kind reform that can deepen NOS understanding. McComas sounds the battle cry for reform saying, “NOS should be a central instructional purpose rather than an optional prelude (McComas, 2004).

Assessing NOS

While science literacy, including the nature of science, has been an important objective of science education for over a century, it was only in the last few decades that measurements to assess science literacy and understanding were really developed and utilized. This period saw the emergence of new nature of science assessments. In 1957, Mead and Metraux developed a short essay test with one question called, “Image of the Scientist” (Bell, 2008). Within a few years, in 1961, Cooley and Klopfer published the Test on Understanding Science (TOUS) that consisted of 60 multiple-choice questions (Karakas, 2007; Lederman, 2007). The TOUS became popular and widely used. Using the TOUS, Klopfer and Cooley found that students did not have adequate views of science as an enterprise (Karakas, 2007; Lederman, 2007). Others did similar research including Mackay (1971), Korth (1969), Broadhurst (1970), and Aikenhead (1972, 1973). As did Cooley and Klopfer, they also concluded that

students had insufficient comprehension of the nature of science (Lederman, 2007).

As shown above, research found that students lacked proficiency in science and the volume of research relative to the topic increased (NSTA, 1962; cited in Lederman, 2007). Other nature of science assessments continued to come forth including the Nature of Science Scale (NOSS) by Kimball (1968), Nature of Scientific Knowledge Scale (NSKS) by Rubba and Anderson, and Chambers' Draw-A-Scientist Test in 1983. In 1987, Aikenhead, Flemming, and Ryan published the Views on Science-Technology-Society (VOSTS), which contains 113 multiple-choice research-based questions (Bell, 2008).

In the 1990's Lederman and others began developing the Views of Nature of Science tests. Between 1990 and 2004, he and his team published five versions of their short answer questionnaire, intended to assess understanding of a variety of NOS concepts in students from elementary to college (Bell, 2008). In 2008 Wenning published the Scientific Inquiry Literacy Test (ScInqLiT) and the Nature of Science Literacy Test (NOSLiT), each with 35 multiple-choice test questions (Wenning, 2008). While there are few exceptions, these tests continue to document shortcomings in science education (Abd-El-Khalick, 2006; Lederman, 1992, 2007).

As research on student NOS conceptions accumulated, students continued to demonstrate an insufficient understanding of the nature of science in the United States as well as in other countries including Australia (MacKay, 1971), Malaysia (Guch, 2003), and South Korea (Kang, et al., 2004). Research has established

over the past few decades and across the globe, that science education is not adequately preparing scientifically literate individuals with an appropriate understanding of the nature of science. Efforts began in the sixties are continuing in order to determine the variables associated with this deficiency and to find ways science education can improve its portrayal and representation of this thing called science (Abd-El-Khalick & Lederman, 2002; Chalmers, 1976 & 1999; Fishwald, 2005; Karakas, 2007; Lederman, 2007; Rudge & Howe, 2004; Shymansky et al., 1983; Wick & Yager, 1966).

Several NOS assessments were considered at the inception of this project (see above). A summative assessment that would show changes in student understanding of the nature of science was sought. The Views of the NOS questionnaire, form C (VNOS-C) developed by Lederman and others was chosen (Lederman et al., 2002). The VNOS-C contains 10 open-ended questions that probe student understanding of the nature of science (see Appendix C).

Each question focuses on an aspect of how science works that is often misunderstood. The test directly asks about the process of science, as well as posing questions about science content by addressing specific cases in science that will allow the assessor to gain insight into student thinking. For example, question nine states:

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? (Lederman et al., 2002)

This question brings up two different theories that explain extinction of dinosaurs to elicit responses about how scientists can look at two one set of data and come up with different explanations. This question addresses the role of creativity as well in science as well as the roles of personal bias and culture. It also gives students an opportunity to comment on the tentative nature of science (see appendix C)

Bell describes the strengths and weaknesses of the VNOS-C (Bell, 2008). The VNOS-C contains open-ended questions that probe for science understanding indirectly which means students cannot guess at the answer, a problem with multiple-choice tests. Multiple-choice and true/false tests are informative and easy to grade, however, open-ended questions allow a more complete view of what students are thinking. They definitely have drawbacks, however. Students may struggle to communicate in writing particularly if they are poor writers or readers. Another issue that may play a role in the effectiveness of the VNOS-C is that students may not answer completely due because they are lazy or unmotivated (Bell, 2008). Ultimately, student responses from the VNOS-C

provide a nice picture of what students actually understand. For this reason, the VNOS-C was the best measurement instrument for this study.

Chapter 3 Methods

Introduction

The purpose of this study was to test the effect of incorporating activities with NOS themes on student understanding of key NOS concepts in a high school anatomy and physiology course. Additionally, the author aimed to see if discussion of those themes following the activities results in an even greater increase in student understanding of key NOS concepts. This study addressed the following questions:

- 1) What is the understanding of NOS among high school students in an anatomy and physiology class?
- 2) Does explicit instruction make a difference in student understanding of NOS?

Design

This was quasi-experimental study using the author's introductory high school anatomy classes, using both qualitative and quantitative data. Two classes participated in this pretest, intervention, posttest study. The duration of the intervention was 180 days. It consisted of 19 activities intended to expose, or let students realize, key NOS themes. See table 2 for a list of activities. Students participated in about two activities per month. One class participated in the activities only. The second class received the first intervention, NOS related activities. Following the activities, this class also participated in explicit discussion of the targeted NOS concepts. The assessment (posttest and pretest) administered was Lederman's Views of Nature of Science-Form C (VNOS-C).

The type of instruction (NOS activities or NOS activities with discussion) was the independent variable and the dependant variable was student knowledge on the VNOS-C.

Study Population.

This study took place at a suburban high school in the Southwest. Students participating in the study were juniors and seniors enrolled in the author's yearlong anatomy and physiology course for the 2008-2009 school year.

For most students, Anatomy and Physiology is an elective they take because of an interest in science or medicine. Nearly all students had completed at least 2 years of high school science including a year of biology and a year of chemistry, the prerequisites for the course. Many had just completed chemistry taught in a very traditional, textbook-based manor. A portion of the students had completed or were concurrently enrolled in physics. Physics at this school is taught using an inquiry, model-based approach, as all of the physics teachers are active in the physics modeling curriculum.

Of the 41 students who completed the study, 29 were female and 12 were male. See Chapter 4 for more on the study population. The activities only group (n=20), had 15 females and 5 males. The activities plus discussion group (n=21), was composed of 14 females and 7 males who completed the study. Of those who completed the study, there was one Egyptian male, an African-American female, and the rest of the students were Caucasian. See table 2 for a summary of student demographics.

Table 2

Demographics

	n	Gender		Ethnicity	
		Males	Females	Caucasian	Other
Activities only (5th hr)	20	5	15	19	1
Activities plus discussion (6th hr)	21	7	14	19	2

Activities Only Group. The author’s 5th hour anatomy class participated in the activities without explicit discussion. The class took a systems approach to studying anatomy. Over the course of the school year, activities were embedded into the curriculum (see Table 3) intended to expose the students to key nature of science concepts either through studying the history of science, looking at science today in the context of the progression of modern medicine, or by following an inquiry or discovery process. The activities were not followed by verbally directing attention to the aspects of science students might come across during the activity such as creativity, tentativeness, and the social aspect of science.

Activities Plus Discussion Group. The activities plus discussion group consisted of the author’s 6th hour anatomy class. Both groups participated in the same activities described in Table 1. The activities plus discussion group, however, participated in explicit teacher initiated discussion of NOS themes following the 19 activities. Discussions usually lasted between 10 and 25 minutes. Discussions were based on questions intended to help students address and clarify common “myths of science” (See Table 5).

Data Collection

At the beginning of the year, students in both the author's high school anatomy classes took the VNOS-C (Lederman et al., 2002). This survey measures student understanding of key nature of science concepts. The survey is designed to be a written response first, with an interview following significant areas. In this study, the written response was adequate and did not necessitate an interview.

Students completed the survey in class and as homework. They were instructed to complete the survey alone, without using any resources such as a textbook or the internet. The author informed students that the intent of the survey was to help the instructor understand how they perceived science and would not be counted toward their grade. However, they should do their best and be as thorough as possible in their answers.

The author implemented activities as a fundamental part of the anatomy curriculum throughout the school year. The intent of the activities was to expose key nature of science concepts while teaching the associated content. The activities involved the history of science, past and modern medical science, and/or a discovery process. See Table 2 for a list of activities and brief descriptions. Table 3 identifies key NOS concepts addressed or exposed in each activity.

Table 3

Activities

Activity	Description
Cell Membrane Activity	History of science activity created by C. Johnson and Julie Luft (2001); students use evidences to generate 3 models that led to the current understanding of the Fluid Mosaic Model of the cell membrane to create their own changing models
Explorations Papers and Projects (9 total)	Students research topics relevant to each unit, then discuss their findings with classmates; topics include: pharmaceutical drugs, stem cells, cancer, and disorders (integumentary, bone and joint, muscular, cardiovascular and respiratory, digestive and urinary, and reproductive system disorders)
NIH Unit: Cell Biology and Cancer	Five E Unit created by the National institute of Health to teach cell function in the context of understanding cancer
Dissections (5 total)	Chicken Wing, Cow Femur, Cow Eye, Sheep Brain, and Cow Heart Dissections
Sliding filament Theory Activity	History of science activity similar in structure to the Cell Membrane Activity, wherein students are given evidence various researchers used, and asked to create, then modify their own models; created by the author
NIH Unit: The Brain: Understanding Neurobiology through the Study of Addiction	Five E Unit created by the National institute of Health that teaches the brain and neurotransmission then shows the specific effect of certain drugs on the nervous system

Table 4

NOS Concepts Addressed by Activity

Activity	NOS Concepts ^a				
	Tentative	Empirical	Subjective	Creative	Social & Cultural
Cell Membrane Activity	•	•	•	•	
Explorations Papers and Projects	•	•	•	•	•
NIH Unit: Cell Biology and Cancer	•	•	•	•	•
Dissections		•	•	•	
Sliding filament Theory Activity	•	•	•	•	
NIH Unit: The Brain and Dugs		•	•		•

^aLederman, et. Al (2002)

Two of the activities used, the Cell Membrane Activity and The Sliding Filament Theory Activity, incorporated NOS concepts by using historical examples of people doing science. In both cases, students were given background information about the scientist(s) as well as information on their goals and work. The students were also given pieces of evidence similar to those the scientist(s) had to work with. They used the evidence to develop a working model of either the cell membrane or the unit of muscle contraction (the sarcomere). Students repeated this process of giving evidence and creating working models until the most recent model was attained.

For example, the Sliding Filament Theory activity involved giving students some historical background surrounding the early development of the sliding filament theory. The teacher and students discussed the information scientists would have had prior to the invention of the microscope, such as; scientists knew that the muscle shortened and lengthened and that it had striations. In small groups or pairs, the students then drew a model for muscle contraction based on the evidence available at that point in history. The class then came together and students shared their ideas. The class evaluated the theories, acknowledging strengths and weakness of each to determine the viability of the proposed models.

The class repeated this process of looking historical background and evidence, coming up with models based on the evidence, and discussing and evaluating the models. Societal conditions and technology advances involved were touched were briefly discussed during the presentation of evidence to give the students context and background. The instructor told students about scientists who played major roles. Ultimately, the students' final models led into a discussion of the modern view sliding filament theory. This activity was modeled after an activity created by Johnson and Luft (2001) that was used in the study.

Another type of activity, called "Explorations," was a part of each unit. This involved research on a particular topic, generally a disease, and included looking at progression of medicine in the context of that disease. Each student or group of students would pick from a list of topics. Students had about two weeks to do the research, outside of school for the most part. The research included a

description of the disease, treatments, prognosis, statistics, as well as a personal reflection. In the case of the “Stem Cell Exploration,” the assignment had students report about the history and development of stem cell research or to focus on current issues surrounding stem cell research such as ethical concerns and political guidelines.

Near the end of each unit, one class period was designated as “Circle of Love” day. Student arranged their desks in a circle to discuss the diseases or other topics. Students voluntarily shared information they had learned about their chosen topic. Often ideas about creative, new treatments would come up. Students often brought up changes in understanding of a disease or body function and certainly changes in treatment. Student often pointed out society’s influence on science. These Exploration activities with the accompanying day for discussion provided opportunity for students to realize and discuss ideas about science in the context of changing medical science.

In the activities only group, the instructor would discuss NOS ideas if the students themselves brought them up. Generally, when students brought up NOS concepts in these discussions, the instructor tried to keep the discussion student led. For example, if a student made a comment about the creative, tentative, or the social aspect of science, the instructor would let other students comment rather than using her own questions or comments to guide the discussion.

In the activities plus discussion group, however, the instructor deliberately interjected NOS questions into the discussion or after the discussion. Some of the topics throughout the year included a report of a specific medicinal drug and it’s

discovery, uses, side effects, and so on; stem cells and the surrounding controversies; and diseases from bone disorders to cancer and reproductive disorders. Questions about the tentative, creative, empirical, subjective, social, and cultural aspects of science fit naturally into these discussions.

Students also participated in five discovery or observation activities such as dissections. During all of the dissections, the teacher instructed students to describe, draw, and/or classify what they saw. Two of the five activities included written NOS questions for both groups. Only the activities plus discussion group participated in discussion of NOS concepts following these activities.

The instructor intended not to initiate NOS discussion with the activities only group. However, if students in this group asked questions or brought up NOS topics, the class discussed their questions or comments mostly in a student led format. Occasionally the instructor would correct or redirect comments made by the students. In the activities plus discussion group, the activities were followed by discussion that centered on questions such as, “How is this like science?” The instructor would pose questions to help students draw connections between the activities they had just participated in and science as a discipline. See Table 5 for questions used in follow-up class discussion.

The purpose of the questions was to address commonly held misconceptions of science. NOS myths addressed include: there is a universal scientific method, science results in sure knowledge or proof, science is not subject to change, there is no room for creativity in science, science is universal and unaffected by bias, and science is objective (McComas, 1996; Lederman,

1992). The questions in table 5 were used to engage students in NOS discussion that would facilitate addressing these myths.

Table 5

Sample Questions for NOS Discussion

Question	NOS Concepts ^a				
	Tentative	Empirical	Subjective	Creative	Social & Cultural
What does this activity show us about how science works?	•	•	•	•	•
How does this activity resemble science?	•	•	•	•	•
What skills did you use to complete the activity?		•		•	•
What skills are important for scientists to draw upon?		•		•	•
Do scientific theories change? Explain.	•				
If science changes why do we take time to learn its' theories?	•		•		
What factors influence science?	•	•	•	•	•

^aLederman, et. Al (2002)

Measures

Students took the VNOS-C (Lederman et al., 2002). The pretest was administered in the beginning of the school year in August and the post-test was

given the last week of school in May (see Appendix A). Students began both tests in class and completed the test as homework. The instructor informed them that the assignment would not be part of their grade. Students were instructed to do the test on their own, using as much detail and as many examples as possible to answer the questions.

Two questions, number 5 and number 7, were not used in this study. Question number 5 asked about the relationship between laws and theories, a topic not directly addressed in this treatment. For the purposes of this study, the ideas probed for in question number 7 were adequately addressed in the remaining questions. Question 2 asks, “What is an experiment?” Question 3 asks, “Does the development of scientific knowledge require experiments” (Lederman et al., 2002). Often student responses to question 2 were clarified by their answers to question 3. The author combined question numbers 2 and 3 for grading purposes because of their similarities.

The author chose the VNOS-C for several reasons. By writing in their own words, students must demonstrate their understanding without the possibility to correctly guess as in true and false or multiple choice tests. The open-ended questions give insight into their thought process (Bell, 2008). These students are juniors and seniors whose primary language is English. They tend to have good writing skills, which minimized the frustration associated with this potential barrier.

A problem with the VNOS is that answers may not adequately reflect true student understanding due to motivation or time issues (Bell, 2008). As students

handed in their questionnaires, the author briefly scanned surveys for complete answers and asked many students to add detail or examples if answers to several questions were obviously deficient.

Data Analysis

To analyze student responses on the VNOS-C, the author used a rubric (see Appendix B) adapted from Brown (2003). The rubric, intended to assess NOS views held by science teachers, was adapted to evaluate student views. The rubric has three main categories: product, process, and situated. A one to six scale was added to the rubric for scoring. A “product” answer scored a one or two, while an answer that demonstrated a more accurate concept of science, or “situated” view was rated five or six. Lederman describes a product response as a “naive” response. He describes a situated response as an “informed” response (2002). The middle scores of three or four, represent a process view of science. This view of science is more aligned with doing science, but not focused on situated qualities. Each question was rated 1-6. Questions 2 and 3 received one score between the two questions because of their connectedness.

A third party covered student identities and shuffled tests from both the activities only and activities plus discussion groups into one group for anonymity in grading. Each test was then assigned a reference number for identification. The author was the grader and did not have knowledge of the student’s identity nor did the author know which group the student belonged. Tests were scored within a month after school ended. The delay helped decrease the chance of

identifying students by their handwriting. Scores for each question on both the pretests and the posttests were analyzed statistically.

This study sought to address two questions. First, what is the understanding of NOS among high school students in an anatomy and physiology class? Second, is there a significant difference between the groups with or without NOS discussion? An ANOVA was conducted to determine differences between pretest and posttest scores as well as between test groups, with a .05 level of significance set. The first factor was 5th period, activities only, versus 6th period, activities plus discussion. The second factor was pretest and posttest scores. This analysis included all 41 students.

Summary

Two high school Anatomy and Physiology classes participated in this study for the duration of one school year to test an intervention to improve understanding of NOS. One class received activities intended to demonstrate key NOS concepts. The other class participated in the same activities with the addition of explicit discussion of related NOS themes following each activity, aimed to dispel common misconceptions of science. Students took the VNOS-C as a pretest and posttest to measure student understanding of how science works.

Findings

Introduction

While efforts were made to maintain a consistent study population, the study was affected by attrition. To begin with, the activities only group, 5th hour, started the school year with 27 students and the activities plus discussion group began the study with 25. Two students dropped anatomy during fall semester. Also, at the beginning of spring semester there were several student schedule changes that necessitated them being dropped from the study.

Two students had schedule changes at the semester that moved them to another teacher. Three had schedule changes that moved them to another experimental treatment group. Two students moved from 6th hour to 5th hour, and one student moved from 5th to 6th hour. These three were dropped from the study. Additionally three students had schedule changes that transferred them into the author's classes from another teacher. Two of the three coming from another class were added to 5th hour, while one was added to 6th hour. However, because the study was halfway through, they were not added to the study.

Six students, four from 5th hour and two from 6th hour, did not complete or turn in any or a sufficient portion of either the pretest or posttest to be included in the data. Overall 5th hour started with 27 students, but six ended up being dropped from the study, and 21 were included in the this study. Sixth hour began the year with 25 students and ended up with 20 completing the study.

Study Question 1

The first study question was what is the understanding of NOS among high school students in an anatomy and physiology class? For this question, scores from fifth period and sixth period pretests were analyzed. Table 6 reports the means and standard deviations for period 5 and period 6. At the beginning of the school year, the students took the VNOS-C. Tests were scored using a one to six scale. The activities only class scored an average of 2.14 out of 6 points per question. The activities plus discussion group scored an average of 1.92 out of 6 points per question. A score of 1 to 2 points on this scale was considered a “naive” response.

The pretests from both classes were compared to see if there was a significant difference between the two classes. SPSS was used to conduct the analysis and a significance level of .05 was used. An analysis showed that the difference between groups was not statistically significant, $t(19) = .88$, $p = .39$. This means the groups were similar at the start of this study.

Table 6

VNOS-C Mean Scores

	n	Pretest		Posttest	
		M	SD	M	SD
Activities only (5 th hr)	20	2.14	0.45	2.83	0.42
Activities plus discussion (6 th hr)	21	1.92	0.69	2.93	0.60
All participants (5 th and 6 th hours)	41	2.07	0.58	2.88	0.52

In order to better understand student understanding of NOS, a second analysis was conducted. Table 7 presents the average pretest and posttest scores by question number. It also shows the differences or gains in NOS understanding over the course of the school year. There were 10 questions. Questions 2 and 3 were combined because of their similarity for the purposes of this study. Questions 5 and 7 were omitted. Questions were scored on a 1 to 6 scale. Naïve beliefs scored a one or two, while informed beliefs scored a five or six. All questions showed improvement between pretest and posttest scores. Question 2 and 3 combined showed the greatest improvement.

Table 7

VNOS Average Scores by Question

	5th hr		6th hr		Average	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Question 1	1.58	1.98	1.20	2.31	1.39	2.15
Question 2/3	2.11	2.80	1.45	2.79	1.78	2.80
Question 4	2.08	2.68	1.86	2.76	1.97	2.72
Question 6	2.21	2.83	2.10	2.62	2.16	2.73
Question 8	2.60	3.53	2.61	3.40	2.61	3.47
Question 9	1.90	2.65	2.06	2.79	1.98	2.72
Question 10	2.53	3.40	2.71	3.76	2.62	3.58

This section is intended to illustrate the kinds of views students typically exhibited for the different questions in the VNOS. Most students had low understanding of all NOS concepts assessed. On a scale of 1-6, one being naïve and six being informed, the highest scoring question on the pretest averaged 2.71 (question 10) and the lowest scoring question scored an average of 1.38 (question 1). The highest average score on the posttest was 3.76 (question 10) and the lowest average score was 1.98 (question 1). Individual student scores can be found in Appendix C. From pretest to posttest, each question showed improvement.

Question 1 asked, “What, in your view, is science? What makes science different from other disciplines of inquiry (e.g., religion, philosophy)?” The responses to this question often used the word “prove.” One student said, “Science is made of ideas and facts that can be physically proven.” Another student replied, “...Things in science can be proven, they can be proven beyond a shadow of a doubt. With religion, not that I don’t believe in it, it’s more of a belief and it can’t be proven 100%.” In responses to this question, students often contradicted themselves. While students did express slightly more informed views of science in the posttest; they continued to say science is trying to prove something.

“Experiments help prove theories correct.” This statement, in a response to question 2, illustrates the ideas of several students indicating that in their view the objective of science is to “prove” theories correct. Because of their similarity, questions 2 and 3 were combined for the purposes of this study. Scores on these

questions showed the greatest gains with the average including both classes improving by 1.02 on the 1 to 6 scale. These questions asked students to define or explain an experiment and then to discuss the role or importance of experimentation on gaining scientific knowledge. Naïve beliefs expressed in the pretest in response to these questions are quoted below.

“An experiment is a test. A test to prove something right or wrong.” This statement in response to question 2 scored a one, on a scale of 1 to 6 using a NOS Rubric (See appendix B). This student continued answering question 3 saying, “no, (the development of scientific knowledge does not require experiments) knowledge can progress without experiments. It can progress from something as simple as an idea. But then, in the end that idea has to be experimented. So I guess it could go both ways, yes and no.” This student began to express a more informed belief but was unable to support it and digressed back to a naïve belief.

Another student also expressed naïve belief in response to questions 2 and 3 as she explained an experiment within the structure of a scientific method. “First having a question about something, making a hypothesis on how you think it works because of research you have done then testing to see if you are correct or incorrect.” With regard to experiments being necessary for science, she responded, “Yes, (experiments are necessary) you cannot make assumptions just based on observations or guesses.” This demonstrates a naïve and limited view of ways scientific knowledge can be obtained as the student seems tied to the idea of a “scientific method”.

Question 4 intends to probe students' understanding of the importance of human interpretation and creativity in science as well as the role of models in science by asking how scientists know what an atom looks like and how certain they are of the structure. Responses to this question were interesting and exposed several misconceptions. One student said, "We can see an atom by looking into a cell with a microscope."

Another student missed the tentative and human aspects of science, and demonstrated a major misunderstanding of models in science saying, "Scientists are very certain because if they weren't they wouldn't allow teachers to teach kids the atom structure if they knew it was incorrect." As a teacher, this response was a little startling and the author saw this idea again in the posttest. Another student had a similar view; however, they touched on the idea of accepting new theories. "Scientists are probably fairly certain of this structure or it wouldn't have been as widely accepted." This response scored a three while the previous response scored a one.

Question 5 was omitted from the study. Question 6 says, "After scientists have developed a theory (e.g., atomic theory, evolution theory), does the theory ever change?" (Lederman et al., 2002). This question had a variety of responses demonstrating a range of NOS understanding. Some students believed that theories never change. "When we talk about theories in class and the experiment, it always turns out to be true." As science educators, we have really misrepresented science if our upper classmen think theories never change because in class experiments always work out.

However, many students recognized the tentative nature of science. “Theories change because of our new way of life.” One student touched on the idea that not all knowledge comes from new discoveries saying theories could change because, “the scientist could remember something.” Several students said “The theories change because the universe changes.” While recognizing that theories change, the reasons students gave are questionable. This response was somewhat comical and scored high on the 1-6 scale: “Scientific theories change because if it is wrong it would be stupid not to change them.”

The purpose of question 8 on the VNOS-C questionnaire is to see if students appreciate or understand the creative aspect of science. On the pretest, students scored highest on this question and on question 10, dealing with social and cultural influence on science. Student responses to these questions, both exhibited significant gains; posttest scores were also the highest on these two questions. Many students recognized that science can be creative, but did not realize the extent to which creativity can be involved in the process of science.

On the pretest, one student said, “I don’t think that scientist would just go into a lab and with their imagination create an experiment. They probably need to create some parts of the planning process but they don’t just make things up.” The author scored this as a naïve response, lacking acknowledgment of the creative process and its importance throughout the process of science. This next quote, from a posttest, shows a better conception of imagination in science, but still misses the idea that it can also be involved in data collection and interpretation. “I do think scientists use creativity and imagination but to an

extent. They can't just come up with a random idea to put in an experiment. I think they base it off what is already known, then from there they use imagination to come up with a possible hypothesis. I think they use it during the planning and design stage.”

Questions 9 asks students how it is possible for scientists to arrive at different conclusions while looking at the same data. This question often elicits a response that describes how both explanations could be true, but neglects to address the role of individual background, perspective, experience, etc of the scientist. A few students began to recognize the role of the scientist as an individual. For example, one student replied, “These conclusions are different because of the evidence left behind, they may have used the same data but everyone's thoughts are different.” This one rated a three on the scale of 1 to 6 because the student begins to take into account individuality of the scientist, but the idea is only emerging and not developed.

The last question, question 10 states:

Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumption, 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.” (Lederman et al., 2002).

As with question 8, students as a whole scored relatively higher on question 10. Still misconceptions were pervasive. This response exemplified a naïve concept of this aspect of science: “I believe science is universal. Scientists in many different countries with different cultures share similar scientific beliefs. Science must be proven to be universally accepted, so scientists do not incorporate religion or any other cultural things in their data and scientific beliefs.” Another student disagreed saying, “Science does reflect society. It is only the brave scientist that go against society. All the others will say what society wants to hear so they can gain prestige.” This response rated a five, as the student recognizes the cultural and political context in which science is conducted and shows evidence that the theories with the most support are more accepted but not always the best theories.

In response to question 10 on the posttest one student said, “I believe science reflects social and cultural values, because of discussions in the classroom this year, a lot of political and religion and social events were brought up. Also, everyone had their own opinion to different situations. In the classroom everything that dealt with social and cultural values were brought up.” This student recognized science as a social endeavor because of the focus in class, however, this student does not articulate her thoughts in way that shows her understanding extends the class discussion to a concept of what science really is. (This student was in the activities plus discussion group.)

Study Question 2

The second study question asked does explicit instruction make a difference in student understanding of NOS? In this analysis, a Paired Sample t-test was conducted to assess the differences between the pretests and posttests for fifth period and sixth period groups. The first factor was between groups variable (5th verses 6th period), and the second factor is the with-in subjects factor (pretest verses posttest). All 41 subjects were included in the analysis. Table 8 reports these scores. Both comparisons are significant at the .05 level. Both classes demonstrated a significant improvement in their perception of the NOS concepts.

Table 8

Matched Sample t-test			
	t	df	Sig. (2-tailed)
Pair 1 Pre 5th - Post 5th	-6.17	19	0.00
Pair 2 Pre 6th - Post 6th	-5.59	20	0.00

Based on the analyzed data, the activities only group as well as the activities plus discussion group improved NOS understanding (n=20). Student views on NOS as a whole, (n=41) as measured by the VNOS-C and analyzed statistically, showed significant gains. On the six point scale, the average increase for all participants was 0.81.

SPSS was used to conduct a repeated-measures mixed factorial. The results are shown in table 9 below. From pretest to post-test there was a significant improvement in NOS scores, however no interaction was found.

There was not a significant difference between the improvement demonstrated by the activities only group and the improvement shown by the activities plus discussion group. The group that did not participate in explicit discussion improved and so group that did participate in explicit discussion. The improvement, however, may not be attributed to teaching method.

Table 9

Summary of ANOVA

Source	Time	Sum of Squares	df	Mean Square	F	Significance
Time	Linear	14.68	1.00	14.68	61.30	0.00
Time * instruction	Linear	0.48	1.00	0.48	2.02	0.16
Error (time)	Linear	9.34	1.00	0.24		

$p < 0.01$

Summary

High school anatomy students demonstrated naïve beliefs about NOS on the VNOS-C. As a group, students who participated in NOS related activities showed statistically significant gains in NOS understanding over the course of the school year regardless of whether or not their class participated in explicit discussion of key NOS concepts in conjunction with the activities. There was no statistically significant difference between classes in their improvement. Both classes improved.

Discussion

Question 1

Question 1 was what is the understanding of NOS among high school students in an anatomy and physiology class? This study found that students in both classes began the school year with a limited or naïve understanding of NOS. These findings were consistent with findings across age groups and throughout science content areas. From elementary to in-service science teachers, misconceptions are widespread. Nowhere in the research was there a study found using high school anatomy students. This study provides evidence to include them in the masses of people that do not sufficiently understand NOS.

Students had some understanding of NOS. The questions they scored the lowest on dealt with defining science and understanding the role of experiments in science. Students scored the highest on the questions about the role of creativity in science as well as the social and cultural context in which science operates. By the end of the year students held more product views of NOS in all areas assessed, particularly their ability to articulate the role of experiments in science and the human context of science.

Research has shown that misconceptions surrounding NOS are pervasive. People of all ages, in a variety of countries, and over the several decades demonstrate NOS misconceptions. These myths, as McComas (1996) describes them, are held by young schoolchildren, by middle and high school children (Karakas, 2007; Klopfer and Cooley, 1961), as well as by their teachers and other

adults (Abd-El-Khalick, 2006; Lederman, 1992; Lederman, 2007). These misconceptions span the globe (Guch, 2003; Kang, et al., 2004; MacKay, 1971).

Improving NOS conceptualization is vitally important in producing a scientifically literate population with: the ability to make informed decisions, the ability to recognize and solve problems in their own lives, and the ability to communicate science concepts and terms appropriately. As Driver (1996) explains, learning the nature of science reaps utilitarian, democratic, cultural, moral, and science learning benefits (1996). Science educators must meet the demand for increased literacy.

Question 2

How does student understanding of NOS change as students are engaged in NOS activities that are accompanied by explicit NOS discussion or without explicit NOS discussion? As many studies have shown, this study supports the idea that there are strategies and practices educators can implement that may improve student views of NOS, aligning them more closely with an accurate view of science as an enterprise. However, due to the lack of a control group, this study is unable to state that student NOS gains were a result of the study interventions. They could have been simply a result of time or other factors. Over the course of the year a variety of activities were implemented into the existing curriculum, some were new to the course others were modified to focus more on the history of science and NOS, and some activities were left the same.

This study is consistent with other studies that show implementing activities that incorporate science history can improve NOS views (Rudge & Howe, 2009; Yager & Wick, 1996). With regard to including the history of science, Allchin warns that the cases from history must be carefully selected. “Contrary to recent claims for reform, we do not need more history in science education. Rather, we need different types of history that convey the nature of science more effectively” (Allchin, 2002).

As students are exposed to carefully selected and carefully presented cases of real scientists doing their work, not just isolated anomalies like those typically found in science curricula, they begin to realize that scientists must use their imagination and creativity. They also see and even experience the way science changes and can begin to appreciate the tentative nature of science. They see the volume of evidence backing theories, they can begin to realize the relationship between hypotheses and theories, and they can appreciate the need for theories to be adjusted or even thrown out on occasion. Students start to see the impact of politics and society on science as they have experiences that expose them to things such as debate concerning ethical issues associated with improved science.

In addition to incorporating cases from science history, curriculum designed to emphasize the process of science has been tested and shown to have positive effects on improving student views of NOS (Aikenhead in 1979; Klopfer & Cooley, 1963; Lederman, 1992). As students work through situations where they have to use their creativity, imagination, and previous knowledge to work together to come up with possible solutions they experience science that is more

authentic. They gain a more accurate view of the process scientists go through and thus can internalize a more accurate view of how science works.

This study appears to be inconsistent with studies that profess that in order to improve NOS understanding, activities need to be accompanied by explicit discussion. However, again due to the lack of a control group and the sample size this study lacks the power to claim explicit discussion is not needed to improve NOS understanding. Several studies claim that explicit discussion must accompany interventions in order to improve NOS understanding (Lederman, 1999; Schwartz et al, 2002; Lederman et al, 2002; Schwartz & Lederman, 2004). This will be discussed more later in this chapter.

On a six point scale, the average increase for all participants was 0.81. Students in both classes demonstrated significant gains in NOS understanding. While this number is statistically significant, it seems small; however, it would be unrealistic to expect deeply held misconceptions to be rooted out in just a school year. More than one science class or one science teacher in a student's educational career is needed for students to recognize and improve misconceptions. It is clear, however, that there are strategies educators can employ to help students gain a more accurate view of the nature of science and overcome common NOS misconceptions.

Science education research over the past decade is replete with studies that have documented the crucial role of explicit discussion in driving home NOS concepts conveyed by a variety of lessons or activities. Rudge and Howe, for

example, conclude that an explicit and reflective approach is needed to deepen the effect of HOS activities on NOS understanding (2009).

Other studies done by Lederman and Schwartz conducted together and independently have supported the findings of other studies showing explicit discussion to be an essential aspect of effective NOS instruction for both high school students, college students, beginning science teachers (Lederman, 1999; Schwartz et al, 2002; Lederman et al, 2002; Schwartz & Lederman, 2004; Fishwald, 2005). Many more studies have documented the need for explicit discussion in improving NOS (Abd-El-Khalick & Lederman, 2000; Matkins, 2002; Moss, 1998; Zeidler & Nichols, 2002).

The results of this study are consistent with the research that demonstrates that students who participate in NOS related activities that incorporate the history of science and inquiry activities show an increase NOS understanding (Klopfer & Cooley, 1963; Lederman, 1992; Rudge & Howe, 2009). The results of this research are inconclusive due to a lack of power. However, they appear to be inconsistent with research showing that when paired with explicit discussion, NOS gains are greater or that in order to be effective an intervention program must include explicit NOS discussion (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Zeidler & Nichols, 2002). These studies delineated effective ways to improve NOS instruction and student understanding. Research has shown that effective methods included history of science and nature of science related activities and explicit discussion of the nature of science. This study does not

necessarily support the necessity of including explicit discussion in programs intended to improve NOS understanding.

In light of current research, it was surprising to see that upon statistical analysis of the data, results of this study are may not be consistent with the research noted above. However, results of this study indicate that perhaps students in upper level high school courses can make the connections between NOS activities and how science works, without explicit discussion. They may be able to make the connections by simply participating in NOS related activities. Perhaps it was the types of activities. More research may need to be conducted and claims that explicit discussion is vital to NOS improvement, may not be extended to all science learners across all science curricula.

However, upon reviewing the literature prior to the 1980's, there are studies that document gains in student NOS conceptualization without discussing emphasis on explicit discussion (Aikenhead, 1979; Crumb, 1965; Klopfer & Cooley, 1963; Kuhn, 1970; Yager & Wick, 1966). A closer look at these studies may provide insight into methods for improving NOS and help us understand the role of explicit discussion. Perhaps more could be gained from examining these older studies.

When the explicit presentation of NOS concepts is presented it seems to help students acquire understanding within the context of the specific activity and transfer that knowledge, extending it to science as an entity, an entity that focuses on certain lines of inquiry and maintains certain values, assumptions and traits. Acquisition and transfer of concepts are cognitive developmental levels. The

research of Lawson and others supports the hypothesis that, “that procedural knowledge skills associated with levels of intellectual development play an important role in declarative knowledge acquisition and in concept construction” (2000).

His research supports the claim that cognitive ability continues to mature as students get older and have more experiences. Perhaps then, as students mature cognitively, their ability process new information and to transfer or apply that information to and within other contexts is increased. Thus, the results of this study support the idea that given the appropriate setting, mature students, even in high school, can make connections between material learned and experienced and NOS.

Psychology has documented that cognitive ability continues to mature (Hales, 2008; Potter, 2008). Perhaps this combined with the context influences NOS improvement. It is clear more research remains to be done to more accurately understand the factors that contribute to NOS understanding.

While in this study the results may not necessarily be attributed to the activities, there may be another possibility for further research. Perhaps a variety of activities that present or expose science from various perspectives may be helpful in presenting a more accurate and complete view of science to students. A varied approach may provide several settings in which students may need to reevaluate their views of science.

Summary

The findings of this study concur with current research supporting the hypothesis that incorporating activities that use the history of science and activities that intend to show science in a truer form into science curricula can improve science understanding. The results of this study, however, could possibly be inconsistent with previous research that claims NOS activities need an explicit tie to NOS for students to deepen the views of the NOS. Although, much research has been devoted to this topic, it seems there may be more to investigate in order to really understand what is going on in the minds of young people and in order to increase the ability of science educators to improve student understanding of the nature of science resulting a more scientifically literate society.

Limitations

There were a number of limitations to this study. The first, deals with the sample size and attrition. The administration assigned class schedules. The author only had three anatomy classes to work with. One of which only had 10 students and class met at 6:30am. This class was not included in the study, because of the many other factors that could affect study results such as class size, time of day, and the type of students taking early morning classes. In addition, due to scheduling conflicts and schedule changes, five students were dropped from the study, reducing the already small sample size. In addition to schedule changes, six students had to be dropped from the study because of incomplete assessments.

As upper classmen taking anatomy and physiology, the students in this study were generally science-minded or had a special interest in science. Many had plans to go into science related fields, such as medicine. They may work harder and have more focus than the average student thus this study may not represent the typical student. Therefore, results may not be representative of students in general.

Another possible limitation relates to the type of intervention. The activities implemented represent a variety of strategies intended to help students see science as it really is. Thus the results of this study will not identify one particular curriculum or activity to improve NOS views, however, it was able to show that activities of these types can improve NOS.

As both the teacher and researcher, I graded the VNOS-C and knowing the questions could have influenced students' choice of wording. For example, they possibly could have written something because they remembered key phrases from class, but didn't really internalize the concept. I am the researcher and teacher grading. As such, I tried to eliminate bias, but it is impossible to eliminate completely. Not knowing whether a test was a posttest or a pretest may have helped minimize that bias. The author scored the VNOS-C pretests and posttests. It would have been better to mix the pretests and posttests so that they were scored without knowledge of which test was being scored. However, the pretests were scored as a group then the posttests were later scored as a group.

Another limitation is that the pretests were completed at the beginning of the school year when students are fresh and eager to make a good impression.

Posttests, however, were completed at the end of the school year when the students are burnt out and may not have been giving their all. These time factors may have affected scores on the VNOS-C.

Lastly, many beginning teachers lack sufficient understanding of the nature of science (Matkins et al., 2002; Schwartz et al, 2002; Lederman, 2007). As a newer science teacher, I also have limited understanding of NOS concepts that would affect my ability to accurately guide class discussions and to score the students responses on the VNOS-C. I participated in a similar study for teachers and only demonstrated average understanding of NOS concepts. I often felt like I was learning along with the students. My personal NOS understanding certainly has improved with researching and writing this paper. This changing view may also have affected student scores.

If I were to do this research again I might would change the design of the experiment. I would consult with administration to see if it were possible to have more sections of anatomy for the duration of the study. More participant numbers as well as class sections would make results stronger. A control group would be set up to allow more conclusive claims about the effect of the intervention. One possible design might include separating the school year into segments. Throughout the year, the various sections would each have a turn or possibly two turns as either the control, the activities only, or the activities plus discussion group. There would be a rotating schedule. The research could also be improved by having the rubric checked for strength and accuracy. Also, the grading process

would need to be revised to include multiple graders and checks for accurate scoring.

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Appendices

Appendix A: Views of the Nature of Science Survey-Form C

Appendix B: Views of the Nature of Science Scoring Rubric

Appendix C: VNOS-C Pretest and Posttest scores

APPENDIX A

VIEWS OF THE NATURE OF SCIENCE SURVEY-FORM C

Views of the Nature of Science-Form C

Instructions

⊕ Please answer each of the following questions. Include relevant examples whenever possible. You can use the back of a page if you need more space.

⊕ **There are no “right” or “wrong” answers to the following questions.**

We are only interested in your opinion on a number of issues about science.

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. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence, or types of evidence, **do you think** scientists used to determine what an atom looks like?

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. After scientists have developed a scientific theory (e.g., atomic theory, evolution 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.

7. 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?

8. 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 that 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.

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 and how. Defend your answer with examples.
- If you believe that science is universal, explain why and how. Defend your answer with examples.

Item Description

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)?

Note: Parentheticals are not part of the questionnaire.

[This question aims to assess respondents' views regarding science as a discipline to address questions about the natural world, the role of science in providing explanations for natural phenomena, and the role that empirical evidence plays in science that separates science from other "ways of knowing." Responses to this question often reveal a common misconception regarding the use of the "Scientific Method" as an objective process by which the knowledge is discovered. Such a view is often presented as an explanation for how science differs from other disciplines of inquiry.]

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.

[Questions #2 and #3 are used in combination to assess respondents' views of investigative processes in science. Question #3 elicits responses regarding the existence of multiple methods of investigation (such as experimentation involving

controlled variables, correlational studies, and descriptive investigations) that do not all follow the traditional “Scientific Method” or set of pre-established logical steps requiring a testable hypothesis. Responses to Question #2 clarify respondents’ ideas of “experiment,” as often this term is defined differently. Question #3 is then interpreted in relation to the provided description of “experiment.” Question #3 also may elicit views of subjectivity and creativity in science.]

4. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence, or types of evidence, **do you think** scientists used to determine what an atom looks like?

[This question refers respondents to a concept from the physical sciences to assess their understandings of the role of human inference and creativity in developing scientific explanations and models based on available data, and the notion that scientific models are not copies of reality.]

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

[This question assesses respondents' views of the development of and relationship between scientific theories and laws. The common misconception of the existence of a hierarchical relationship is often revealed. This misconception is presented by the explanation of a progression from scientific theory to law with the accumulation of more and more evidence until the theory has been "proven true" at which time it becomes a law. Views regarding distinctions between observation and inference are also commonly elicited. Additional ideas are often expressed by respondents as they attempt to describe the differences between scientific theories and laws.]

6. After scientists have developed a scientific theory (e.g., atomic theory, evolution 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.

[This question assesses respondents' understanding of the tentative nature of scientific theories and reasons why science is tentative. Respondents often

attribute change solely to the accumulation of new observations or data and/or the development of new technologies, and they do not consider change that results from reinterpretation of existing data from a different perspective. Views of the theory-laden nature of scientific investigations, the notion that the prevailing theories of the time impact the direction, conduct, and interpretation of scientific investigations, are assessed through the explanation of the role of theories in science. Additionally, responses often indicate views of the role of subjectivity, creativity, inference, and the sociocultural embeddedness of the scientific endeavor, as well as the interdependent nature of these aspects.]

7. 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?

[This question refers respondents to a concept from the biological sciences to assess their understanding of the role of human inference, creativity, and subjectivity in science. Desired responses describe the idea that “species” is defined by scientists to explain observed and inferred relationships, and that definitions as well as concepts in science are created by scientists to be useful for their endeavors. Additionally, this question elicits responses concerning the role of models in science and that scientific models are not copies of reality.]

8. 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 that 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.

[This question assesses respondents' views of the role of human creativity and imagination in science, and the phases of scientific investigations at which respondents believe these aspects play a role. Often creativity is described relative to design only, and usually in regard to resourcefulness necessary to set up and conduct investigations (such as design of new trapping methods in the wild). Respondents are less likely to recognize the role of creativity in question development, data analysis, and interpretation. Ideas of "discovery" versus "created patterns" are elicited.]

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?

[This question assesses respondents' understandings of reasons for controversy in science when scientists use the same available data. Ideas of subjectivity, inference, creativity, social and cultural influences, and tentativeness are often elicited. The question aims to assess respondents' beliefs about what influences data interpretation including personal preferences and bias (personal subjectivity) to differing theoretical commitments and impacts of social and cultural values.]

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 and how. Defend your answer with examples.
- If you believe that science is universal, explain why and how. Defend your answer with examples.

[This question assesses respondents' views of the impact of social and cultural values and expectations on the scientific endeavor. Naïve views are often indicated by responses describing science as "value free" and stating that different cultures and belief systems do not impact the way science is conducted or the interpretation or use of scientific knowledge. Views of connections between sociocultural influences on science and subjectivity, creativity, inference, and tentativeness are often elicited.]

NOS aspects and descriptions that serve as a basis for evaluation of VNOS responses

Aspect	Description
Tentativeness	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge.
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world.
Subjectivity	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
Creativity	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.
Social/cultural embeddedness	Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
Observations and inferences	Science is based on both observations and inferences. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
Theories and laws	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.

APPENDIX B
VIEWS OF THE NATURE OF SCIENCE ADAPTED SCORING
RUBRIC

Adjusted NOS Rubric

	1 2	3 4	5 6
	PRODUCT	PROCESS	SITUATED
Philosophies 1	Positivism, Logical Positivism, Empiricism, Realism	Post-Positivism, Falsificationism, Sophisticated Falsificationism	Kuhn's Scientific Revolutions, Lakatos' Research Programmes, Constructionism, New Experimentalism, Instrumentalism
Epistemology 1,2,3	Knowledge is discovered through empirical methods (observation, etc.).	Knowledge is formed by testing theories in experiments, and replacing false or weak theories with stronger ones.	Knowledge is constructed within a societal framework and grows in structured wholes within paradigms. It relies on the empirical evidence in rigorous, repeatable experiments.
Scientific Method 1,2,3	Scientists follow a specific method which involves objective observation and experimentation.	Scientists do not follow a specific method, but rather a general method that can be cyclical. This method can also propose hypothesis that can be supported or refuted through experimentation.	There is no one scientific method. Different scientists use different methods to arrive at their findings, and methods are determined by the parameters of the field or paradigm. The role of evidence and explanation is focused on rather than the methodology.
Scientific Advancement 6	Science progresses linearly in an additive manner as more is learned through experimentation. Technology can be important in improving knowledge and drives this linear progression	Science is a dynamic process that changes as theories are modified, and new understandings lead to changes in the pursuit of knowledge. Knowledge can be replaced and can change. Technology can be important in our understanding of science and is a result of a need in science.	Scientific understandings can be aided or hindered with new evidence. This can lead to new theories replacing old theories, a reconceptualization of ideas, and/or knowledge changing. Technology is developed in response to the need in science, while science drives the need for new technology.

<p>Experimentation</p> <p>2,3,4</p>	<p>Experiments are experimental in nature and have specific qualities which can include: controls, variables, and multiple trials. Experiments are conducted to explain nature (make the unknown known) and yield the truth.</p>	<p>Experiments are conducted primarily to refute an existing explanation. During experimentation, induction is not viewed as a form of science, experiments are not instruments of knowing, and the goal of experiments is to reduce the known to the unknown.</p> <p>Can support or refute a theory/law but cannot prove it right or wrong. Experiments are necessary for scientific advancement.</p>	<p>Experiments are conducted in various ways (including non-empirical methods) depending on the paradigm, field of science, background knowledge, and the equipment/technology available, and involve curiosity, creativity and imagination.</p> <p>Experiments provide an empirical basis to develop scientific knowledge and lead to new questions for future research. Experiments are conducted in various ways (including non-empirical methods) depending on the paradigm, field of science, background knowledge, and equipment/technology available, and involve curiosity, creativity and imagination. Experiments are not necessary for scientific advancement.</p>
<p>Theories and Laws</p>	<p>Theories are derived from observations and help predict phenomena; laws are statements that combine observations to explain regularities without exception.</p>	<p>Theories are conjectures that lead to the growth of scientific knowledge as old ones get replaced by new ones. Laws are statements about phenomena provisionally accepted as true after surviving every attempt at falsification through experimentation.</p>	<p>Theories make predictions and help design experiments. They are influenced by the context of the scientist, and can influence the design of the experiment and the interpretation of the results. Laws characterize what is implicit in science, but are limited by the fallibility of the observer, and the assumptions inherent in the paradigm.</p>
<p>Science as a Socially Constructed Entity</p> <p>9,10</p>	<p>Since science discovers an objective meaning, and the scientific method is universal, then it is isolated from societal influence. Therefore, scientists from different cultures would arrive at the same conclusions, and would have gone through the same processes to get there. If different scientists disagree on the nature of phenomena, then further experimentation will point to a correct conclusion.</p>	<p>Since theories are constructed based on the experiences and decisions of the scientist, and there is a general, but not universal scientific method, scientists from different cultures may or may not arrive at different conclusions and go through different processes when studying the same phenomena. The phenomena should lead scientists to the same answer, but due to human fallibility this is uncertain. If different scientists disagree on the nature of phenomena, then the theory that is stronger or cannot be falsified will replace the weaker one after more experimentation.</p>	<p>Since all theories and experiments are socially constructed, scientists will approach phenomena differently based on their background, belief system, training, political and social context, etc. Therefore, it is possible for scientists from different cultures to arrive at different conclusions and go through different processes (although similar) when studying the same phenomena. If different scientists disagree on the nature of the phenomena, the scientific community will critique both theories and further experimentation will ensue. The theory with the most support (socially and politically) will be accepted.</p>
<p>Creativity 8</p>	<p>Creativity is involved in design only, with regard to resourcefulness in set-up and conducting of experiments. "Discovery"</p>	<p>In development</p>	<p>Creativity is involved in developing questions, analyzing data and in interpretation. "Created patterns"</p>

APPENDIX C

VNOS-C PRETEST AND POST-TEST SCORES

Anatomy/phys (5) Sem 2, 2008-2009 Mandy Flake		VNOS Pre-test									VNOS Post-test								
Period	Test #		Q #1	Q #2,3	Q #4	Q #6	Q #8	Q #9	Q #10		Q #1	Q #2,3	Q #4	Q #6	Q #8	Q #9	Q #10		
Student #1	5	2	1.4	1	2	1	1	1	2.5	na	2.9	3	3	2	3	5	2	2	
Student #2	5	12	1.9	2	2	3	2	1	2	1	2.4	2	2	2	2	3	3	3	
Student #3	5	37	1.9	1	2	1	3	1	1	4	3.0	2	2	3	2	5	2	5	
Student #4	5		2.5	2	1	2	3	3	4	na	3.0	1	2	3	5	3	3	4	
Student #5	5	22	2.3	na	na	na	na	2	2	3	2.7	2	2	4	3	4	1	3	
Student #6	5	7	2.1	2	3	2	1	3	1	3	3.1	2	3	3	3	2	4	5	
Student #7	5	45	2.7	2	3	2	3	2	2	5	3.4	2	3	3	3	5	4	4	
Student #8	5	19	2.3	1	3	2	4	2	2	na	3.0	2.5	2.5	2	3	5	2	4	
Student #9	5	15	2.3	1	2	2	4	5	1	1	2.7	2	3	5	3	2	2	2	
Student #10	5	14	1.7	1	2	3	2	2	1	1	3.1	3	5	3	3	4	2	2	
Student #11	5	36	1.7	1	2	2.5	1	1	2.5	2	2.2	1	2.5	2	3	2	4	1	
Student #12	5	26	1.7	1	2	2	2	3	1	1	2.4	2	2	2	1	3	2	5	
Student #13	5	28	2.6	3	3	3	2	2	3	2	2.4	1	2	2	3	2.5	3	3	
Student #14	5	9	2.0	1	2	2	3	3	1	2	2.8	3	3	2	3	2	2	4.5	
Student #15	5	27	2.4	1	1	2	3	4	2	4	2.7	3	1.5	2.5	3.5	3.5	2	3	
Student #16	5	6	2.7	2	2	3	2	3	2	5	3.6	2	5	2	3	5.5	3	5	
Student #17	5	44	2.7	3	2	2	1	5	2	4	3.4	1	5	3	3	3	4	5	
Student #18	5	1	1.3	1	1	1	1	2	2	1	3.1	3	1.5	2	3	5	4	3	
Student #19	5	38	2.7	3	3	2	2	5	3	1	2.8	1	3	3	2	4	3	3.5	
Student #20	5	30	1.9	1	2	2	2	2	1	3	1.9	1	3	3	2	2	1	1	
Totals			42.9	30	40	39.5	42	52	38	43	56.7	39.5	56	53.5	56.5	70.5	53	68	
			2.1	1.58	2.11	2.08	2.21	2.6	1.9	2.53	2.8	1.98	2.8	2.68	2.83	3.53	2.65	3.4	

Student #21	6	46	1.8	1	1	3	2	na	na	na		1.8	1	1	2	2	2	1.5	3
Student #22	6	11	3.7	2	2	4	3	5	5	5		2.4	2	1	3	2	3	3	3
Student #23	6	32	1.7	2	1	2	2	2	1	na		3.1	2	2	4	3	4	2	5
Student #24	6	42	1.0	1	na	1	1	na	na	na		2.6	2	3	3	1	4	2	3
Student #25	6	24	1.3	1	1	1	1	1	1	3		2.9	2	4.5	2.5	2	3	2	4
Student #26	6	17	1.7	1	3	1	2	2	2	1		2.6	1	1	1	3	4	5	3
Student #27	6	20	1.4	1	1	1	1	2	1	3		2.5	4.5	3	2	2	3	2	1
Student #28	6	21	2.2	na	1	1	3	2	3	3		3.4	2	3	4	3	5	4	3
Student #29	6	29	2.1	1	2	1	3	3	2	3		3.9	2.5	5	3.5	1.5	5	5	4.5
Student #30	6	16	1.7	1	1	2	1	2	2	3		2.9	3	2	5	2	2.5	2	4
Student #31	6	43	2.1	1	1	2	2	5	1	3		3.2	3	3	3	3.5	4	2	4
Student #32	6	35	2.4	1	1	3	2	2	3	5		2.5	1	4.5	2	3	2	1	4
Student #33	6	40	3.0	2	3	4	3	4	2	3		3.6	2	3	4	4	4	4	4
Student #34	6	18	1.5	1	1	2	2	na	na	na		3.9	3	4	3	3.5	4	5	5
Student #35	6	8	1.3	2	1	1	1	1	2	1		1.9	1	1	2	2	3	1	3
Student #36	6	3	1.6	1	1	1	2	3	2	1		3.3	3	3.5	3	3	2	4	4.5
Student #37	6	23	1.4	1	2	1	2	1	1	2		3.0	3	2	2	3	5	2	4
Student #38	6	35	1.9	1	1	1	2	2	3	3		3.7	5	3	3	3	4	3	5
Student #39	6	41	2.4	1	2	3	3	5	2	1		2.6	2	3	3.5	2.5	2	3	2
Student #40	6	5	3.1	1	2	3	4	4	3	5		3.4	1.5	4	3	3	4	3	5
Student #41	6	10	1.1	1	1	1	2	1	1	1		2.4	2	2	3	3	2	2	5
Totals			40.5	24	29	39	44	47	37	46		61.5	48.5	58.5	59.5	55	71.5	58.5	79
Averages for 6th hr			1.9	1.2	1.45	1.86	2.1	2.61	2.06	2.71		2.93	2.31	2.79	2.83	2.62	3.40	2.79	3.76
Totals			83.4	54	69	78.5	86	99	75	89		118.2	88	115	113	112	142	112	147
Averages for both classes			2.0	1.38	1.77	1.96	2.15	2.61	1.97	2.62		2.9	2.15	2.79	2.76	2.72	3.46	2.72	3.59

Averages for 5th hr	2.14	1.58	2.11	2.08	2.21	2.60	1.90	2.53	2.84	1.98	2.80	2.68	2.83	3.53	2.65	3.40
Averages for 6th hr	1.93	1.20	1.45	1.86	2.10	2.61	2.06	2.71	2.93	2.31	2.79	2.83	2.62	3.40	2.79	3.76
Averages for both classes	2.03	1.38	1.77	1.96	2.15	2.61	1.97	2.62	2.88	2.15	2.79	2.76	2.72	3.46	2.72	3.59