THE EFFECT OF A PROFESSIONAL DEVELOPMENT INTERVENTION ON INSERVICE SCIENCE TEACHERS' CONCEPTIONS OF NATURE OF SCIENCE

by

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CHAPTER 1

INTRODUCTION AND THEORETICAL BASIS

> *"[An] important criticism on the results of our teaching frequently made by those who are not biologists at all, is that the apparent subject-matter of an ordinary course in botany or zoology consists of a congeries of facts more or less closely related among themselves, but having no evident connection with the life of man. To these critics it seems that biologists as a class contribute little or nothing out of their store of knowledge to the solution of the manifold problems of human life. Do scientific biologists contribute no more to the progress of human society than, for example, the scientific philologists?" – Henry R. Linville*

The criticism described by Linville as well as his question could likely be heard by science educators who attend national and international conferences and lament the state of K-12 science instruction in today's public schools. Linville, however, wrote this passage over a century ago, indicating that the roots of this current problem in U.S. science education run deep (Linville, 1907, p. 264). The point Linville makes, is that a disconnect exists between the content material taught in science classes and the applicability of this knowledge by the average citizen to help navigate his or her way through life. Much research has focused on the need to temper content knowledge with an emphasis on the philosophical nature of science (NOS) so that science learners can have a more sophisticated view of how scientific knowledge is generated and how it relates to real world problems. Clear evidence of this is seen in the numerous studies described in the literature which involved researchers aiming to discover the level of understanding that science teachers (Anderson, 1950; Behnke, 1950; Carey & Strauss, 1968; Miller, 1963; Schmidt, 1967) and their students (Bady, 1979; Cotham & Smith, 1981; Klopfer & Cooley, 1961; Mead & Metraux, 1957; Wilson, 1954) have about NOS. The National Science Teachers Association's (NSTA) position statement from 1982 clearly indicated the importance of understanding NOS as a critical element of scientific literacy (NSTA, 1982). The need for true scientific literacy which includes an understanding of NOS is brought to the forefront by Driver, Leach, Millar, and Scott (1996). They argue that scientific literacy serves the utilitarian purpose of allowing citizens to comprehend and manage the technological and scientific advances of our society. It empowers the citizen to make informed choices about social and cultural issues; thus serving a democratic function. It serves a cultural function by allowing citizens to understand and appreciate the function of science in our cultures (and others). They claim scientific literacy serves a moral function by allowing the public to understand the norms and values of the scientific community, which exemplify a moral code that is of value to our society. Finally, they claim that understanding NOS leads to better acquisition of scientific content material. Whether or not their claims are valid is still questioned as sufficient research has not been conducted to validate their claims; however, the general agreement among science educators persists that NOS is, indeed, a worthy component of science curriculum (American Association for the Advancement of Science, 1993; National Research Council, 1996). With such emphasis on the importance of teaching NOS to science learners, one would imagine that a clear definition of NOS exists. Unfortunately, no such definition emerges in the literature.

Defining Nature of Science

While it has been claimed that well-known reform documents such as the National Science Education Standards (NRC, 1996) include, "explicit statements about the meaning of NOS" (Lederman, 2006; p. 3), upon review of the Standards as well as the Benchmarks for Science Literacy (AAAS, 1993) no clear definition emerges. Rather, the characteristics of NOS are spread across chapters as if these ideas will somehow coalesce into a larger abstraction that can be adopted by the reader. Although these two documents emphasize the same major characteristics that define NOS, the views held by scientists, science teachers, and philosophers of science fail to achieve this same level of agreement. In a study involving practitioners, teachers, and philosophers of science, Alters (1997) found disagreement among the philosophers of science as to what tenets best describe science as a way of knowing. He further found differences among science teachers and scientists. His ultimate appraisal of the situation was, "…there is no one agreed-on philosophical position underpinning the existing NOS in science education" (p. 48). While characteristics of science might be widely debated among philosophers of science and between these philosophers and the teachers/practitioners of science, many researchers in science education (Smith, Lederman, Bell, McComas & Clough, 1997; Smith & Scharmann, 1999) argue that more agreement than differences exist and that the differences that do exist are not relevant to K-12 science teachers (Lederman, 2006). Seven commonly-held tenets of NOS that are consistent between and among philosophers, educators and practitioners of science and are considered important for K-12 science teachers have been identified by leading researchers in NOS (Bell, Blair, Crawford & Lederman, 2003; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Smith, Lederman, Bell, McComas & Clough, 1997; Smith & Scharmann, 1999). These seven tenets are considered important for K-12 instructors as they allow for more authentic delivery of science as a way of knowing that serves younger learners.

They are:

- Scientific knowledge is tentative
- Scientific knowledge is based on empirical evidence
- Scientific knowledge is subjective and theory-laden
- Scientific knowledge is created by scientists
- Scientific knowledge is socially and culturally embedded
- Scientific knowledge is based on observations and inferences
- Scientific knowledge is based on laws and theories

This dissertation research focuses on these seven specific tenets of NOS with the primary objective of determining in what ways inservice science teachers' conceptions of nature of science can improve through NOS-centered instruction. Specifically, this research will examine eleven science teachers' conceptions of nature of science before and after engaging in an explicit, long-term, professional development intervention.

Teachers' Conceptions of NOS

Upon review of past studies on science teachers' conceptions of NOS, the overwhelming consensus is that teachers lack a sophisticated view of NOS (Anderson, 1950; Barufaldi, Bethel & Lamb, 1977; Behnke, 1950; Billeh & Hasan, 1975; Bloom, Sawey, Holden & Weinburgh, 2007; Bloom & Weinburgh, 2007; Carey & Strauss, 1968; Gruber, 1963; Klopfer & Cooley, 1963; Miller, 1963; Riley, 1979; Scharmann & Harris, 1992; Schmidt, 1967; Trembath, 1972; Welch & Walberg, 1967-1968). Although these studies claim that teachers lacked sophisticated views of NOS, they fail to clearly identify teachers' conceptions of science in several ways. First, many studies use quantitative measures to grade teachers' general understanding of science but fail to identify what characteristics of science teachers do or do not understand (Scharmann & Harris, 1992; Schmidt, 1967; Welch & Walberg, 1967-1968). Second, many of the past studies focus on teachers' understanding of much less tangible ideas about science such as general methodologies of science (Anderson, 1950); attitudes about science (Riley, 1979); assumptions, products, processes, and ethics of science (Billeh & Hassan, 1975); science as both a body of knowledge as well as a way of knowing (Carey & Strauss, 1968; Gruber, 1963). Third, if the studies addressed specific characteristics of NOS, they narrowed the focus to just one or two characteristics such as the role of science in society (Klopfer & Cooley, 1963) or the tentative nature of science (Barufaldi, Bethel & Lamb, 1977; Behnke, 1950). Not all studies, however, have suffered these same limitations. More recent studies, many of which investigate the ability of professional development to improve teachers' conceptions, have had a broader focus on more than one tenet of NOS but many still lack a comprehensive approach that addresses multiple tenets of NOS (Scharmann, Smith, James & Jensen, 2005; Lederman & O'Malley, 1990), fail to identify in what ways teachers' understandings of individual tenets improved (Abd-El-Khalick, Bell & Lederman, 1999), or demonstrate what instructional strategies affected improvement in understanding of NOS tenets (Akerson & Hanuscin, 2007; Lederman, 1999).

Scharmann, Smith, James, and Jensen (2005) examined the effect of explicit, reflective NOS instruction on preservice teachers' conceptions of science, but narrowed the focus on the teaching of evolution in the classroom. They measured preservice teachers' ideas about evolution, intelligent design, and an imaginary science called *umbrellaology* before and after NOS instruction. At the end of the instruction, they found that preservice teachers' views about these three *sciences* had changed, but they did not identify what characteristics of NOS instruction were influencing their changing opinions. They concluded that explicit, reflective NOS instruction in the preservice science teachers' course led to cognitive disequilibrium which is a starting point for conceptual change.

The recent works of Akerson, Abd-El-Khalick, and Lederman (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000; Lederman, 1999; Schwartz & Lederman, 2002) have addressed the *lack of focus* of in some contemporary research, which only looked at individual characteristics of science (Lederman & O'Malley, 1990; Scharmann, Smith, James & Jensen, 2005) by investigating specific NOS tenets, using explicit, reflective teaching methods, and using interviews and other qualitative methodologies to gain richer insight into participants' knowledge of these individual tenets. Their studies revealed that teachers were able to develop more informed views of all tenets of NOS being addressed. They further found that contextualizing NOS instruction within the framework of distinguishing science from religion as two distinct ways of knowing appeared to be a stimulus for learning NOS and provided the teachers a sense of utility behind understanding and teaching NOS.

Studies have been conducted, which examined whether improved conceptions of NOS (held by science teachers) improved instruction and delivery of NOS to science students and have resulted in mixed conclusions. Abd-El-Khalick, Bell, and Lederman, (1998) and Lederman (1999) concluded that improved conceptions of NOS by science teachers did not, necessarily, improve their delivery of NOS to their students. After observing their teacher/subjects in their classrooms, Abd-El-Khalick, Bell, and Lederman (1998) concluded that little emphasis was placed on NOS as they delivered their content material to their students. When asked why they failed to deliver NOS to their students, the subjects generally responded that they viewed NOS as a less significant instructional outcome, that they found classroom management issues and other routine necessary activities impaired their ability to focus on or plan for NOS instruction, and that they still felt enough discomfort with their own views of NOS and did not feel they had access to enough resources to deliver NOS instruction effectively. In 1999, Lederman found similar results with five inservice science teachers ranging in experience from 2 to 15 years. Through multiple data sources including in-class observations, questionnaires, reviewing lesson plans and instructional materials, interviews with students, and other informal discussions with teachers, he concluded that there was no significant change in classroom practice due to an understanding of NOS.

Schwartz and Lederman (2002) found somewhat different results in their case study of two beginning secondary science teachers. Their two teacher/subjects held widely different views of NOS. One had a well-developed view of NOS while the other lacked such an informed view and held a more compartmentalized view of NOS. Through questionnaires, interviews, observations of classroom practices and review of lesson plans, they found that the subject with a more informed view was able to address NOS in his science classroom while the other subject's less developed views of NOS impeded her ability to weave NOS into her classroom instruction. Their findings indicated that a well developed conception of NOS can improve instruction but that a myriad of variables can influence this effect. Knowledge of subject matter along with informed views of NOS in conjunction with intentional classroom implementations are all important to translating teacher knowledge of NOS into better instruction.

Even more recently, Akerson and Hanuscin (2007) found more favorable results. These researchers studied inservice science teachers' and their students' conceptions of NOS using the VNOS-B (for the teachers) and the VNOS-D (for their elementary students) over a three year period in which the teachers were enrolled in a long-term professional development experience. Data were collected through VNOS responses, interviews, classroom and professional development workshop observations (audio and/or videotaped, and field notes), and reflective discussions with the teacher/participants. The data were analyzed to determine pre and post conceptions of NOS. Their results indicate that extensive, long-term, professional development that includes explicit delivery of NOS joined with reflective dialogue about the experiences, can improve both teachers' conceptions of NOS and their classroom practices.

Assessing Teachers' Conceptions of NOS

In his review of past instruments used to measure teachers' and students' conceptions of NOS, Lederman (2006) identified eleven that he considered, "valid and reliable measures of NOS" (p. 55). He justified their validity based upon their focus on at least one major idea that is traditionally associated with NOS along with their reliability and validity data. In addition, he identified many weaknesses among them. The most common weaknesses noted were that the instruments were too focused, failed to give subscales, or, due to their quantitative nature, failed to adequately address the complexity of the concepts being assessed (Lederman, 2006). These problems have led to the development of the Views of Nature of Science Questionnaire (VNOS) which is used in this research.

The VNOS consists of open-ended questions which are designed to elucidate understanding of the seven major tenets of NOS upon which this research focuses. The VNOS is designed to be used only in conjunction with individual interviews in order to better understand the subjects' conceptions of each tenet being studied. The necessity of qualitative methodologies to evaluate the interviews and the VNOS responses makes this instrument much more labor-intensive. However, the researchers (i.e. Lederman, Abd-El-Khalick, Schwartz, and Akerson) who use it realize the richer, more authentic description of the subjects understanding that it provides.

Improving Teachers' Conceptions of NOS

With a more developed way of assessing teachers' understanding of the seven tenets of NOS now created, the question arises: How do we affect change in their conception of NOS through professional development? The major area of discussion focuses on the mode of delivery; explicit or implicit. Much of the research (Barufaldi, Bethel & Lamb, 1977; Riley, 1979; Scharmann & Harris, 1992; Trembath, 1972) used the implicit approach which expects learners to develop more informed views of NOS by being exposed to it without the need for reflective dialogue, explicitly describing what concepts are being conveyed. They generally meet with poor success in reaching their goals. Other researchers (Akindehin, 1988; Billeh & Hasan, 1975) adopted a more explicit approach and found various levels of success. The general implication made by these researchers is that explicit delivery of NOS instruction is much more able to change learners understanding of NOS.

Research Question

This research builds upon the aforementioned research in several ways. It focuses on inservice science teachers before and after a two-week intensive summer professional development program that included explicit NOS instruction. It combines this explicit approach to NOS instruction with reflective, dialogue about the interventions used throughout the professional development. It addresses the seven commonly-held tenets of NOS that are deemed significant to K-12 science teachers. Finally, it borrows qualitative methodologies for analyzing the Views of Nature of Science Questionnaire and associated interviews to gain a richer understanding of the teachers' NOS understanding before and after the interventions. By using this analysis approach, this research better describes the *ways* in which teachers' conceptions of NOS aspects align with and/or deviate from the desired understanding put forth in the professional development. This description of their understanding avoids reducing the participants' diverse and complex conceptions of these tenets into simple "informed" or "naïve" (or "adequate"/"inadequate") categories. It is through this more detailed analysis of the participants' data that this research examines inservice science teachers' conceptions' of nature of science before and after engaging in an explicit, long-term, professional development intervention.

CHAPTER 2

REVIEW OF THE LITERATURE

The National Research Council (NRC) and the American Association for the Advancement of Science (AAAS) produced the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993). These documents were composed in hopes of making "scientific literacy for all a reality in the 21st century" (NRC, 1996, p. ix) and to ensure that "…all students would become literate in science, mathematics, and technology by graduation from high school" (AAAS, 1993, p. vii). One theme consistent between and throughout both of these documents is the emphasis of teaching Nature of Science (NOS). The rationale for emphasizing NOS in science curriculum is built upon the assumption that teachers' more informed understanding of NOS will lead to a more-accurate perception of science as a discipline and a more-authentic delivery of science to their students. The NRC states,

> All teachers of science have implicit and explicit beliefs about science, learning, and teaching. Teachers can be effective guides for student learning only if they have the opportunity to examine their own beliefs, as well as to develop an understanding of the tenets on which the Standards are based. (NRC, 1996, p. 3).

AAAS echoes this sentiment:

> When people know how scientists go about their work and reach scientific conclusions, and what the limitations of such conclusion are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically. (AAAS, 1993, p. 3)

With the emphasis on teaching NOS, one would expect there to be a clear understanding of what characteristics are commonly accepted as inherent to the discipline of science. The literature, however, points to the contrary. In actuality, there appears to be many conflicting ideas of what should be identified as NOS. Smith and Scharmann (1999) recognize that differing views may be found among positivists, radical constructivists, empiricists, realists, feminists, Marxists, multiculturalists, universalists, logical empiricists, radical empiricists, scientific realists, instrumentalists, idealists, and many other factions. It is sometimes stated that there exists no one definition of NOS (Alters, 1997). Others assert that NOS cannot be clearly defined because it is a dynamic, changing set of properties, which must adapt to changing times, cultures, and societal values (Suchting, 1995).

To further confuse the situation, science teachers, themselves, have historically displayed a general lack of understanding of NOS (Lederman, 1992; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Schwartz & Lederman, 2002). The literature describes science teachers as generally naïve regarding science in general and as uninformed about some of the most-commonly accepted tenets of NOS. If a major goal of science classes today is to convey NOS to the students, then it follows that the teachers should be well educated on the issue. Although the long held belief is that once teachers become aware of NOS issues, they will modify their teaching strategies in order to convey this knowledge to their students, the literature does not clearly support this notion (Lederman, 2006).

Finally, there is the issue of how NOS can be taught in the classroom. Some have proposed that by engaging in science (*doing science*) through inquiry-based activities, the students will naturally develop an understanding of NOS (Barufaldi, Bethel & Lamb, 1977; Haukoos & Pennick, 1983, 1985; Riley, 1979; Spears & Zollman, 1977; Trembath, 1972). Others assert that this implicit delivery does not accomplish the desired level of understanding and that a more explicit approach to delivery of NOS must be used (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akindehin, 1988; Bell, Blair, Crawford & Lederman, 2003; Billeh & Hassan, 1975; Carey & Strauss, 1968; Lavach, 1969).

This review of literature aims to explain the current emphasis to 1) incorporate NOS in the science classroom curriculum, 2) describe the conflict in identifying an agreed-upon set of characteristics with which to describe NOS, 3) discuss the current status of science-teachers' understanding of NOS, 4) describe the past approaches to assessing NOS and discuss ways of improving their conceptions of NOS.

NOS in Science Curriculum

The National Science Standards (AAAS, 1993) and the Benchmarks for Science Literacy (NRC, 1996) were established to clearly define what content material all students should understand by the time they finish high school in the United States. The goal was to create scientifically literate individuals. A widely accepted critical component of the curriculum, necessary for developing scientific literacy in young learners, is an understanding of NOS (NSTA, 1982; Lederman 2006). In their book "*Young People's Images of Science*", Driver, Leach, Millar, and Scott (1996) put forth the following five arguments which describe the need to be scientifically literate in today's society.

<u>Utilitarian:</u> understanding NOS is necessary to make sense of science and manage the technological objects and processes in everyday life

<u>Democratic:</u> understanding NOS is necessary for informed decision-making on socioscientific issues

<u>Cultural:</u> understanding NOS is necessary to appreciate the value of science as part of contemporary culture

<u>Moral:</u> understanding NOS helps develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society

<u>Science learning:</u> understanding NOS facilitates the learning of science subject matter

Lederman concedes that these are all valid arguments for the need for scientific literacy, but maintains that until there are sufficient educators with an understanding of NOS, we cannot know if learning NOS leads to the attainment of the goals set forth. Other literature claims that the connection between NOS understanding and better instruction is already established. According to the National Science Education Standards, teachers' understanding of NOS leads to better instruction in their science classrooms. The Standards (NRC, 1996) clearly asserts, "The actions of teachers are deeply influenced by their perceptions of science as an enterprise and as a subject to be taught" (p. 28). The Benchmarks (AAAS, 1993) supports this argument with,

> The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, the study of science as a way of knowing needs to be made explicit in the curriculum. (p. 3)

These statements support the notion that an understanding of NOS by the teacher leads to better teaching and learning of science in the classroom. Lederman, however, argues that such a connection, although intuitively sound, is not supported with evidence. He claims that his research on teachers' conceptions of NOS was, "…unable to find any clear relationship between teachers' conceptions and classroom practice" (Lederman, 2006, p. 38). Despite this current argument as to the need for understanding NOS by teachers and students, there seems to be a need to identify what is meant by NOS.

Defining Nature of Science

The historical account of how philosophers of science characterized science can be grossly divided into two distinct periods which are separated by Kuhn's (1962) *Structure of Scientific Revolutions*. Pre-Kuhnian philosophers were generally characterized as empiricists who focused more on the logical justification of scientific claims than on the context in which such discoveries were made (Gierre, 1988). Pre-Kuhnian scientists viewed their work in a way that Kuhn might have characterized as *normal science* and the philosophers of that time constrained themselves to this narrow focus and excluded the psychological and sociological foundations of the discipline which they claimed to be external to pure science. Philosophers of science who addressed the social and psychological aspects of scientific discovery were accused of conflating logic and psychology and were said to have committed the sin of "psychologism" (Popper, 1959, p. 31). While Kuhn did not dismiss the logical, empirically-based, *normal science* as a major force in scientific advancement, he shifted the philosophy of science by acknowledging the important role of *revolutionary science* as well. This shift in how philosophers viewed science addressed the role of discovery and creativity, as well as the social, psychological and cultural elements involved in science (Kuhn, 1962). In *The Structure of Scientific Revolutions*, Kuhn (1962) describes the major idea behind this paradigm shift as follows; "…a concept of science drawn from them [textbooks] is no more likely to fit the enterprise that produced them than an image of a national culture drawn from a brochure or a language text" (p. 1). This new description of science was met with mixed reviews. While some philosophers of science such as Feyerabend, Foucault, and Rorty embraced the new *anti-realist* paradigm, others such as Putnam, while adopting similar ideas, believed they went too far into relativism (Popper, 1994; Rorty, 1991). This emerging philosophy was so new, in fact, that even those who were adopting it disagreed among themselves (Abd-El-Khalick & Lederman, 2000; Lederman, 2006). Despite the controversy of the newly emerging, post-Kuhnian paradigm, the door had been opened expanding the idea of what characterizes science as a way of knowing.

In more recent decades, the debate over what characteristics describe the NOS has continued (Alters, 1997; Smith & Scharmann, 1999). In the 1970's, Lucas argued (to the developers of NOS instruments of the time) that there must be a realization that multiple, and sometimes conflicting, models of science exist (cited from Alters, 1997). Indeed, Alters' own research on science educators' views regarding the defining characteristics of NOS revealed 39 basic tenets of NOS that were commonly held among various NOS researchers (Alters, 1997). When Alters compared these views on NOS with philosophers of science, however, many of them were strongly contested as accurately portraying science as a discipline. The philosophers of science, themselves, could not come to a consensus on what tenets were appropriate. Ultimately, Alters concluded that there was, "…no one agreed-on philosophical position underpinning the existing NOS in science education" and that ultimately, "…we should acknowledge that no one agreed-on NOS exists" (p. 48).

Leading researchers in the study of NOS have identified some common tenets of NOS that are particularly important to K-12 instructors (Bell, Blair, Crawford & Lederman, 2003; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Smith, Lederman, Bell, McComas & Clough, 1997; Smith & Scharmann, 1999). Seven of these generally accepted tenets of NOS are the focus of this dissertation research. They are tentativeness, empirical basis, subjectivity, creativity, social and cultural embeddedness, the use of and distinction between observations and inferences, and the relationship between theories and laws. A brief description of each tenet summarizes the main ideas held by most contemporary philosophers of science.

Scientific Knowledge is Tentative

Although scientific knowledge is based upon observations (empirical evidence), the explanations behind these factual components are tentative and subject to change as new information is acquired. Scientific knowledge changes in two distinct ways: (1) new knowledge is acquired and is added to the canonical knowledge and (2) current knowledge may be replaced when new technology or discoveries disprove it. Examples of science changing in the additive sense include the discovery of new microbes which cause disease and/or new treatments to cure them, the discovery of new fossilized remains of an unknown dinosaur, or better technological advances such as CT scanning allowing scientists to see internal structures that were previously unknown. Examples of scientific knowledge changing in a revisionary way include the discovery of bacteria living in hostile environments such as the stomach (previously thought impossible), the discovery that continental plates were not stationary but are, rather, moving at a gradual pace, and that neural cells in the brain can regenerate to some degree.

Scientific Knowledge is Based on Empirical Evidence

All scientific knowledge must be, at least partly, based upon empirical evidence. Empirical evidence is any evidence that is measurable or observable. Any *way of knowing* that lacks empirical evidence is not counted as scientific knowledge. Although many people involved in science (researchers, teachers, philosophers) recognize that empirical evidence is useful in developing new scientific knowledge, they may lack the understanding that empirical evidence (of some sort) is a requirement of science. Ways of knowing that lack empirical evidence could be religion (based on faith) or philosophy (based on laws of logic).

Scientific Knowledge is Subjective and Theory-Laden

Scientific knowledge is based upon theories and is, therefore, somewhat subjective. Although many scientists may dislike such a characterization of science, those who care to look deeper realize that they are viewing their particular field through a metaphorical set of lenses created by the paradigm in which they have trained. The theories under which they have studied have an influence upon the interpretations they make of the phenomena that they observe. Anyone who has been educated about Darwinian processes of evolution will interpret his or her observations in light of that particular paradigm. This theory-laden quality allows for consistency in science, but can also fuel dogma in science which can impede new interpretations of scientific facts.

Scientific Knowledge is Created by Scientists

Scientific knowledge, although grounded in empirical evidence, is oftentimes furthered by human imagination and creativity. Too many times, science educators believe the idea that scientists routinely use an orderly, series of steps to uncover new ideas and fail to realize that creativity and imagination are integral to uncovering new ideas and breaking free from scientific dogma. While many recognize that scientists use creativity in designing experiments and presenting their findings, they often fail to realize that scientific discoveries are actually *new knowledge* created by the scientist who presents it to the scientific community. A recent example is Bassler's discovery at Princeton University. Her research on chemicals secreted by bacteria (called autoinducers) has revealed a previously unknown bacterial capability known as quorum sensing. This newly created knowledge describes bacteria as being able to sense levels of these chemical signals and act collectively in expressing their genes based upon the size of the bacterial population within the host organism (Bassler, 2008).

Scientific Knowledge is Socially and Culturally Embedded

Scientific knowledge proceeds based upon contributions from a community of scientists. Through collaboration and sharing, any individual within the community benefits from the knowledge acquired by all. Furthermore, each member of the community is a product of the culture in which he/she lives and is, therefore, influenced by that culture. Knowledge about stem-cell culturing is proceeding at differential rates in different cultures; faster in Europe and Asia, slower in the U.S. (due, in part, to the culture of our citizens). Research into women's health issues developed long after research into those that plague both genders (or specific to men) were well-researched.

Scientific Knowledge is Based on Observations and Inferences

Observations of natural phenomena that exist in nature are measurable, identifiable phenomena that are directly accessible to the senses. In other words, they are empirically based. Inferences, on the other hand, go beyond the senses (Lederman, 2006). Inferences demand that observers make explanations that are not directly accessible by observation. Inferences often extend upon past observations, theoretical background, cultural perspective, and social norms and involve some degree of creativity. Both observations and inferences are integral to scientific process and the growth of scientific knowledge. For example, with advanced technology in plate tectonics, scientists can observe the movement of land masses. Using this knowledge, scientists retrodict how the continents would have been connected as a supercontinent in the past (unobservable).

Scientific Knowledge is Based on Laws and Theories

The distinction between laws and theories parallels the distinction between observations and inferences. Laws are general descriptions that explain observable phenomena such as the Law of Gravity; gravitation or gravity is the tendency of objects with mass to accelerate toward each other. While the Law of Gravity describes this phenomenon, it does not explain it. A theory, on the other hand, contains an inferred explanation of the observable phenomena (McComas, 1997). The Theory of Evolution, for example, attempts to explain the diversity of life on Earth by identifying natural selection as a mechanism to account for the observed phenomena.

Lederman (2006) makes sure to point out that the above listed seven tenets are not intended to be interpreted as an exhaustive list of the characteristics of NOS, but maintains that there are many other characteristics that might also be included (see

Osborne, Collins, Ratcliffe, Millar & Duschl, 2003; Smith & Scharmann, 1999). He even asserts that NOS is somewhat like scientific knowledge itself in that it is subject to change with the times, culture and societies in which science is being practiced.

A final point that should be made is that Nature of Science (NOS) is different from Processes of Science (POS). Processes of science deal with how scientists collect and analyze data (i.e. inquiry) and how they draw conclusions based upon their findings. NOS refers to the philosophical underpinnings of the way in which scientists conduct their work and describes the resulting body of knowledge gained through their endeavors. This distinction is of key importance when looking for connections between understanding of NOS and a resulting change in practice of teaching (within the teacher) or in the learning of content and the conducting of science (within the learner).

Teachers' Understanding of NOS

The literature is rich with descriptions of studies on science teachers' conceptions of NOS. The general consensus within the research is that teachers lack an adequate understanding of the philosophical underpinnings of the subjects that they teach (Anderson, 1950; Behnke, 1950; Carey & Strauss, 1968; Miller, 1963; Schmidt, 1967). This research line began approximately 60 years ago. An early study by Anderson (1950) examined 58 biology and 55 chemistry high school teachers in Minnesota. Serious misconceptions regarding NOS were uncovered across the subjects. Behnke (1950) compared science teachers with practicing scientists and found similar results. Among the 400 biology teachers and 600 physical science teachers studied, 50% did not recognize scientific claims as being tentative. Even more interesting, however, was the finding that 20% of the 300 scientists studied also failed to recognize this important aspect of scientific knowledge. Miller (1963) compared views of NOS among science teachers and their students using the Test on Understanding Science (TOUS). He found that students out performed the teachers by 11%-68% at different grade levels. Schmidt (1967) replicated Millers study and found that 14% of 9th graders and 47% of 11th and 12th graders scored higher on the TOUS than 25% of the teachers. Carey and Strauss (1968) examined 17 preservice teachers and found a lack of understanding of NOS across the participants. Upon further analysis, they found no correlation between their level of understanding of NOS with their high school coursework, their college coursework, their overall GPA or their proficiency in mathematics.

More recent work along this same research line continues to find that teachers possess naïve and/or inadequate conceptions of NOS (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Akindehin, 1988; Bloom, Sawey, Holden & Weinburgh, 2007; Bloom & Weinburgh, 2007; Scharmann, Smith, James & Jensen, 2005). Akindehin (1988) studied the effects of an instructional package on preservice teachers' conception of NOS. He measured his subjects' conceptions of NOS using the NOSS and found improvement was needed. Akerson, Abd-El-Khalick, and Lederman (2000) examined NOS conceptions held by 50 preservice teachers and found that, "the majority of participants, both graduate and undergraduate, harbored naïve views of one or more of the seven target aspects of NOS" (p. 305), and that, "None of the participants held adequate views of all seven investigated NOS aspects at the beginning of the study" (p. 305). In a subsequent study conducted by Abd-El-Khalick and Akerson (2004) involving 28 preservice teachers, 90% of the participants expressed an absolutist view of science (as indicated by their conceptions that scientific laws are proven true). Furthermore, 72%-82% of the participants failed to demonstrate an informed view of the inferential, creative, or subjective nature of science. Scharmann, Smith, James, and Jensen (2005) found that the preservice science teachers who participated in their study, "…clearly wrestled with substantive abstractions concerning the NOS – some (quite obviously) for the first time" (p. 34). Akerson and Hanuscin (2007) found that inservice teachers' conceptions of NOS were not well developed and were often self-contradicting.

> Although many of the teachers began our project with views that were consistent with several aspects of NOS advanced by reforms (e.g., science involves creativity and imagination; scientific knowledge relies on evidence), they simultaneously held views that contradicted these ideas. For example, while Carrie believed science involved creativity and imagination, she also viewed scientific knowledge as 'truth'. (p. 663)

Bloom and Weinburgh (2007) examined science teachers' knowledge about evolution and discovered naïve views of NOS among teachers enrolled in professional development programs. Significant discrepancies in NOS understanding were found involving the tentativeness of science, that scientific knowledge relies on empirical evidence, and understanding of what is meant by a scientific theory.

The resounding theme between and among these studies are that teachers lack a sophisticated view of NOS from as early as the 1950's up to today. This lack of understanding is of special importance in light of the emphasis on teaching NOS to K-12 students as indicated by the Benchmarks (AAAS, 1993) and Standards (NRC, 1996).

Assessing Teachers' Conceptions of NOS

With the rich history of assessing teachers' (and students') understanding of NOS, a review of the instruments that have been used in the past to gauge their understanding is in order. Lederman has critically analyzed numerous instruments used, since the early 1950's, to assess understanding of NOS. Lederman criticizes many as lacking in validity stating that their primary focus was, "beyond the scope of "nature of science" (Lederman, 2006, p. 54). Table I lists eleven instruments (excluding his own Views of Nature of Science Questionnaires – VNOS) which Lederman claims are "generally considered to be valid and reliable measures of NOS" (Lederman, 2006, p. 55). Lederman views these instruments as being valid due to the, "…virtue of their focus on one or more ideas that have been traditionally considered under the label of 'nature of science,' as well as their reported validity and reliability data" (Lederman, 2006, p. 55). A brief description of each of these eleven instruments will be provided here in order to contrast them with the Views of Nature of Science Questionnaire which is used in this research.

Table I

Eleven NOS Assessment Tools Generally Considered Valid

Date	**Instrument**	**Author**
1961	Test on Understanding Science (TOUS)	Cooley & Klopfer
1967	Science Process Inventory (SPI)	Welch
1967	Wisconsin Inventory of Science Process (WISP)	Scientific Literacy Research Center
1968	Nature of Science Scale (NOSS)	Kimball
1975	Nature of Science Test (NOST)	Billeh & Hasan
1975	Views of Science Test (VOST)	Hillis
1976	Nature of Scientific Knowledge Scale (NSKS)	Rubba
1981	Conception of Scientific Theories Test (COST)	Cotham & Smith
1989	Views on Science-Technology-Society (VOSTS)	Aikenhead, Fleming, & Ryan
1992	Modified Nature of Scientific Knowledge Scale (MNSKS)	Meichtry
1995	Critical Incidents	Nott & Wellington

Test on Understanding Science (TOUS)

Until recently, Cooley and Klopfer's TOUS (1961) was the most widely used NOS instrument. It is a 60-item multiple choice test that focuses on three distinct aspects of NOS; understanding the scientific enterprise in general, understanding of "the scientist", and understanding of the methods and aims of science. Despite its frequent past use, it is no longer regarded as a favorable instrument for assessing NOS knowledge.

Wisconsin Inventory of Science Processes (WISP)

The Science Literacy Research Center's WISP (1967) is the second most widely used instrument to assess NOS knowledge. It was developed for high school use and consists of 93 statements which the student must rank as 'accurate', 'inaccurate', or 'not understood'. This instrument reports excellent validity and reliability, but some concerns should be addressed. First, in the scoring of the instrument, answers of 'inaccurate' or 'not understood' are combined and considered opposing to 'accurate'. Furthermore, the test takes over an hour to administer which proves problematic for classroom settings as this exceeds the time given for one class session.

Science Process Inventory (SPI)

Welch's SPI (1967) is a 135 item agree/disagree, forced choice test. Its content is very similar to the TOUS third focus on methods and aims of science. Problems associated with the SPI include its length and its failure to accommodate students' uncertain or neutral opinions.

Nature of Science Scale (NOSS)

Kimball's NOSS (1968) is similar in format to the WISP in that it is composed of 29 statements which must be ranked as 'agree', 'disagree', or 'neutral', however, this instrument was designed to determine if high-school teachers held similar views of science as did scientists. The main criticism of this instrument lies in its development. The items of the test were validated by science educators and the reliability measures were carried out with college graduates which were unrelated to the high-school population in which it was to be used.

Nature of Science Test (NOST)

Billeh and Hassan's NOST (1975) contains 60 multiple choice questions which focus on assumptions about science as well as the processes, products, and ethics of science. The questions are divided into two types; those that directly question the subject's knowledge about the characteristics of science and others that give scenarios where the subject must apply their knowledge of science to make judgments. The main criticism of this instrument is its lack of a subscale to assess each characteristic of science individually, but rather, only gives a single score of their generalized knowledge of science.

Views of Science Test (VOST)

Hillis' VOST (1975) uses a Likert scale (1-5) to rank the level of agreement that the test taker has with 40 statements about science. All statements are focused on whether scientific knowledge is absolute or tentative. This instrument is considered insufficient to gauge understanding of NOS due to its narrow focus on one particular aspect of NOS.

Nature of Scientific Knowledge Scale (NSKS)

Rubba's NSKS (1976) is another five-option Likert scale test consisting of 48 items. Rubba designed the NSKS to focus on six major characteristics of science; amoral, creative, tentative, parsimonious, testable, and unified. This instrument, which has been found to be valid and reliable when used with high-school students, is largely accepted by the research community, but Lederman warns of some issues of concern. His main concern is that many items have a paired, negative, statement which could cause the test-taker to refer back to prior answers and further enhance that opinion. This could result in inflated reliability and could, therefore, call into question the overall reliability of the instrument itself.

Conception of Scientific Theories Test (COST)

Cotham and Smith's COST (1981) differs remarkably from the previously mentioned instruments. It was designed to allow differing interpretations of science to emerge without viewing them as incorrect or inaccurate. The test is divided into five sections with the first four dealing with actual theories in science; Bohr's theory of the atom, Darwin's theory of evolution, Oparin's theory of abiogenesis, and the theory of plate tectonics. Each of the first four sections gives a brief summary of the theory. The fifth section of the test deals with scientific theories in general and is, therefore, not prefaced with a summary. The test is composed of forty four-choice Likert scale statements. The developers of the instrument strived to construct the items without reference to any single *correct* interpretation of science. The main concerns that Lederman addresses in regards to this instrument involve its level of sophistication. The test was developed for teachers and validation was achieved using college graduate students. The descriptions of the theories are thought to, perhaps, be overly complex for use with high school students themselves. A second concern centers on the emphasis that the test places on the tentative nature of science. Cotham and Smith, while attempting to create a value-free test, actually violated their own agenda by linking certain items to a positive understanding of tentativeness.

Views on Science-Technology-Society (VOSTS)

Aikenhead, Flemming, and Ryan's VOSTS (1989) differs even more from the previous NOS instruments. It consists of 114 multiple choice items which focus on science, technology, and society. The test was designed for 11th and 12th grade students. The test does not provide a numeric score, but rather, has the student generate an argumentative paragraph which defends his or her decision on each statement's answer. This instrument required approximately six years to develop and gain validity. The primary concern that emerges is the length of time necessary to administer such a test.

Modified Nature of Science Knowledge Scale (MNSKS)

Meichtry's MNSKS (1992) is a revision of Rubba's NSKS test (mentioned earlier). This shortened instrument focuses on four of the NSKS foci on characteristics of science; creative, developmental, testable, and unified. This instrument has been tested and found to have achieved reliability and validity in its use with 6th-8th grade students.

Critical Incidents

Nott and Wellington's Critical Incidents test (1995) is perhaps the most different of all the aforementioned instruments for measuring NOS understanding. It is designed for use with science teachers (preservice or inservice) and it presents a series of 'critical incidents' which could occur in science and asks the teacher 'What would you do?', 'What could you do?', and 'What should you do?' The teacher might be faced with a critical incident such as an experiment not working correctly in their science classroom. The assumption of this instrument is that teachers' understanding of NOS will translate into practice and that their answers to how they would/could/should address these critical incidents will shed light on their understanding of NOS. The literature, unfortunately, does not support this assumption at this time (Lederman, 2006, p. 61).

All of the instruments described thus far have some inherent problems in their ability to assess NOS understanding. Many are time intensive and limit their use in public school classrooms. Some are overly sophisticated and could only be used in assessing NOS understanding in highly educated audiences. All, however, are paper and pencil tests which some argue fail to adequately capture knowledge about something as complex as understanding NOS. In an attempt to address these issues, Lederman and others have developed a series of questionnaires which are less time intensive and combine the paper and pencil format with individual interviews to better assess NOS understanding.

Views of Nature of Science Questionnaire (VNOS)

The instrument being used in this research is the Views of Nature of Science Questionnaire – Version D (VNOS-D). This instrument is one of five iterations of the VNOS which are designed for various grade levels. Table II lists the five versions with their authors and dates.

Table II

Iterations of Views of Nature of Science Questionnaire

Date	Instrument	Authors
1990	Views of Nature of Science A (VNOS-A)	Lederman & O'Malley
1998	Views of Nature of Science B (VNOS-B)	Abd-El-Khalick, Bell, & Lederman
2000	Views of Nature of Science C (VNOS-C)	Abd-El-Khalick & Lederman
2002	Views of Nature of Science D (VNOS-D)	Lederman & Khishfe
2004	Views of Nature of Science E (VNOS-E)	Lederman & Ko

The VNOS-A consisted of seven open-ended questions which focused primarily on the tentativeness of science. It was designed to be used with interviews which would allow the respondent to expand his or her answer and clarify graders interpretations of their answers. In early analysis of results of the VNOS-A, Lederman found that answers to the paper and pencil portion of the assessment revealed answers which strayed from the intended target issue: tentativeness. The interviews helped to resolve this issue, but it further emphasized the need for interviews in conjunction with the assessment and guided the evolution of the instrument. Versions B through E show a gradual progression of improvement in the instrument specifically in regards to developmental appropriateness, language usage, and length of time needed to administer the test. Generally speaking, version B and C are too long for a typical class period with some taking as long as 90 minutes to finish just the written portion. Version D was developed to shorten the time needed to complete it and has been shown to yield the same results as the prior versions. Version E was specifically designed to deal with younger students (grade K-3). Because this research will deal primarily with middle school and high school science teachers, the VNOS-D was selected.

One last issue must be addressed concerning the assessment of NOS understanding. Criticisms regarding the use of the aforementioned instruments have centered on the appropriateness of using a pre-determined *correct view* of science to judge the responses of the test takers. The use of the VNOS does not avoid this same criticism. However, the judgments being made when grading the VNOS should not be interpreted as a determination of the 'rightness' or 'wrongness' of the conceptions held by the teachers being examined, but rather a determination of how closely or distantly their conceptions compare to those that are being used (which were guided by the current literature) as a standard for comparison.

Improving Teachers' Conceptions of NOS

Past efforts to improve teachers' conceptions of NOS have met with mixed results. Gruber (1963) studied 314 teachers who participated in an NSF funded summer institute and found little improvement in their understanding of NOS. In his study, Gruber focused primarily on the distinction between science as a way of knowing versus science as a body of knowledge. At the end of the academic year institute only 25% of the participating teachers showed a strong emphasis on teaching science as a way of knowing.

Welch and Walberg (1968), however, found that 162 physics teachers did show some improvement as indicated by a statistically significant gain in both their TOUS and SPI scores. Unfortunately, descriptions of the intervention activities were not documented and, therefore, there is no way to account for the gains that were seen. Others have also seen improvement during the course of professional development instruction. Klopfer and Cooley (1963) studied 26 science teachers who were involved in instruction with a historical approach. Eleven teachers received instruction in the historical aspects of many fields of science while the other 15, serving as a control group, received traditional instruction. The experimental group showed statistically significant gains in their TOUS score while the control group did not. Billeh and Hasan (1975) echoed these results when they studied science teachers enrolled in a four-week course for chemistry, physical science, physics and biology. The chemistry, physical science, and physics teachers all received twelve lectures throughout the course which emphasized NOS, while the biology teachers received no formal instruction regarding NOS. Those teachers who received formal NOS instruction showed significant gains in their NOST scores while the biology teachers did not.

When these past efforts are examined, however, some problems should be addressed. The primary issue of concern is that the conclusions of these studies, that teachers' understanding of NOS improved (or did not improve), were based solely on numeric scores on the instruments used in the studies, no description of the nature of the gains is given, and many studies were characterized by a narrow focus which may have only addressed one characteristic of NOS.   Without more, in-depth analysis, one cannot tell in what way the teachers' conceptions improved, or if they merely performed better on the test. There is also the issue of how all the early tests of NOS understanding (aside from the VOSTS) relied upon the interpretation of paper and pencil tests without the opportunity for the test taker to expand on their answer or clarify their results. The interview component of the VNOS addresses this concern.

In more recent years, studies have addresses some of these issues. Akerson, Abd-El-Khalick, and Lederman (2003) examined NOS views held by 25 undergraduate and 25 graduate preservice elementary teachers over the span of a science methods course. Their interventions included explicit delivery of NOS instruction joined with specially designed instruction. The tenets being studied were those upon which, this dissertation focuses; tentative, empirical, subjective, creative, social/cultural, observations/inferences, and theories/laws. Using an open-ended questionnaire along with individual interviews, they found that the preservice teachers gained a more sophisticated view of some of the tenets targeted by the instruction. They specifically found most improvement in the subjects' understandings of tentativeness, creativity, observations/inferences, and theories/laws. They found less improvement on the tenets subjective and social/cultural aspects of NOS.

Abd-El-Khalick and Akerson (2004) conducted research on a preservice elementary science methods course and found similar results. By using the VNOS-B along with interviews and incorporating explicit, reflective NOS instruction, they found 50% or greater gains in understanding across all tenets being studied. By selecting a focus group of six who showed differential change over the span of the course, they began to determine what accounted for the changes that occurred. They found that motivational, cognitive, and worldview factors were highly influential in the effectiveness of NOS interventions. Special importance was connected to demonstrating the utility of teaching NOS and contextualizing it within the framework of viewing science and religion as two distinct enterprises.

With the mixed results found in the effectiveness of professional development on improving science teachers' conceptions of NOS, the need for examining the types of professional developments used becomes clear. Generally speaking, intervention efforts have fallen into two distinct categories in regards to the way in which they were delivered; implicit approach versus explicit approach (Abd-El-Khalick and Lederman, 2000). The implicit approach, recommended by Gabel, Rubba, and Franz (1977), Haukoos and Penick (1983, 1985), Lawson (1982), and Rowe (1974), suggests that teachers will develop a more informed conception of NOS through development which emphasizes process skills, content knowledge, and practicing science as a discipline (sometimes called *doing science*).

Implicit Approach

As stated previously, the implicit approach to teaching NOS is based upon the assumption that teachers will develop a more mature understanding of the philosophical nature of science by participating in science activities, by learning science content, and participating in scientific inquiry; in short by *doing science*. Trembath (1972) used this approach in a small curriculum for preservice science teachers. In his program, he presented his participants with scenarios in the form of paragraphs and then required the participants to form hypotheses, predictions, and inferences. The goal was for the participants to develop a more mature understanding of hypotheses, theories and laws.

Although he reported significant gains in knowledge, the mean score only increased from 7.0 to 10.7 out of 18 possible points. Barufaldi, Bethel, and Lamb (1977) also adopted the implicit approach in their junior and senior college-level methods course for preservice science teachers. The course included many hands-on activities, inquiry-based experiences, and problem-solving activities. The major emphasis was on the tentativeness of science. No explicit delivery of NOS was included in the course. Although they concluded, based on VOST scores, that a methods course which incorporates inquiry methods and a hands-on approach, "…develops, alters, and enhances" preservice teachers' views of the tentative nature of science (p. 293), Lederman argues that they offer little evidence for their claims (2006, p. 28). With no mean pretest or mean gain scores for any of the treatment groups, all that can be seen is the comparison between their posttest scores and those of the control group. The control group did score lower on the post-VOST, but the difference was no more than 6 percentage points. With no pretest scores, it is difficult to determine if an effect did, indeed, exist. Riley (1979) also used an implicit approach in preservice teachers' methods course. He divided the students into three groups in which one had extensive hands-on, active inquiry, one observed inquiry occurring (but were not actively engaged), and one group with no inquiry in their class. Using the TOUS, Riley measured change in scores pre to post. He found no significant difference in understanding of NOS among the three groups. Most recently, Scharmann and Harris (1992) used implicit delivery to attempt to improve teachers' conceptions of NOS in a three-week summer institute funded by NSF. Throughout the institute, the teachers engaged in readings, activities, and discussions in which they would discuss their views of NOS, but no explicit delivery was given. Pre and post NOSS scores indicated no significant change in their understanding of NOS. However, Scharmann and Harris argue that while the participants' *philosophical* understanding of NOS may not have changed, that a second instrument developed by Johnson and Peeples (1987) indicated an improvement in their *applied* understanding of NOS. They did not, however, comment on the practical significance of such a gain and the pre and post test scores were 61.74 and 63.26 respectively. Once again, any gain in understanding through the implicit approach is not overly impressive. With such lackluster results of implicit NOS delivery, we must look to explicit delivery and examine if it is more effective.

Explicit Approach

In contrast to the implicit approach described above, Kuhn, (1974) asserts that explicit delivery is much more effective at conveying concepts to a new learner. In his 1974 work, *"Second Thoughts on Paradigms"*, Kuhn describes learning by *Ostention*. Kuhn describes learning of concepts by way of ostention as the learner being repeatedly shown examples to which the concept applies. Over time, the learner understands the concept as well as the teacher. The example give by Kuhn, is a young boy learning to distinguish different types of waterfowl; swans, ducks, and geese. While walking through a park, the young boy's father continues to point out geese, ducks, and swans until eventually the boy has mastered the categories and has developed a more informed view of each type of waterfowl purely by continued exposure to them. The following studies support the notion that explicit delivery of NOS shows a similar effect at improving teachers' conceptions.

Lavach (1969) studied 26 teachers participating in a professional development experience. Eleven of the teachers received instruction based upon historical aspects of astronomy, chemistry, heat, electricity, and mechanics. The experimental group was presented lectures which covered the content material as well as the historical perspective and demonstrations of experiments. They were then given lab time in order to attempt to replicate the experiment themselves. The control group was not taught using the historical perspective, but was instead, presented lectures in the traditional manner. Using the TOUS, Lavach found that the experimental group scored significantly higher than the control group on post-testing. Billeh and Hasan (1975) used explicit delivery with 186 science teachers from four different disciplines; biology, chemistry, physical science, and physics. All teachers participated in a four week course emphasizing their particular discipline. The biology teachers formed the control group and received no formal instruction in NOS. The chemistry, physical science, and physics teachers' courses, however, included demonstrations in teaching methods, guided-discovery laboratories, activities to enhance science concepts, and 12 lectures which emphasized NOS. All three experimental groups showed significant gains on their NOST post-test. The biology control group showed no such gain. More recently, Akindehin (1988) argues that NOS interventions must be explicit in nature. In his study he used an Introductory Science Teacher Education package with preservice secondary science teachers. The educational package included lectures, discussions and laboratory activities and emphasizes NOS. Using the NOSS, he found a significant change in conceptions pre to post-testing.

Summary

In summary, some researchers still adhere to the notion that implicit delivery of NOS (*doing science*) is an effective way to improve learners' conceptions of NOS. However, the literature supports the argument that the most effective method for improving conceptions of NOS is through explicit, reflective, discussion-based instruction. This dissertation research followed the advice of those researchers who recommend explicit delivery for good NOS delivery.

While many studies cited in this review have studied science teachers' conceptions of NOS, this study addresses the issue from a different perspective. Rather than focusing on one or two major characteristics of science (Barufaldi, Bethel, & Lamb, 1977; Behnke, 1950), I focused on seven major characteristics of science that are important to K-12 science instruction (Bell, Blair, Crawford & Lederman, 2003; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Smith, Lederman, Bell, McComas & Clough, 1997; Smith & Scharmann, 1999). I limited my research to practicing science teachers and I used an explicit approach in my NOS instruction joined with reflective dialogue with the teacher/students as recommended by current and past research (Abd-El-Khalick & Lederman, 2000; Akindehin, 1988; Billeh & Hasan, 1975; Lavach, 1969; Smith & Scharmann, 2006) and made NOS a daily emphasis throughout the intensive two-week academic program. Finally, I analyzed the verbal and written data using methodologies borrowed from qualitative research in order to better describe the ways in which the participants' conceptions were more or less aligned with the desired understandings put forth in the professional development.

This research addressed a gap in the research conducted thus far by examining the *ways* in which the participants' conceptions align and/or deviate from the desired understanding rather than merely identifying their conceptions as informed or naïve. It is hoped that this richer description of their mental constructs will allow for more thoughtful planning of future professional development intended to focus on NOS. It is through this more detailed analysis of the participants' data that this research examines inservice science teachers' conceptions of nature of science before and after engaging in an explicit, long-term, professional development intervention.

CHAPTER 3

RESEARCH PARADIGM AND METHODOLOGY

This chapter addresses the paradigm within which this research was conducted as well as describes my role in the study. I describe how the professional development was conducted, how the participants were selected, how the data were collected and analyzed.

Research Paradigm

While this research used some qualitative methodologies in how the data were initially analyzed, it should not be confused with naturalistic inquiry (N.I.). The research differs from N.I. in that it used these methodologies only to better identify the many ways in which the research participants expressed views of specific NOS aspects (ranging from informed to naïve) as well as identify misconceptions about these NOS aspects. This use of qualitative methodologies reduces the data (unlike N.I.) to discrete categories ranging from informed to naïve and then uses these categories to observe potential change over time. This research is an experimental study which relied on verbal and written data (rather than quantitative data) to gain better insight into teachers' complex and highly varied conceptions of NOS concepts. This methodology was chosen so that the overall evaluation of any participant's conception of any particular tenet of NOS would not be simply labeled as "informed" or "naïve" (or "adequate"/"inadequate") as seen in many studies upon which this research builds (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick, Bell & Lederman, 1998; Abd-El-Khalick, Lederman, Bell & Schwartz, 2001; Akerson, Abd-El-Khalick & Lederman, 2000; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) but rather their "informed" or "naïve" view could be better described.

Definition of Analysis Terms

Since methodologies have been borrowed from qualitative researchers but are being used in an experimental research design, the terms being used may imply different meaning when used in naturalistic inquiry than they do in this dissertation research. Despite this potential confusion, the terms are purposefully used to maintain consistency with the described methodology in published works of other contemporary researchers who use the VNOS instrument. To clarify the meaning of these terms, the following definitions are provided.

Data Unitization – a process by which any verbal or written data, once transcribed and formatted for analysis may be divided into data units that represent any particular aspect of NOS being examined. In this research, the data were initially color-coded in seven different colors (one color for each NOS tenet being investigated). Once color coded, each participant's data units could be pulled from the transcriptions and viewed tenet by tenet. This method of data unitization allowed the researcher to view all statements made by a participant regarding any one tenet and allowed contradictory statements about a tenet to be observed and weighed in context of all other statements.

Coding – a process by which all data units (within and across participants) for any one particular tenet could be viewed and common themes could be identified. After reviewing all data units, those which conveyed similar meanings could be given an identifying phrase (a code). In this research, coding the data in this manner allowed for commonalities and differences between and among the participants to be observed.

Classification of Codes – a process by which any code identified (for any tenet) could be identified as "informed", "transitional", or "naïve" based on its alignment or deviation from the desired understanding of the tenet to which it relates. In this research, classifying the codes into these three categories allowed for any participant's statements regarding any one tenet to be viewed together and for their informed statements to be weighed against their less informed statements (and vice versa). This process allowed for the participant's overall conception of any particular NOS aspect to be ranked as "informed", "transitional/informed", "transitional", "transitional/naïve", or "naïve".

Ranking of Overall NOS Tenet Conception – a process by which all codes for a particular tenet within a single participant's data (categorized as "informed", "transitional", and "naïve") could be viewed together and an overall determination of the participant's conception could be ranked into one of five categories ("informed", "transitional/informed", "transitional", "transitional/naïve", or "naïve"). In this research, ranking of participants' conceptions required much reflection and comparison to other participant data.

Researcher Role in the Interventions

As I played two distinct roles in this study; both the researcher (collecting and analyzing the data) as well as the content deliverer of the materials related to nature of science, it is important to describe this phenomenon in light of the research paradigm in which I worked. Despite the use of qualitative data and, arguably, qualitative methodologies, the post-positivist paradigm under which I approached this research is flavored with many positivist characteristics unlike most qualitative research. This may be largely attributed to my background in biological sciences and my many years of educational background in the bench sciences. Although I admittedly approached this research from a post-positivist perspective, I did not hold the positivist belief that I could accurately measure other individuals' conceptions of such a complex concept as NOS. With this in mind, I attempted to measure these inservice science teachers' understanding of and gauged their level of sophistication against an external constructed reality of what characteristics truly describe science as a discipline as described by Lederman (2006). I measured their understanding through empirical observations and attempted to come close to a realistic interpretation of their understanding. While I attempted to remain objective in these endeavors, unlike the classical positivist, I realized that measuring my participants' understandings of such a complicated concept as NOS was no easy task. My personal subjectivity and bias affected my interpretation of their written responses to the instrument I used. Furthermore, my dual role as researcher and content deliverer offered even more opportunities for my objectivity to be lessened as I interacted with the participants while delivering lessons, participating in activities, and engaging in reflective dialogue with them. These opportunities, rather than be seen as detrimental to my objectivity, were rather considered a way to more greatly enhance my insight into their understanding of the concepts on which I focused. In an effort to maximize the benefit of this intimate participant/researcher approach, I combined the validated, open-ended, VNOS-D (Appendix A) with individual interviews of each participant before and after the workshop to look for change in conceptions of NOS over the course of the workshop interventions. These four sources of data were used to help gain an approximation of the participants' conceptions of NOS. Using individual interviews along with the questionnaire helped to avoid problems with trustworthiness which might arise when analyzing the questionnaire alone.

Teacher Quality Professional Development Workshop

The professional development, during which this research was conducted, was offered at a small private university in north central Texas as a part of a teacher quality grant. The professional development, entitled “Increasing Pedagogical Content Knowledge (PCK) and Understanding of Nature of Science” is, in part, based upon the State approved Teacher Professional Development module developed in 2004 for the Dana Center in Austin (Drenner & Weinburgh, 2004).

The professional development consisted of a two-week summer institute and follow-up monthly day-long meetings. The intention of the professional development was to use popular press “contemporary issues” in biology to increase/update the participants’ biological content knowledge as well as to help them develop an informed view of nature of science (NOS). This research focused on the aspect of NOS. In order to help the participants increase their understanding of NOS, a series of interventions were planned and were incorporated into the professional development activities.

Participants

The participants involved in this research were public school teachers selected from a pool of applicants who responded to an announcement of the workshop that was sent to school districts in the surrounding area, or who learned of the workshop by word-of-mouth. Participants were selected based upon the criteria set by the Dana Center which focuses on the teachers’ personal needs for such a professional development. Teachers who were teaching out of their subject field or who lacked professional development credits were given priority. Twenty-five middle-school and high-school teachers were invited to participate in the workshop. Of those invited, 19 participated. Of those who participated, 11 accepted the invitation, signed an informed consent to participate in the research, completed the two-week workshop and answered both pre and post-intervention assessments. These 11 participants who completed all components of this study are the focus of this research.

Pre-Assessment Strategies – VNOS-D and Interviews

Multiple types of data were collected during the two-week workshop. In addition to the responses to the VNOS and interview questions (both pre- and post-workshop), audio and video recordings were collected throughout many of the interventions. With this amount of data, many questions could be addressed. Some questions of interest include: What types of interventions affected the most change in conceptions for each tenet being studied? What characteristics of the interventions caused them to be more or less effective? How many interventions are needed to begin to see change in conceptions? Did the order of the interventions have an effect?

This research, however, was limited to one particular question: In what ways do inservice science teachers' conceptions of nature of science change by engaging in a long-term, explicit, professional development? All of the interventions described in this research were conducted in a way that explicitly addressed the seven tenets of nature of science being studied. This research did not analyze the individual interventions, but rather, looked for change in conceptions among the teachers after experiencing these interventions. With this focus of the research, the data that were analyzed included the VNOS responses and the interview transcriptions only.

To develop a rich description of the teachers' conceptions of NOS, I used two distinct forms of assessment; the Views of Nature of Science Questionnaire – Version D (VNOS-D) and individual interviews. Both of these assessments were conducted prior to any content delivery and again at the end of the two-week summer workshop. These two assessment tools were used in pairs. The initial VNOS and the initial interview data were analyzed in a manner similar to that used by leading researchers in the field of NOS (Abd-El-Khalick, 2007; Akerson, 2008; Koehler, 2008; Lederman, 2008; Lederman, 2007; Schwartz, 2008). This pre-intervention analysis of data was used to construct a participant "pre-profile" in order to attempt to describe the participants' conceptions of NOS prior to any intervention efforts. The post-intervention VNOS and interview were used to construct a second participant "post-profile" which attempted to describe the participants' conceptions of NOS after the interventions. This strategy resulted in two distinct points in time that each participant's knowledge of NOS was assessed using two different forms of assessment.

Pre-Intervention VNOS-D

Although characterized as "pre-intervention", the pre-workshop VNOS-D questionnaire was actually the first of many NOS interventions that the teachers experienced during the two-week workshop. The survey was administered using the on-line survey tool, Zoomerang©. The survey web link was e-mailed to the participants prior to the beginning of the summer workshop along with the invitation to be included in the research and the appropriate consent form. Using Zoomerang© ensured that each participant had ample time to finish the seven, open-ended questions. The survey introduction advised the teachers that the questions do not have right or wrong answers and instructed them to take all the time they needed to fully fill out their answers. The very act of asking the teachers to answer the VNOS questions forced them to begin thinking philosophically about how science works as a discipline and what characteristics set it apart from other ways of knowing.

The VNOS-D responses were accessed via Zoomerang© as digital files in the form of excel spreadsheets. The responses were coded with random numbers substituted for the participants' names to maintain confidentiality. A master list of the participants and their code numbers was maintained for future use in matching participants with their responses. All originals were kept locked in the office of the researcher and will be kept for seven years as required.

I conducted an initial, cursory, examination of the VNOS responses in order to guide the follow-up pre-intervention interview. While reviewing each individual's responses and determining their conceptions of each tenet, I developed individualized VNOS-follow up questions which were used to clarify the participants responses and to ensure they had adequate opportunity to express their understanding. The questions also helped to identify whether the participants had better understandings of the tenets in question than was revealed by their answer. Care was taken to construct interview questions that were not directly tied to the research question as cautioned by Glesne (2006). Questions were designed to give participants an opportunity to provide evidence of their conception of a tenet but not guide them towards the answer itself; if they provided no evidence regarding a particular NOS aspect that the supplemental question was designed to address, this could be indicative of a lack of understanding of that tenet.

Instead, the questions were related to participants' individual VNOS responses and were used to allow me further insight into their conception of NOS.

Development of Pre-Interview Profile

After assigning code numbers to the 11 participants' VNOS responses, I unitized the data by color coding any phrase that related to any of the seven tenets of NOS being studied. I assigned a different color to each tenet for ease in separating the data later when preparing the participant profiles. If a single phrase related to more than one tenet of NOS (i.e. empirical NOS as well as Observations and Inferences) I would color code it first with one color and then add a tenet-identifying "tag" at the end of the phrase and color code it accordingly so that the phrase would be easily identified as dealing with more than one tenet. Once the data were unitized and color-coded for all seven tenets, I then created a participant profile word document which pooled all phrases for each tenet so that I could score the participant's understanding of each. When creating the participant profile page, I was careful to identify each phrase with the VNOS question number to maintain an audit trail for the data. This audit trail was crucial for identifying exactly where the phrase was used so I could interpret it in context of the whole VNOS. Once I had created the pre-interview profiles, I was then ready to qualitatively code each data unit according to the underlying meaning behind the statement. For example, take the following three hypothetical statements that could be found within a VNOS; "scientists must have hard data or else it's just a wild guess", "scientists have to have real, concrete evidence", and "without hard data there is just no way to know". All of these statements imply the need for concrete evidence and none describe the way inferences are based on hard data, but lack the empirical data to directly support them. In these cases, all three data units (phrases) could be coded as [*MUST have empirical data (no inferences)*]. This code would apply to any related data unit within this participant's VNOS and all other sources of data among all participants. I began the coding process by simply writing a short descriptive statement of each phrase that served to identify the interpreted meaning behind the phrase. For example, if the data unit read, "Scientific knowledge will change as new discoveries are made" I might have identified it with the code, [*Scientific knowledge grows*]. If the data unit read, "Scientific knowledge sometimes is found to be incorrect when new discoveries are made or new technology allows us to understand it better", I might have identified it with the code, [*Scientific knowledge is corrected over time*]. By using these preliminary codes, I was able to begin noticing common themes emerging within individual VNOS's as well as across all VNOS's. After coding all data units for all of the all participants' VNOS's, I then revised the codes to accommodate all data units across all VNOS's. While revising the codes, some became more inclusive to contain what I had previously identified as more than one code. In other words, multiple codes were collapsed into one. For example, the codes [*New cures for diseases will be found*], [*New species will be discovered*], and [*New technologies will improve human lives*] all related to new discoveries being made in science. These three codes could be collapsed into one code [*New scientific knowledge will be added*]. Likewise, during code revision, some codes were split into two distinct codes to identify multiple codes within a related area. For example, [*Describes hypotheses and/or theories well*] was split into [*Theories are explanatory*] and [*Laws are descriptive*]. Once all data had been unitized and codes were created, each code was classified as being informed, transitional, or naïve. A list of all codes identified during this research is found in appendix B.

For each tenet being studied, the participant received an overall ranking of informed, transitional/informed, transitional, transitional/naïve, or naïve based upon all codes found within their dataset. The rankings for each participant's conception of each tenet were determined as follows:

Informed Ranking – For a participant's conception of a tenet to be ranked "informed", they must have 1) provided data that only included informed codes, their data must have demonstrated an understanding of all aspects of the NOS tenet, and their data could include no evidence of any misconceptions or naïve views or 2) all as above, but also demonstrated a "transitional" or "naïve" code which was clarified and corrected for by another "informed" code; in this case, any "transitionally" or "naïvely" coded statement that was a direct contradiction of an informed statement (indicating a misconception or contradictory viewpoint) would be addressed in the follow-up interview questions (if it was not corrected-for in the interview, the overall conception would not be ranked informed).

Transitional/Informed Ranking – For a participant's conception of a tenet to be ranked "transitional/informed", their data must have included 1) more "informed" than "naïve" codes, but failed to demonstrate an informed understanding of all aspects of the tenet or 2) demonstrated an informed understanding of all aspects, but also demonstrated a less-than-informed understanding as well and not have corrected for this discrepancy during the follow-up interview questions.

Transitional Ranking – For a participant's conception of a tenet to be ranked "transitional", they must have provide data that 1) included relatively equal amounts of "informed" and "naïve" codes (with or without "transitional" codes), or 2) only included "transitional" codes.

Transitional/Naïve Ranking – For a participant's conception of a tenet to be ranked "transitional/naïve", their data must have included more "naïve" than "informed" codes, but demonstrated some degree of informed understanding of at least one aspect of the tenet.

Naïve Ranking – For a participant's conception of a tenet to be ranked "naïve", they must 1) have provided data that included only "naïve" codes (no "informed codes") or 2) provided data that included no codes for the tenet whatsoever; in this case, the participant would have been able to offer no statements to the "supplemental VNOS questions" which directly addressed the tenet of concern (indicating a lack of understanding of the tenet).

It is important to note that although a participant might have made statements which indicated an informed view of a particular tenet, its informed value might be lessened by more naïve statements made during interviews or found in their VNOS responses which could result in their overall conception as being rated less than informed. The same effect could, and was, seen with seemingly naïve statements being valued less when they were accompanied by more informed views expressed elsewhere in the data. Furthermore, just because a participant's data might include a statement which was classified as informed, it might not include enough of the informed aspects of a particular tenet to give them an overall informed ranking (likewise with naïve views expressed).

Last, a particular statement could be coded and labeled as naïve even though the statement might well be factually correct.

When coding and classifying the data, I was not determining how true or false the statement was, but rather how closely it demonstrated a sophisticated understanding of the tenet in question. The common statement “scientific knowledge will increase as scientists make new discoveries is a prime example. Because prior studies of NOS conducted by this researcher (Bloom, Sawey, Holden & Weinburgh, 2007; Bloom & Weinburgh, 2007) have revealed that some hold the naïve view that the only way that scientific knowledge changes is by adding new material to the canonical body of knowledge, a statement such as this may indicate that a participant holds a simplistic view of the tentative NOS. Because of this, such a statement, while being absolutely true, would be classified as a naïve conception of NOS. If it was not accompanied by other statements which indicate that knowledge can also change as new discoveries reveal that previous scientific claims are found to be incorrect and so the body of knowledge corrects over time, the participant could receive an overall ranking of naïve for his conception of NOS. Conversely, if a participant made such a naïve statement, but then articulated a more informed view that scientific knowledge corrects over time with new technology, her overall ranking would reflect this more informed view.

These data were summarized on a data summary excel spreadsheet (Appendix C) which was used to document their “pre-intervention” and “post-intervention” conceptions for comparison purposes. As a basis for determining how to rank participants’ conceptions, I used modified and updated definitions of the seven major tenets building upon the definitions of Lederman (2006b).

Although the participants' responses were categorized into one of five distinct categories for each tenet, it may be the case that a continuum would better represent how the participants responded. The categories serve as the best approximation of their conceptions that I could achieve. These approximations were used to develop the follow-up interview questions to better identify where along the continuum they fall.

Pre-Intervention Interview

The pre-workshop interview served as an opportunity for me to clarify my initial perceptions of the participants' understanding of the seven tenets and add validity to my interpretations of their VNOS responses. During the interviews, I discussed any VNOS responses about which I was unclear and gave the participants ample opportunity to clarify their answers. I then addressed each tenet directly by asking the participants supplemental VNOS questions. Many of these supplemental questions used a Likert scale to identify how much influence a participant believes each tenet to have on the processes of science. All tenets were addressed in the interviews.

Interviews took place in a prearranged room at Texas Christian University and were recorded with a digital voice recorder. Interviews ranged in length from 25-45 minutes. At the beginning of each interview, the participants were informed of the purpose of the research project and were informed that the interview would be audio taped for later analysis as indicated on the signed consent form. I began the interviews with "warm-up" questions (i.e. Did you have any trouble finding me?, Did you have to drive far?, Have you participated in professional developments before this?) to help the participants become more comfortable answering questions and to offer them a chance to develop rapport with the researcher as recommended by Silverman (1993). After an initial discussion time (a couple of minutes) the formal interviews began. I used the prepared individualized questions from the participants' personal profiles to ask any pertinent questions which addressed themes found in their VNOS responses and to verify questionable "grading" of participant responses by the researcher. This portion of the interview was less structured since the prepared individualized questions sometimes led to further questions. I tried to allow the participant opportunity to fully articulate their answers and did my best to not guide their responses.

After the individualized questions were addressed, I then offered each participant an opportunity to address each of the seven tenets of concern directly. The VNOS itself, does not directly ask the participant to offer his or her opinion about each tenet, but rather contextualizes the aspect of NOS in question to see if the participant naturally addresses it in any way. I believe this allows some participants, who may have an informed view, to fail to demonstrate it in their answer. To this end, I developed standardized follow-up questions which were offered to all participants during their interview to directly address the seven tenets being researched. These supplemental VNOS interview questions are provided in Appendix D. I was very explicit with the participants that the standardized follow-up questions were in no way tied to their VNOS responses, but were being used for all interviews. For some of the questions, part of the response involved ranking their agreement or disagreement with a statement. For these questions a visual diagram to which the participants could refer was provided where the participant could identify on a scale of 1-10 their level of agreement or disagreement. I was careful to make sure the participant understood the visual diagram and then asked them to place a marker on the diagram indicating their level of agreement or disagreement with the statement. After ranking each question, the participant was then asked to explain his/her answer and give examples when possible. The rest of the "follow-up" questions were open-ended questions. I gave the participants all the time they need to answer the questions to their satisfaction and refrained from offering them any guidance in how to answer.

Development of Pre-Intervention Profiles

The interviews were transcribed into word documents for analysis. I carefully read each transcription and unitized them into data units in the same manner that I unitized the VNOS responses. Once unitized, I then added these data units to the participant profiles and coded them as I did the VNOS data units. This collection of data units (including both VNOS responses as well as interview data units) were then used to, once again, determine each participant's comprehension of the seven tenets of NOS being studied and I awarded each participant a revised ranking of naïve, transitional/naïve, transitional, transitional/informed, or informed for each of the seven tenets of NOS.

Interventions

The following interventions were conducted in order to challenge the participants' views of NOS and to help improve their conceptions of the seven tenets being addressed by this research. These interventions were conducted throughout the two-week workshop and were interspersed among the classical and contemporary content knowledge delivery of the workshop curriculum.

- The Checks Lab – Discussion of Models
- "The Three Legs of Good Instruction" – Lecture/Discussion
- Paired Statements – Activity/Discussion
- The "Proof" Wall – Language Use Inventory
- "Footpath Murders" – NOS Checklist/Discussion
- "Ulcer Wars" – NOS Checklist/Discussion
- "Origin of AIDS" – NOS Checklist/Discussion
- "How's Your Horoscope" Activity/Discussion
- Evolution/Creationism/I.D. "School Board Debate" – Activity/Discussion

Checks Lab

The "Checks Lab" was perhaps the most explicit opportunity to deliver NOS to the participants. This activity has a long history and many versions have been found. All versions, including the one used in this research, are based upon an original publication by Crue (1932). In the checks lab, the teachers were divided into groups and each group was given an identical set of 16 canceled checks and a data gathering form (Appendix E). Each group was instructed to randomly pull four checks from their set and to begin making observations and record any evidence that they found. Once their information from the checks had been recorded, they were asked to make up a story that they believed adequately accounted for the data collected. After constructing their initial story, they were instructed to draw another four checks and to use the new information they gathered to revise their story. Finally, they drew four more checks and finished revising their story so that it accounted for all the data collected from their 12 checks. Once all groups had their final stories, they shared them with the rest of the class. Because none of the groups were able to view all 16 checks and because of the random drawing of the checks, each group had some information the other groups did not. Because of this, their stories varied to some degree. When one group found flaws in another group's story, its' members would use their data to contradict the story being presented thereby adding to the body of knowledge shared by the class. Finally, as a class, the groups shared all their information and developed the most plausible story to fit the collective data. In a debriefing of this activity, I explained how this activity exemplified the tenets of NOS.

3 Legs of Good Instruction

In "Good science instruction: A leg (or three) to stand on", Weinburgh (2003a) discusses the three important components to quality science instruction. Traditionally, teachers have focused on either emphasizing process skills with "hands-on" activities or have focused more on content knowledge delivery (using worksheets and lectures). Weinburgh addressed, by way of a lecture, a need for not only blending these two methodologies (collectively called pedagogical content knowledge or PCK), but also adding the "third leg" of good instruction, which is presenting NOS.

Paired Statements

The “Paired Statements” activity (Appendix F) was developed by Smith and Scharmann (2006). In this activity the participants were given 10 pairs of statements and were asked to rate one of each pair as being “more representative of science” and the other as “less representative of science”. Rather than being forced to call one “not scientific” and the other as being “scientific”, the participants were asked to discuss why they choose to designate each statement the way they did. Each participant was told to use the seven tenets of NOS as the determining factor in their decision. The objective of the activity was to get the participants thinking in terms of NOS tenets and then to defend their decisions based upon them. They first did the assignment individually and then as small groups. When working in groups the participants were told to share out why they designated their statements the way they did and to come to a consensus. After all groups completed the activity, all group-answers were compared and discussed. Because they were asked to use the seven tenets as the determining factors and because a whole-class discussion/debriefing followed the activity, all seven tenets were well represented in this activity.

“Proof Wall”

The “Proof Wall” was not an activity, per se, but rather an opportunity to stress the importance of the tentativeness of science. In discussions early in the workshop, the participants were clearly told that science advances by disproof and that we, as scientists and science educators, need to take the word “proof” out of our vocabulary. Everyday use of the word proof in scientific discussions can obscure the fact that scientific knowledge is tentative and always participant to change. To help the participants replace the word proof (with more authentic descriptors like “supported by”, “validated by”, etc.), a poster was placed on the wall with the word “Proof” on it. Anytime a participant used the word prove (or proof, proven), a check mark was placed on the poster. Whenever this occurred, a short (1 minute) discussion followed to reiterate the need to stop using the word proof and how we need to find a better way to make these statements. Once the statement was reformulated, the previous discussion would continue. This activity stressed the tentative nature of science.

Footpath Murders: DNA Profiling’s Landmark Case

“The Footpath Murders: DNA Profiling’s Landmark Case” (Films for the Humanities and Sciences, 1997) is the title of a video that was shown in order to engage the teachers in the topic of DNA fingerprinting. The video tells the story of the first time that DNA fingerprinting was used in a criminal case to exonerate a charged felon and to identify a murderer. In past professional developments teachers recognized many of the tenets of NOS in this film. In an attempt to see if the participants could recognize NOS tenets within the context of “real science” rather than just as an abstraction, I provided them with a NOS checklist (Appendix G) and instructed them to fill in examples of the seven tenets while they watched the film. At the conclusion of the film, all examples of NOS were discussed as a group.

Ulcer Wars

“The Ulcer Wars” (Films for the Humanities and Sciences, 2005) is another film that demonstrates some of the major tenets of NOS such as scientific knowledge changes over time (tentative), and that the scientific community exercises healthy skepticism regarding new discoveries (theory-laden subjectivity), and scientific findings are based upon empirical evidence. It also shows that science does not always follow a strict linear methodology. Once again, I provided the NOS checklist for them to fill out while they watched the film. They were asked to document any evidence of the tenets of NOS while they watched the film and we discussed their observations as a class once the film had ended.

Origin of AIDS

"The Origin of AIDS" (Galafilm, 2003) is a documentary film describing a controversial, alternative theory of the origin of HIV and AIDS. The documentary was not presented as accepted scientific knowledge, but rather was used as an example of scientific methodologies merging with investigative journalism and served as an example of many tenets of NOS. Before showing the documentary, I conducted a quick review of the seven major tenets of NOS and then provided them another copy of the NOS checklist. The documentary was shown to the participants and then time was given for a group discussion at each table to determine if the controversial "attenuated polio virus" theory (APV theory) seemed more or less scientific. A debriefing was conducted after this activity to explicitly discuss each tenet once again. Care was taken to ensure that I did not guide them to decide if the theory should be accepted science or not, but rather to analyze the statements being made as fitting with the methodologies of science or not.

How's Your Horoscope?

In the astrology activity (Flammer, 2002), the participants were each given a list of twelve personality profiles and then asked to identify which one they thought best represented their personality. The personality profiles were based upon the moon-signs commonly used in astrology. After they decided on which personality profile best matched them, I revealed the birth dates associated with each profile. As a class, we then calculated the percentage of participants who accurately identified their moon-sign (matched) and how many did not match and compared our findings to chance alone. We then discussed and debated how scientific astrology really is. Instead of classifying astrology as science or non-science, we instead opted to use a continuum on which we could place astrology as “more like science” or “less like science”. The arguments (for or against astrology as a science) were based upon the seven tenets of NOS being studied. With the help of some guidance in the discussion, all tenets of NOS were examined and discussed.

Evolution, Creationism, I.D. Debate

For the last NOS intervention of the two-week summer workshop, we conducted a debate with an imaginary school board about what should be included in a science curriculum; evolution, intelligent design, or creationism. I randomly divided the participants into three groups and asked them to investigate one of the three *theories*. They were instructed to act as supporters for their particular theory and asked to use the seven tenets of NOS and the associated language of philosophy of science to make recommendation for their theory to be included in the curriculum. Each group was given adequate time to research their theory and were then given the opportunity to present their argument to the school board. The school board will be made up of the other two groups. After a 10-15 minute presentation, the school board members were given the opportunity to argue against the inclusion of each theory in their science curriculum (again using the language of philosophy of science and the seven tenets of NOS). With instructor guidance, all NOS aspects were discussed.

Post-Assessment Strategies – VNOS-D and Interviews

Post-Intervention VNOS-D

At the conclusion of the two-week summer professional development, the participants were asked to answer the VNOS Zoomerang© survey once again. The survey was administered on the last day of the professional development. This was another opportunity for the participants to articulate their understanding of NOS concepts in relation to the VNOS questions. As with the pre-intervention VNOS, some tenets of NOS were more easily elucidated than others. Because of this, a post-interview accompanied this VNOS as well. The post interview was conducted prior to the first academic year follow-up session.

Post-Intervention Interview

Between the end of the summer two-week workshop and the first academic school year Saturday meeting, each participant was contacted by telephone to conduct a post-interview. During the post-interview, each participant was first asked to convey his/her conception of NOS. Once they had conveyed their conception of NOS, I asked the teachers how their conception had changed over the course of the two-week workshop. I asked the participants to discuss each of the seven tenets of NOS individually in order to allow them another opportunity to overtly explain any other thoughts that they may have left out of previous answers. To finish the interview, the participants were asked whether they believed a better understanding of NOS empowered them to make decisions about what should and should not be included in a science curriculum. These interviews were audio-recorded for future analysis.

Development of Post-Intervention Profiles

The post-intervention profiles were created using the data from the post-VNOS and the post-interview. The post-intervention VNOS's were accessed through Zoomerang© and the data were unitized in the same manner as the pre-intervention VNOS's. These new data units were added to the data summary page along with the first two sets of data collected. The post-intervention interviews were transcribed, formatted, and unitized using the same methods as the pre-intervention interviews. Once the data was unitized, I added it to the data summary page as well to create the post-intervention profile. I then carefully examined the newly added data units and coded them in the same manner that I coded date units from the pre-intervention VNOS's and interviews. After the newly added data had been coded, I looked for instances where new data units contradicted data units from before the intervention. For example, in the pre-intervention data, a participant may have only addressed the tentative nature of science by describing how scientific knowledge grows and would have been given the naïve code [*New scientific knowledge will be added*]. In the same participant's post-intervention data, she may have referenced how scientific knowledge grows, but also described how, with new technology and new interpretations, previously held beliefs could be improved and corrected. This post-intervention conception would have been given the informed code [*New knowledge grows AND is corrected*]. If a contradiction such as this occurred, I interpreted the first data unit in light of the subsequent contradictory data unit with the assumption that the previously held conception of NOS had been replaced with a new conception. If no contradiction of old conceptions were identified, the old data units were left in the post-intervention profile under the assumption that the prior conceptions had persisted throughout the interventions.

Comparison of Pre- and Post-Data

The three distinct participant profile's data for each participant were aggregated onto the data management spreadsheet to organize the pre and post participant profile scores for each tenet of NOS being studied. I then looked for changes in each participant's perceptions that occurred over the course of the professional development for each tenet for description in individual case studies. This gave me the opportunity to identify any tenet-conceptions that improved or worsened over the course of the professional development and any tenet-conceptions remained unchanged.

CHAPTER 4

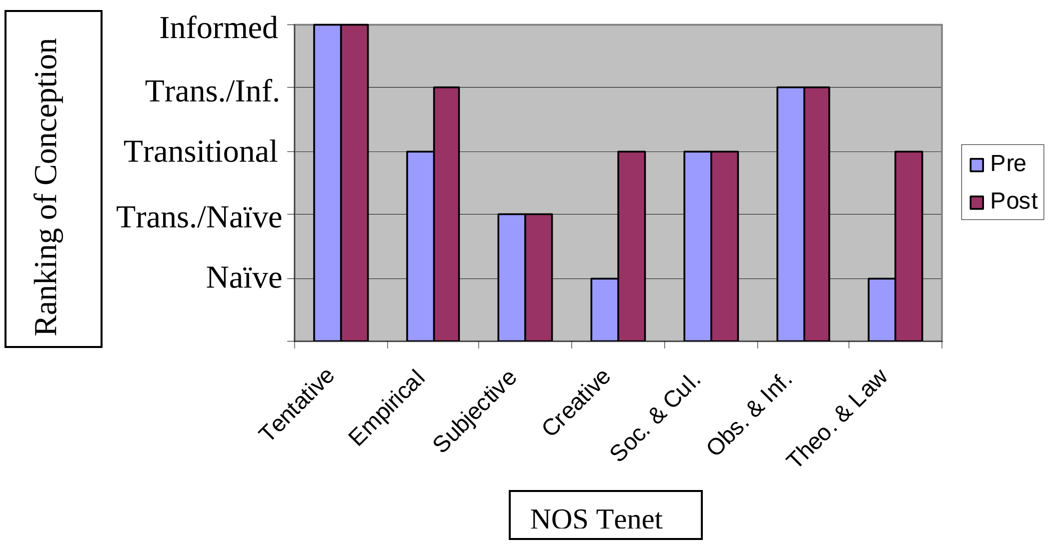
RESULTS BY CASE

This chapter presents the results of this research in context of each participant's pre- and post-conception of NOS. I will begin by introducing the participant and give some brief demographics about their academic background, grade level taught, and how many years experience that they had teaching when they began the professional development. I will then provide a graphic illustration of their conceptions of the seven tenets of NOS being studied in this research that will display how I classified their conception of each tenet both before and after the intervention. Following this graphic display, I will carefully describe each informed, transitional, and naïve code that was identified in their pre-intervention data, give examples of each code, and reiterate how their pre-intervention conception of each tenet was classified. Then, I will describe any additional codes that were identified in their post-intervention data and give examples of each. If these codes necessitate re-evaluation of their understanding of any particular tenet (either as more informed or less informed), the reclassification of their understanding will be described and their post-intervention conception of each tenet will be described.

Case study #1 – Angela

Angela is a 9th grade teacher who has six years experience teaching science. Her educational background includes a Bachelors of Science degree in biology and she is alternatively certified. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure I. Examples of Angela's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure I. Angela's Pre- and Post-Intervention Rankings



Angela – Tentative

Angela began the workshop with an informed conception of the tentative nature of science. She made numerous references in her VNOS responses and in her interview which corresponded to the informed code [*New knowledge grows AND is corrected*]. Question #4 on the VNOS asks "Scientists produce scientific knowledge. Some of this knowledge is found in science books. Do you think this knowledge may change in the future? Explain your answer." Angela expressed a clearly informed view of the tentative nature of science with the following response:

> *When I am telling my students about spontaneous generation, Aristotle's theories, Lamark (sic), etc., my students always laugh at them and remark on how stupid they were. I remind them that as technology has evolved, science has evolved. What we believed as correct back then, is not completely correct today, but it was at least a starting point. Most of the theories have valid thought, but like Lamark (sic), he did not understand or even know about genetics. I then tell them that in 100 years, our society may look at what we thought was the law in science, but come to find out, we were completely wrong and think that we were stupid. Currently, scientists are looking at DNA and how proteins are coded. They are now thinking that proteins are not coded as we once thought they were. Science is always evolving. Text books just cannot evolve that fast. Text books are good for the basics.*

This description clearly matches the informed view of the tentative nature of science put forth in this research. While Angela readily admits that scientific knowledge changes continually, she does not exhibit the naïve view that there is no reliability in science. She discussed how, despite having arrived at incorrect conclusions, Aristotle and Lamarck had done the best they could with the technology of their day. She further balanced the constantly-changing face of science with the fact that some scientific knowledge is highly reliable and remains unchanged as seen in the following interview statement:

> *[Scientific knowledge] is changing everyday. It does, it's probably changed today, yesterday. There's a lot things will stay the same, but there's the sub-parts of that, maybe the smaller inner workings of that, that change constantly. That they find out more, technology changes, as it gets better, science does too.*

Most important is the fact that she emphasizes that the changes that occur in scientific knowledge makes it more reliable. The only naïve statements made included the use of the word proof or proved, however, Angela clarified the use of these words and indicated that she was only using them in the colloquial, non-scientific sense as seen in this interview segment:

> *Angela – To me, that [proof] means that they ran an experiment and came out with what they… some valid answer at the end and did it a few hundred more times and that's proof that that happens.*

Mark – So is it 'take it to the bank', you can count it?

Angela – It's science, no. Again, as our technology gets better, at this moment in time, that is our final word.

The only post-intervention change detected in Angela's conception of the tentative nature of science was in a positive direction with her indicating that she would use caution to not use the word prove in her science classrooms anymore. In her post-interview she stated,

I'm not going to use the word 'prove'; you substantiate your claim.

This statement was given the informed code [*Won't Use Proof Anymore*] and her post-intervention conception of this tenet retained the informed ranking.

Angela – Empirical

Angela's pre-intervention conception of the empirical nature of science was not as sophisticated as her understanding of tentativeness in science and was ranked transitional. Angela clearly communicated that science must have some basis in empirical evidence as seen in this segment from her interview:

Mark – Does there have to be empirical evidence for it to be science?

Angela – Yes, because if not then you kind of goes toward faith.

The above statement was coded [*Must have a basis in empirical evidence*]. Although she demonstrated this informed view of the empirical nature of science, she also demonstrated a naïve view that is closely related to the informed code; that all science must have direct empirical evidence. Her statement which showed this naïve view was coded [*Must have empirical evidence (no inferences)*] and was found in her interview.

That's one thing we talk about with our kids, the difference between science and faith is that faith is something you believe, science is something that you can physically test and physically experiment on. If it's not there, then it's not science.

This statement indicates that all scientific knowledge must have empirical evidence which can be directly observable to the senses. This view would discount the credibility of inferences and scientific theories which can only be tested indirectly but are clearly based on empirical evidence.

In her post-interview, her position changed to a slight degree. While she still did not convey the most informed view of the empirical nature of science, she did make statements which indicated that a basis in empirical evidence was necessary and did not make any statements which demanded empirical evidence for all scientific claims. One statement in her interview which seemed to strengthen her claim that an empirical basis was needed but softened her position that all scientific claims must have direct, observable evidence was:

> *Mark – Can you have something called science if there's no empirical evidence that it's based on?*
>
> *Angela – I don't know what my opinion was the first time, but I would still say no. To me, that's what science is based on, based on empirical data. There are thought processes you go through before you have empirical data to then… But I still think you have to have empirical data for it to be science.*

She further demonstrated a more-informed view by adding a statement which was coded [*Science doesn't study supernatural*]:

> *Science is the study, like of natural science, of natural things. And so when you look at the other, creationism and intelligent design, that's super-natural, non-natural things, but that should be separated out. I think that a lot of people just kind of had an 'ah ha' as to why maybe that separates out…evolution you've got empirical, you've got that information there. It's natural science versus the other.*

Because Angela reinforced her view that science depended on an empirical basis but did not reiterate that all scientific claims had to have direct observable evidence and since she further distinguished natural sciences from supernatural by referencing empirical evidence, her post-intervention conception of empirical was classified as transitional/informed.

Angela – Subjective

Angela maintained a transitional/naïve conception of the subjective nature of science throughout the interventions, although there were slight changes in her conception. Before the intervention, Angela demonstrated transitional view that personal backgrounds could contribute to subjectivity in science, but did not reference the theory-laden nature of scientific interpretation. This transitional view was coded [*Different backgrounds cause subjectivity*] and was found in her interview.

> *Every one of those scientists have different backgrounds and different beliefs and they interpret that information a little bit differently*.

She demonstrated two naïve codes; [*Subjectivity "just a human thing"*] and [*Subjectivity is bad for science*] in the following interview excerpt where she responds to the question of how scientists could disagree on how dinosaurs became extinct:

> *Angela – Their background, their beliefs, everyone's got…it was millions of years ago. You have a whole bunch a set of information and I can give it to you and you can give it to me and we're reasonably intelligent people and I may interpret one piece of data a little bit differently than you do… But to me, it would be interpretation of that data of that information, which of course you're not supposed to do in science, but it still happens.*
>
> *Mark – You're not suppose to in science?*
>
> *Angela – Not data, not hard data…*
>
> *Mark – But you're saying that interpretation should be kept out of the data analysis?*
>
> *Angela – When you're doing a true experiment, which they're not able to do really those experiments that, yes, interpretation…it should have some interpretation in there, but that's when bias comes into play.*

After the two-week workshop, she softened her statement that subjectivity was bad for science, but still implied that there was something to be careful about with subjectivity:

Mark – So would you say that subjectivity is a negative aspect of science?

Angela – I don't think it's negative. I just think it's reality. It does have some negative affects in some circles, but I really think it just happens, we're human. I don't think it should be looked on negatively. I just think it should be looked on with caution to make sure you're not too subjective looking at something.

This transitional statement was coded [*Subjectivity isn't bad, but we need to be aware of it*]. Although some might consider this a somewhat informed statement, it still misses the desired understanding that subjectivity is caused by the educational background and theoretical framework from which a scientist approaches her data. Because of this, her post-intervention ranking remained characterized as transitional/naïve.

Angela – Creative

Angela began the workshop experience with a naïve understanding of the creative nature of science. She demonstrated the naïve code [*Creativity in setting up experiments or developing questions*] in many statements in both the VNOS and in the interview. The following statement exemplifies her thoughts on the role of creativity in science:

Angela – So, anyways, that takes a lot of creativity to figure out sometimes how to set it [the experiment] up so that it will work.

Mark – I seem to interpret your response as saying creativity at the analysis portion could taint pure science.

Angela – uh huh.

Note that she not only implies creativity is only useful in the beginning of the experiment, the above quote also indicates that she believes creativity could have a negative influence on science.

At the end of the two-week workshop, Angela's conception of creativity in science had improved. In her VNOS response to the question about the role of creativity in science, she stated:

> *Scientists nullify their hypothesis more than they accept them. Through this can come creativity on the how and why it occurred leading to an even bigger discovery. Scientists use creativity when setting up an experiment. Scientists use creativity to explain occurrences that are not explained well, or have questions about the explanation - HIV stemming from Polio.*

In this statement, however, some naïve, transitional, and informed codes are identified. She does reference to how scientists are creating explanations for phenomena not previously understood [*Creativity in explaining occurrences*] which is an informed view. But she also seems to confuse creativity with subjectivity (theory-ladenness) [*Conflates creativity and subjectivity but realizes its import*] which is a transitional code, and still relegates creativity to the beginning of experiments in the design and questioning phase [*Creativity in setting up experiments or developing questions*] which demonstrates a persistent naïve view. Because of this movement toward a more informed view, but statements which indicate a persistent naïve view, her post-intervention conception of creativity was characterized as transitional on creativity at the end of the workshop.

Angela – Social and Cultural

Angela's conception of the social and cultural aspect of NOS remained classified as transitional throughout the workshop experience. In the pre-intervention data only one code was identified; [*Social and cultural values can limit science*]. A prime example of her ideas of social and cultural values is seen in the statement:

> *Oh sure, it's like stem cell research. In America, we can't officially do a lot of stuff because President Bush is up there saying 'no.' Cloning of humans we can not try because President Bush is up there saying 'no'.*

Although this is not an incorrect view about how societal pressures can limit science, it fails to recognize the fact that they can also be the impetus for scientific research. No other evidence of any kind related to social and cultural nature of science was detected in the post-intervention data.

Angela – Observations and Inferences

Angela's conception regarding observations and inferences was classified as transitional/informed throughout the professional development. Her pre-intervention data revealed two informed codes [*Use of current knowledge and theory to make inferences*] and [*Confidence in inferences increases with more data*] as seen in the following statements in relation to how scientists know what dinosaurs looked like:

> *Mark – So when they're determining what color to paint their model…*
>
> *Angela – They're basing it off today's plants, today's reptiles, the way that they look, their coloration, the way that they blend in. It would make sense, green plants, they would be greens and browns to blend in with their environment.*

And in relation to weather predictions:

> *Angela – So even in their computer models that they've got all these nice little bits of variables and information they're putting in here and they go 'ok the jet stream is gonna be here and this is gonna be here and the high's gonna be here and low's gonna be here, what's gonna happen.' Well what if this low in Texas isn't gonna move? Well that's gonna affect all those other pieces of that puzzle and so it's going to throw their prediction off. That's why we have 20% chance of rain, 40% chance of rain. They don't know if we had 100 days or 10 days like that, 30% of them would have rain.*
>
> *Mark – And they vary those percentages based upon…?*
>
> *Angela – The data they throw in there.*
>
> *Mark – How much they've collected?*
>
> *Angela – They've collected, yeah.*

While Angela was able to describe how observations and inferences worked in predicting and retrodicting, she also made some statements which seemed to imply she lacked confidence in inferences without hard data. In relation to how dinosaurs became extinct:

> *You don't really know what happened. Number one, you don't really know the physiological anatomy make-up of the dinosaurs, so how do you really know? I think it's just interpretation of the information given. I don't know. I don't know how to answer that one. That was my best guess on that one.*

and in weather predictions:

> *We live in Texas. We know a prediction is just a prediction. A lot of times they're dead on, a lot of times they're not. They take a computer model and they put the information in there and they look at past patterns and what has happened there and what you assume is gonna happen here.*

These statements which indicate a lack of confidence in scientific inferences kept her from being awarded an informed ranking for observations and inferences. No change was detected in her post-intervention data.

Angela – Theories and Laws

Angela began the workshop with a naïve conception of the role of theories and laws in science. She made comments that exemplified several common naïve codes about theories and laws. Twice she made statements that indicated she was using the word theories and ideas (or thoughts) interchangeably which were coded [*Conflates hypothesis, theory, and law*]:

> *He [Lamarck] had knowledge, he had good theories.*

And:

> *Like Aristotle when he was talking about the atom, he had good thoughts, he had good theories.*

She further exhibited a naïve conception of theories and laws by undervaluing the reliability of a scientific theory:

> *To me, theory is something that can't be proven, like the Big Bang Theory. There is a scientific foundation for the Big Bang Theory, but there's no way that we really know that that's what happened. We know, we can physically measure that the earth is expanding. We have scientific evidence that it's expanding, but we can't go back billions of years and go 'ok, this is what really happened.' The Miller-Urey experiment; we can assume based on rocks and what we…the inference of what chemicals we think were back then and if everything happened just perfectly and you have this little lightening strike, the theory is that we get the DNA, amino acids, and all those things, but there's no way of us truly knowing, it's a theory. Theory of Evolution… there are many theories. A lot of people stick with Darwin and natural selection, those kinds of things, but there's things that happened millions of years ago, we don't really truly…don't really know that it really happened.*

She also contrasted a law to a theory by stating the naïve idea that a law was more permanent and unchanging, while a theory was much less so;

> *Scientific law is something that holds true time and time again. A lot of times it's like a mathematical equation.*

The last code identified in her data was that there was a hierarchical relationship between hypotheses, theories and laws:

> *Well you start with a hypothesis. Some question in mind, you say 'ok, why did that apple fall off that tree and go down and not go floating off into space?' And then you do experiments on it and you do enough experiments on it and you get enough people looking at it and then you go 'ok, well we've got this theory that this thing called gravity pulls this thing down and it does it at this rate, and it won't go up.' And then over tried and true and it happens over and over again, to me years, it's not gonna change, something that's not gonna change. Then you go, 'ok, well then it's a law.'*

By the end of the two-week intervention, Angela's conceptions of theories and laws had changed. She appreciated the explanations offered during the workshop and made transitionally-coded statements that she would try to use the more informed explanations in her classroom [*Lacks confidence in new understanding*] and recognized that there was a distinction between theories and laws, but did not articulate them well [*Recognizes difference between theory and law*]:

> *I liked the way you described theory and laws. I'm definitely gonna use that when I talk about theory and laws with my kids in the way to look at that and the real difference between a hypothesis and a theory and a law. So that will change. And I'm gonna try to use the terminology correct in class too and not try to intertwine them.*

Despite her appreciation of the new explanations of theories and laws, she lacked confidence in this new knowledge [*Lacks confidence in new understanding*];

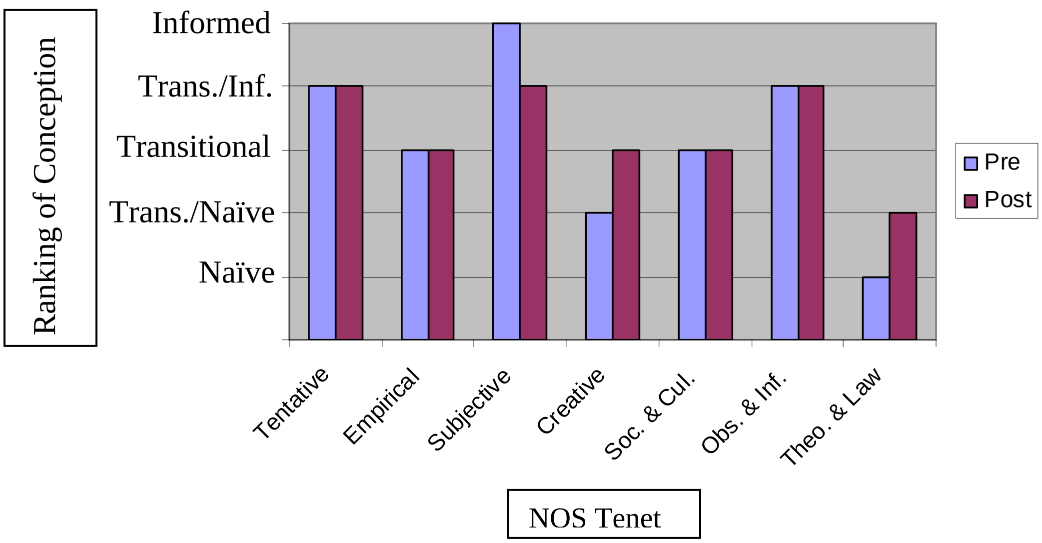
> *I think it will be an easier way and a better way to explain it. I think the kids will understand it better… I'm hoping that will help clarify in my head a little bit better and in their [her students] head a little bit better as to what really a theory and a law is.*

After reviewing the improvement in her understanding of theories and laws, her post-intervention conceptions of theories and laws were classified as transitional.

Case study #2 – Brenda

Brenda is a 6th grade teacher who has four years experience teaching science. Her educational background includes a Bachelors of Arts in Home Economics with an emphasis in nutrition and dietetics which included 15 hours of science credits. She is alternatively certified. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure II. Examples of Brenda's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure II. Brenda's Pre- and Post-Intervention Rankings



Brenda – Tentative

Brenda pre-intervention conception of tentative was classified as transitional/informed. In response to question four on the VNOS regarding how scientific knowledge will change in the future, Brenda responded with:

> *There is so much that we have not begun to understand in our universe. We can continue to make observations. Much like in the field of medicine; understanding DNA and how the body functions on a cellular level.*

This answer was coded with the naïve code [*New scientific knowledge will be added*] and was consistent with the naïve view that the only way scientific knowledge changes is through the addition of new information. In another interview statement, Brenda reiterated the idea that more scientific knowledge is added and also described the changing state of science by referencing the change in the classification of Pluto. This statement was consistent with the naïve code [*Classification and Terminology*].

> *You know, I mean…the kids say 'Pluto was a planet, why is it no longer a planet?' And I can say because those people right now at these governing bodies of these groups of scientists, the argument is swaying them to say it's not a planet because of these things. And they use these criteria to base their decision. We don't know what's gonna come about as they are able to actually explore those areas, so there's a lot of science that has come about as they've gained knowledge.*

Despite these naïvely-coded responses, in her interview discussion of her answers, she conveyed a more sophisticated view that demonstrated the informed code [*New knowledge grows AND is corrected*]:

> *I think a lot of times, I think what was believed at one point in time, especially in the microscopic or macroscopic worlds, if we have better ways of looking at that we find that what we first thought to be true, isn't as we look at those things. So we have to be flexible and say 'when I learned it, I was taught this, but as I've grown and scientists have studied it more in depth, there's more possibilities and that* [old knowledge] *was not necessarily correct.'*

And:

> *We're gonna continue to find that what we thought worked, doesn't work in all situations.*

Clearly she possessed an informed view of the tentative nature of science, but because she also described the tentative nature of science in naïve ways in other answers, her overall pre-intervention conception of tentative was described as transitional/informed. No change was observed in the post-intervention data.

Brenda – Empirical

Brenda's conception of the empirical nature at the beginning and end of the workshop was classified as transitional. The only statement which offered any view into the conception that Brenda had of the empirical nature of science was in response to the interview question "Is there any science that exists completely in absence of empirical evidence?"

She replied:

> *I don't know if we call is science, or if we call it…when we think about science fiction, when you look at fantasy and when you look at where dreamers have always come from, that's some of what we call as now science. So, I can't say no.*

This answer indicated that she felt that empirical evidence was important to scientific claims and that without it one might have to call such statements something other than science. Her reference to statements not supported by empirical evidence as being less than science, but perhaps maturing into science was identified with the transitional code [*Some current scientific knowledge once lacked empirical evidence; "pre science"*]. Since this was the only evidence of her understanding of the empirical nature of science, her conception of this tenet was described as transitional. There was no evidence of change found in her post-intervention data.

Brenda – Subjective

Brenda began the workshop with a conception of the subjective nature of science which was classified as informed. In explaining how scientists could disagree on how dinosaurs became extinct, she described how their educational background could influence their beliefs. In her VNOS response, she stated:

> *I believe they disagree from the interpretations of the data and their instructors' presentations and their assessment of what they read.*

And in her interview she added:

> *Pangaea wasn't in my education. It hadn't come about even as a discussed theory when I was all the way through school.*

And:

> *Mark – What would cause them to interpret it [dinosaur extinction] differently?*
>
> *Brenda – Different way they found different information they got, or who taught them and who believed whatever they taught them. Whatever was passed down to them to formulate their foundation knowledge.*

These statements convey an informed view of how educational backgrounds and theoretical framework could influence how scientists make conclusions and were coded [*Educational background can influence interpretation*].

At the conclusion of the workshop, Brenda's conception of the subjective nature of science appeared to have become less informed. In her post-intervention interview, Brenda expressed confusion about the meaning of subjectivity in science. When asked to describe subjectivity, she responded:

> *Correct me if I'm wrong, but when I think of subjectivity, I think of conditions; as conditions change the relative nature…now when we talk, I'm skipping I know…I really have to in my mind separate the objectivity and subjectivity of things and look at those… We have to be open to look at the changes of the conditions of the world. But does science change? Yes it does change as we get more ways of measuring it. But does the science change? See this is what I have a hard time sharing with the kids and there's not a…you know life as we know it may not always be the same way. I can't teach the kids and say that it will always be this way, but for what we know now, this is the way it is. So, subjectivity, it is open to move.*

This response (coded [*Does not understand "subjective"*]) indicated that she was confusing the subjectivity of science with the tentative or changing nature of science.

Because of her confusion regarding the meaning behind subjectivity her post-intervention conception of the subjective nature of science was described as transitional/informed.

Brenda – Creative

Question twelve of the VNOS asks if creativity plays a role in science and if so, how? Brenda responded with:

> *During the planning part of their investigation and perhaps on their interpretation.*

This answer seemed to indicate that she found creativity important in developing questions, but was uncertain of its role in other areas of scientific methodology. She further expressed this view in her interview:

> *Brenda – Oh I think scientists a lot of imagination and creativity as they write their hypotheses.*
>
> *Mark – Oh I sure did on* [question] *11, you said that "they use creativity during the planning part of the investigation and perhaps on the interpretation."*
>
> *Brenda – Or when they're drawing their conclusions.*
>
> *Mark – How does their creativity impact their interpretation?*
>
> *Brenda – Well if their experiment did not support their hypothesis, they have to think of other hypotheses to test in their conclusions. They have to come up with what could have happened, so they have to imagine and think about other things to test or what other possibilities could happen.*

These statements were consistent with the naïve code [*Creativity in setting up experiments or developing questions*]. Brenda also conveyed the conception that creativity and curiosity were synonymous in scientific research rather than addressing how scientists literally create new knowledge:

> *Mark – Ok. To what degree* [on a scale of 1-10] *do you believe creativity plays a role in science?*

Brenda – 10. There's fact, but it's driven by curiosity. Creativity to me also means curiosity.

This statement was identified with the naïve code [*Creativity equals curiosity*]. Since Brenda stated that creativity might also be used in the analysis portion of scientific research, her naïve view of creativity only in planning or questioning was somewhat softened and so her overall pre-intervention conception of the creative nature of science was described as transitional/naïve.

In the post-VNOS, Brenda's view of the role of creativity in science had widened. In answering question twelve after the intervention, she replied:

Planning, developing experiments to test, analysis of data, interpretation.

Clearly she recognized that the role of creativity extended beyond just asking the right questions or designing an experiment, but she could not clearly articulate what role creativity played in these other areas. Her post-intervention conception of the creative nature of science was described as transitional.

Brenda – Social and Cultural

Brenda's conception of the social and cultural nature of science was described as transitional both before and after the intervention. She demonstrated one transitional code [*Social and cultural values can limit science*]:

Mark – What about a scientist in a scientific lab, bench scientists? Do social and cultural values influence them?

Brenda – Probably about what they would be willing to do research on. So it's an ethical thing about…I can see bench scientists, if they are…the food industry isn't going to attract those bench scientists if it's dealing with animal proteins if they're Muslim or Hindu. It's going to attract them to a different field.

She also made one statement that indicated she might have confused social and cultural influences on science with the subjective nature of science; the following interview statement was given the naïve code of [*Conflates social and cultural with subjective and conditional*]:

> *I have a difficult time between subjective and conditional, that's where, when you use the word conditional, I kind of have a hard time disassociating subjective with conditional. And that may be observable and not, conditional's the right word for it, I don't know. It's a vocabulary thing.*

After weighing the strength and weaknesses of all statements made regarding the social and cultural nature of science, Brenda's conception was identified as transitional. No further evidence was found in the post-intervention data.

Brenda – Observations and Inferences

Brenda started the workshop with a relatively informed conception of the role that observations and inferences had in science. One of her statements was coded with the informed code [*Describes observations and inferences*]:

> *Brenda – They [observations and inferences] play a great role. Sorting out and knowing what is an observation versus an inference and if it's an inference, you need to be able to justify the inference by data.*
>
> *Mark – So what is the difference between an observation and an inference?*
>
> *Brenda – An observation, to me, is what you can see, what you can measure, what you can record. An inference is more what you think. You infer something.*

Brenda goes on to describe that scientists use data to make inferences but does not articulate how. In response to "how certain are scientists about the way dinosaurs looked?" (VNOS question six), she replies:

> *Piecing together fragments of bones to form skeletons and observations of the surrounding areas.*

Whereas she does reference the use of data such as the surrounding areas to help determine what the dinosaurs would have looked like, she does not even attempt to describe how the surrounding areas are related to the physical appearance of the dinosaurs and, therefore, has not demonstrated a sophisticated knowledge of observations and inferences. She made a similar statement in her interview in discussing how scientists would have constructed a dinosaur model:

> *I'm thinking as they put that together again and as they found the pieces of it and they used modern day skeletons and probably figured out how what went with what and built up what they had. But they also had other decaying matter or other fossilized matter in those same areas and that's how they could come up with what it may have looked like and what it may have eaten.*

Both of these statements were given the transitional code of [*Describes use of past/present evidence, but does not explain*]. One other transitional code was identified in Brenda's pre-intervention data. In discussing how confident a scientist could be in a prediction, she conveyed more confidence could be placed in predictions about weather than she indicated in context of dinosaur appearances:

> *I believe the weather persons combine the data and make predictions based on the current level of knowledge and technology available, combined with previous occurrences and observations. They develop increasing accuracy as equipment and previous patterns are processed.*

This statement was identified with the transitional code [*More confident in context of weather*]. After reviewing all of Brenda's statements relating to the role of observations and inferences, her pre-intervention conception of this tenet was described as transitional/informed. No further indications of her conception were identified in the post-intervention data and so her post-intervention conception was described the same.

Brenda – Theories and Laws

Brenda began the workshop with a naïve conception of the role and nature of theories and laws in science. Early in her interview, she showed her lack of understanding of the terminology itself as she stated:

> *You can prove whether your thought, whether your belief, whether your theorem, whether your hypothesis, to use the right science language, is valid in whatever setting you're working with it.*

In this statement, she has interchanged the words thought, belief, theorem, and hypothesis and then characterized this interchange as using the "right science language". This statement was given the naïve code [*Conflates hypothesis, theory, and law*]. She also demonstrated her naivety by making a statement which devalued a scientific theory:

> *Pangea wasn't in my education. It hadn't come about even as a discussed theory when I was all the way through school.*

By using the statement "even as a discussed theory", she is implying that a theory is like an idea that can be discussed without recognizing the amount of evidence that supports scientific theories. This statement was given the naïve code *["just a theory"*]. She also made statements which described theories as being more tentative than laws:

> *Something that you…it can be…where a theory has been proven over and over again, but it hasn't been fully, totally accepted as a law. So a law is the utmost and theories are proving laws to a point.*

This statement was given the naïve code [*Theory is tentative, Law is permanent*]. Finally, the last code identified in her pre-intervention data was [*Hierarchical view*]. Her statement indicated a hierarchical view to hypotheses, theories, and laws:

> *A hypothesis becomes a theories become laws. Yes, there's a relationship.*

Brenda's overall pre-intervention conception of theories and laws was described as naïve.

After the two-week intervention, Brenda's conception of theories and laws had improved. One transitional code was identified in the post-intervention data; [*Recognizes difference between theory and law*]. When asked to describe theories and laws, she stated:

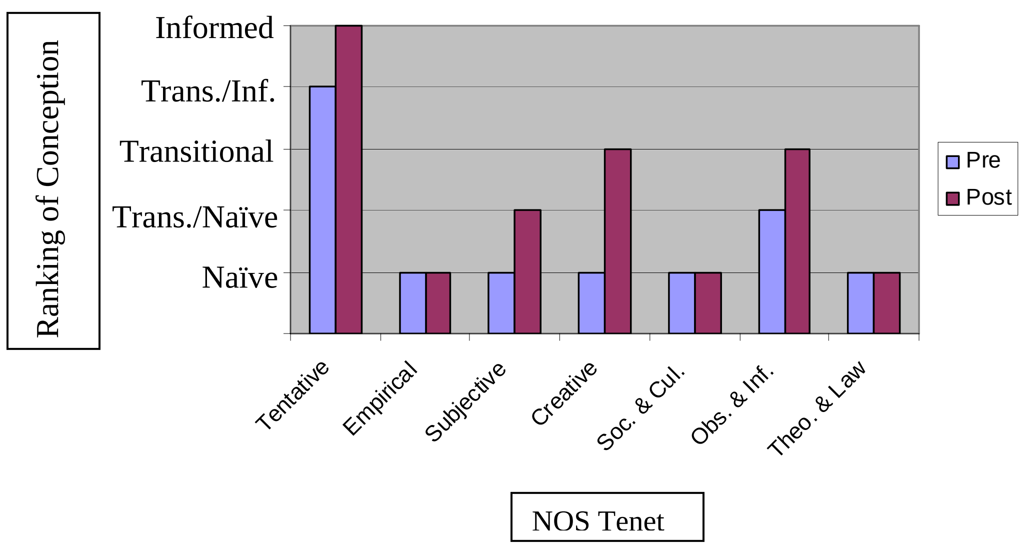
> *Brenda – It really helped me a lot personally understand the difference between…and more importantly how I will use the terminology theories and laws.*
>
> *Mark – So you liked the article that I gave out?*
>
> *Brenda – Yes.*

This statement reconciles her pre-intervention conception that thoughts, hypotheses, and theorems were one and the same. It further indicated that she recognized the hierarchical relationship did not exist and that she would try to use these "new" descriptions in her teaching. Despite the great progress that was made, she still could not describe theories and laws and lacked confidence in her answers (coded [*Lacks confidence in new understanding*]). Because of this lack of confidence, her overall conception of theories and laws after the intervention was described as transitional/naïve.

Case Study #3 – Christina

Christina is an 8th grade science teacher who has eight years experience teaching science. Her educational background includes a Bachelors of Science which included 15 hours of science credits. She is certified to teach through the composite K-12 exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure III. Examples of Christina's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure III. Christina's Pre- and Post-Intervention Rankings



Christina – Tentative

Christina began the two-week workshop with a somewhat sophisticated conception of the tentative nature of science. She did make statements that could be interpreted as naïve (and were coded as such) but these were countered by other statements which clarified her position. The naïve codes which emerged in her data included [*New scientific knowledge will be added*]

> *As new information is added and new aspects of discovery are restudied we will add to and change what we know. We can see things farther away*

> *than we ever have and we can see things smaller than we ever have, this allows information about the universe and DNA to be updated all the time.*

She also made statements which only mentioned scientific knowledge changing in the sense of terminology or classification. This statement was given the naïve code [*Classification and Terminology*]:

> *I've been out of college for 25 years, so what I was taught in college for the number of kingdoms, how many kingdoms there are. I asked someone the other day because I'm going to be moving up to the high school, I said "how many kingdoms are there now?" because I remember 4 kingdoms, I remember 5 kingdoms, I remember 6 kingdoms, and how many do they say we have now?*

And:

> *…so those kind of things we're talking about, classification of life, but those kinds of things change varying with what is now acceptable or known or as new things are added. It's not changing what we're actually looking at.*

Despite these naïve-sounding statements, Christina made other less-naïve statements which clarified her understanding of the tentative nature of science. In one statement (with the transitional code [*Scientific knowledge "may" be corrected*] in her interview she remarked that there was a possibility of scientific knowledge actually being revised or corrected, but she lacked confidence in this answer:

> *To me it's kind of like the picture of evolution of the horse. That was in textbooks for years, but what I've read in recent, I don't know if that really in true is the evolution of a horse. It's a consecutive set of skeletons put in a size order, but does it truly show the evolution of the horse? That picture was in books for a long time even though it was being questioned and so whether it's still there or not, it's not in ours, but… According to some things I've read that that was just actually, it looks good, but it was a compilation of things from different times and places and not necessarily…they necessarily could not confirm that this one actually led to this one, this one led to this one…The other thing ontogeny recapitulates phylogeny. I learned that and that was just the coolest thing to me. So many things that I've read lately is that doesn't really hold true in all these species that we're looking at, so ontogeny recapitulates*

> *phylogeny was one of those things that I was like yeah, I just like saying it…[laughs]*

At one point in her interview, Christina clearly addressed the tentative nature of science and made a statement that very closely reflected the informed view of this tenet.

> *The other thing is the universe, whether the universe is expanding or collapsing. Everything now says expanding, but there's those people that say "no," but all measurements are showing that it is expansion and so that has gone back and forth as far in the data or whatever. And so, looking at what we say we know about what's happening right now, something new can happen tomorrow. The gene, there are things that are happening there, that's not what the scientific community thought. It's different from what was thought in times past, but we're still talking about genetics and ATCG is still all there, but there's new things that we didn't know existed. So that's what I'm just talking about.*

This description of how scientific knowledge may change includes both how it grows and how it is corrected and revised with new knowledge. This statement was given the informed code [*New knowledge grows AND is corrected*]. After reviewing all statements related to the tentative nature of science, Christina's conception was described as transitional/informed.

The only improvement observed in Christina's conception of tentative was in her assertion that she would not use the word "proof" in her classroom anymore which was coded [*Won't use "proof" anymore*]:

> *But I may not directly give them that working definition, but it will definitely change some of the things I say because I'm really gonna work this year on not saying that it's proven because the fact is everything changes. If we go back to tentativeness, 'It's proven today', may not be so tomorrow, that kind of thing.*

After reviewing all statements regarding the tentative nature of science, Christina's conception of this tenet was considered informed.

Christina – Empirical

Christina began and ended the workshop intervention with a naïve conception of the empirical nature of science. In the pre-intervention data, only one code was identified; [*Must have empirical evidence (no inferences)*]. Her statement indicates that she believes all scientific statements, other than the creation (of Earth presumably), must be backed with observable evidence which negates all inferential knowledge in science:

> *I think everything goes back to some type of empirical evidence. I think the only place you can actually go back to with that is the whole creation thing, because what do we have solid right now that we can watch and hold and see? We don't have that and so that would have to be the only thing. I think as far as anything else, I think pretty much we can back it up with what we've got and what we can actually see and observable evidence.*

At the end of the two-week workshop, Christina conveyed another misconception related to the empirical nature of science. In the following statement, Christina conveys that scientific claims do not even need to have a basis in empirical evidence and that some scientific knowledge is *based* upon belief.

> *I also think that people have moved forward on a hunch and then the empirical evidence may follow or may not, but I do believe that people can move forward with science on a hunch, so it doesn't necessarily have to be grounded in the beginning in empirical evidence, necessarily, course I know there's some science stuff that's out there that the evidence isn't there, they still just believe that it should be and they're still working towards that. There's science happening based on something they believe could or could happen.*

This statement was given the naïve code [*No empirical evidence needed*]. With no improvement in her conception of the empirical nature of science, Christina's post-intervention conception was still classified as naïve.

Christina – Subjective

Christina's conception of the subjective nature of science was classified as naïve at the outset of the two-week workshop. Two naïve codes were identified in her pre-intervention data. The first was that she attributed subjectivity to being just a quality of any human endeavor and did not identify its source as being grounded in theoretical training. Her statements below to this effect were coded [*Subjectivity "just a human thing"*]. In response to how scientists have multiple theories on dinosaur extinctions when working with the same data, she responded:

> *Christina – Because they're human … [laughs]. Just like so many interpretations of the Bible. Why do we have all these denominations when it's the very same book? What is it, it is people, it's human beings with their own biases, interpretations, feelings, philosophies, whatever.*
>
> *Mark – …where does that bias come from?*
>
> *Christina – Where you grew up, what you've personally dealt with, I don't know.*

She further explained that subjectivity (which she is using interchangeably with "bias") is a flaw in science and implies that it should be avoided if at all possible. This statement (coded [*Subjectivity is bad for science*]) ignores all the positive effect that interpreting data through a theoretical lens offers to scientists:

> *In science I would think bias is a very detrimental thing because it's a concrete kind of situation.*

After reviewing all of her statements relating to subjectivity in science, her conception of this tenet was classified as naïve.

After completing the two-week intervention, her conception of subjectivity had slightly improved. In her post VNOS and post interview, she related information that indicated that the subjectivity could be attributed to a persons "background" but still could not tie the subjectivity to the theoretical framework from which a person was interpreting data. These statements were given the transitional code [*Different backgrounds cause subjectivity*]:

> *…in a room of people you're gonna have the different subjectivity, the span from one to the other because of our own personal feelings and so science is subjective. Based on where you stand and where you come from and prior knowledge and those kinds of things, and so that's definitely a part of what science is.*

While this statement does address that prior knowledge plays a role in subjectivity, it does not clearly articulate what kind of knowledge she is referring to. After reviewing all of her statements regarding subjectivity, her post-intervention conception was classified as transitional/naïve.

Christina – Creative

Christina's pre-intervention data revealed she also had a naïve conception of the creative nature of science. The only evidence found that related to creativity was her assertion that creativity was useful in setting up experiments with no reference to its usefulness in any other aspect of science. She also clearly states that creativity should not be used in reporting results:

> *Certainly you're going to be creative in your experimentation, but that's because you made a plan that this is what I'm gonna do and so I think the planning is where it starts. You certainly don't want to be creative when reporting results…I would think that your results need to be dead-on and that doesn't have to be creative.*

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*].

In Christina's post-intervention data, she reiterates this sentiment in her response to the VNOS question regarding the place of creativity in science. She states:

> *Mostly planning and experimenting - when something does not work a scientist must be creative and find another way to test or think or investigate.*

Despite this reiteration, in her interview, she explains how creativity could be used to explain occurrences and showed a move toward a much more informed conception of this tenet. This statement was given the informed code of [*Creativity in explaining occurrences*]:

> *Well when we talked about it in the beginning and I said that creativity was in the planning , and I still think that that's probably an important part, but also in the actual investigation. Being creative and how you look at things or make decisions, I think creativity is still there. I guess I didn't feel like it was as big a part of it before until we had to watch those videos and look at, ok what were the creative aspects of all of this stuff that's happening, and oh yeah, ok they were pretty creative. They were thinking outside the box, so to speak, to try to come up with ways to make sense of things. So I see it as a greater part than I did before.*

Christina also mentioned in her interview that sometimes scientists move forward based upon a "hunch". This description was given the transitional code of [*Creativity means open to new ideas*]:

> *I also think that people have moved forward on a hunch and then the empirical evidence may follow or may not, but I do believe that people can move forward with science on a hunch.*

It should be noted, that this quote was part of a larger quote that was viewed as a naïve conception of the empirical nature of science. After reviewing all of her statements regarding the creative nature of science, her post-intervention conception of this tenet was described as transitional.

Christina – Social and Cultural

Christina began and ended the two-week workshop with a naïve conception of the social and cultural nature of science. Nowhere in her pre- or post-intervention data did she ever relate any information that indicated she understood how social and/or cultural values could influence the direction of science or the questions that were asked by the scientific community.

Christina – Observations and Inferences

Christina began the workshop with a working definition of observations and inferences and described them as:

> *Observations are what you actually see and observe and inference is what you take from that, what you assume from that. That's the in between line stuff, this is what I saw, and this is what I believe that means. So the observation is the concrete, absolute, this is what it is and the inference is what you take from that and apply…from your observations you take that as an idea.*

This statement was given the informed code of [*Describes observations and inferences*]. Despite articulating this somewhat sophisticated knowledge of observations and inferences, however, her overall conception of this tenet was described as transitional/naïve because of some other statements which made her conception seem less sophisticated. When discussing how scientists make models of dinosaurs, she references rebuilding the skeleton and applying clay to get the full figure of the dinosaur. In her discussion of how this is done, she reveals that she understands how it could be done in humans because we have humans to compare our models to, but that with dinosaurs, it is much less certain. When she discusses skin color, she reveals that she has a very naïve conception of how inferences could retrodict the appearance of an extinct animal:

> *Mark – And so, how do they know how much clay to put on there?*
>
> *Christina – I have no idea how they do that. I don't know how and from what I've seen, one of the seminars I went to, it was a lady that does that kind of stuff, they look at what the basic structure is. Of course, with a human it's easy because you have humans to go by. With a dinosaur you're kind of stretching it, you having to guess, based on what I know*

about reptiles, or birds, or animals then this is what it could look like, so that's where your discrepancies could lie.

Mark – What about like the texture of the skin that they put on them and the color of the skin?

Christina – The only way they would know color they would totally have to guess on that. But texture there have been some, very few, of the fossilized skin surfaces have been found as that gives them some idea, but again they're going to have to grasp at that.

By describing the inferential description of dinosaur skin color as a "guess" she has revealed that little confidence can be placed in an inference that lacks hard data to back it up. This statement was given the naïve code [*MUST have hard data or just speculating*]. Another naïve code identified in Christina's pre-intervention data was [*Trust in technology without understanding*]. Christina exhibited a naïve trust in technology because she had seen it on a popular television crime show. Again, when in context of human skeletal reconstruction, she had confidence in the inferences being made, but when dealing with extinct dinosaurs, the confidence faded:

Now what I do is take what I see on CSI where it's really cool and they take the bones and they recreate the muscle based on the muscle structure and all those kinds of things so I believe that if we have that, where we can recreate the faces from bones and give a fully accurate description of what the human person once looked like and try to identify that person, which I do believe we have that capability.

After reviewing all statements relating to observations and inferences in the pre-intervention data, her overall conception of this tenet was classified as transitional/naïve.

In the post-intervention data, she expressed more confidence in how scientists retrodict the appearance of dinosaurs. She describes their certainty as:

Fairly certain using reconstructive technology they can make some inferences based on prior knowledge of bone structure and musculature.

By referencing the use of prior knowledge as well as our current understanding of skeletal and muscular anatomy, she exhibits a more sophisticated conception of how inferences are made. Her post-intervention conception of this tenet was classified as transitional.

Christina – Theories and Laws

Christina made one statement about theories and laws which was coded informed. In her interview she stated:

> *A theory is an idea that explains something and it gives us ideas based on somewhat evidence but it is not absolutely provable and not necessarily repeatable.*

While this statement does describe the explanatory nature of theories (coded [*Theories are explanatory*]), her other statements showed a much less sophisticated view of theories and laws and indicated that she may have been using common academic language of which she lacked a good understanding. Numerous times, she alluded to the tentativeness of a theories and certainty of laws indicating that theories were much less certain than other kinds of scientific knowledge. These statements were coded [*Theory is tentative, Law is permanent*]:

> *Newton's laws are the ones that come to mind because when I teach laws of heredity. Those things that we know if you cross this with this, this is what you're gonna get because that's the way it is and if something else happens then you have a problem. If anything ever does show up to be the contrary to the evidence and holds true then we have to change the law, or say it's not a law, it's a theory, but a law is undisputable.*

She also conveyed the idea that hypotheses become theories which become laws. This statement was coded [*Hierarchical view*]:

> *A hypothesis is probably going to be the first, and yes they are related, and a hypothesis has to be created and tested. When you see regular results that lead to one idea about that or one set of facts that you can*

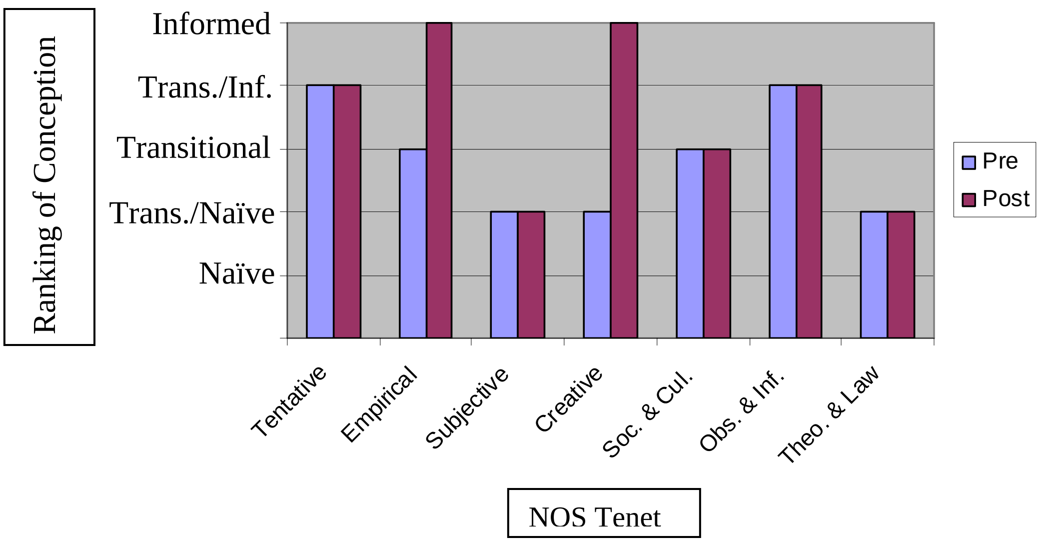
hang your hat on, then you can create that theory. The theory then says when this does then this happens and that's your theory based on that same hypothesis. A theory has been tested and has come up to hold true in almost every case, then if continues to hold true and if it's tweaked or whatever to hold true in every case, then you can write it in as law. I believe that the law is the end result of the hypothesis in the beginning.

Her overall conception of theories and laws was determined to be naïve and no change was observed in her post-intervention data.

Case Study #4 – Dana

Dana is a 6th grade science teacher who has six years experience teaching science. Her educational background includes a Masters of Science and she is certified to teach through the ExCET exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure IV. Examples of Dana's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure IV. Dana's Pre- and Post-Intervention Rankings



Dana – Tentative

Dana began the workshop with a fairly sophisticated conception of the tentative nature of science. In her response to the VNOS question about how science knowledge will change in the future, she clearly acknowledged that scientific knowledge will grow with more discoveries and that some knowledge may have to change as new data is gathered. This statement was given the informed code [*New knowledge grows AND is corrected*]:

> *Absolutely. As we develop more technology and access more places and makes more discoveries, we will have to change. Our view of the atom*

has changed in my lifetime tremendously. Even now there is dispute over the carbon dating and genetics and DNA. The more we study and experiment and redo and redo, we will discover more and more that has to be rewritten if only to be given more detail.

Although her description of the tentative nature of science, in this one statement, comes close to matching the informed view being used in this research, there are a couple of reasons her overall conception was not classified as informed. First, in the end of the informed statement above, she openly accepts that scientific knowledge will grow but when it comes to re-writing old knowledge, she adds the caveat of "if only to be given more detail". This caveat almost apologizes for admitting that scientific knowledge may be incorrect today and will change as new knowledge is created. An example of this is in her response to the interview question about how scientific knowledge is changing:

Mark – Do you think it will change in the future?

Dana – It already is. [Long pause]. Some of the knowledge is already changing that we have.

Mark – And changing in what way?

Dana – Example when I was in high school the example of the molecule is very different than what we know the molecule looks like now.

Mark – So it was incorrect then?

Dana – Or incomplete maybe, I should say. We still studied that it actually went to rings, specific rings, like orbits, this doesn't. I think we even have more elements now than in my periodic table, so it's just I guess becoming more complete. The moons, we now only have 8 planets instead of 9 planets, so things are changing. I just think that they keep finding out maybe more smaller detail of things that are possible or not possible. So it does change.

The other reason her conception was not classified as informed lies in the fact that in every other opportunity to discuss the changing state of scientific knowledge, she only addressed how the body of knowledge would grow with new information; a naïve view which was coded [*New scientific knowledge will be added*]. In these examples she never references how the current knowledge might be corrected over time:

> *But we're finding more and new species and different…and more things, but it's becoming more in depth, more…we're finding smaller quirks, something smaller than a quirk because we now have the technology to find things that are even smaller than that.*

And in her explanation of why she believes scientific knowledge will very likely change:

> *Because it does change as we learn more and study more, it changes. It becomes more in depth.*

Dana also expressed that although scientific knowledge is subject to change, that she considered it reliable; an informed view coded [*Scientific knowledge isn't 100% sure, but it is still reliable*] in the following statement:

> *They are not 100 certain except for the few that they may have found intact. Even when they have found complete skeletons they have to base the "look" on what they believe the animal would have been like according to what we know about animals today. They know certain things about walking on two or four legs based on bones and animals today, or type of teeth, or being reptiles so they have certain skin types. But I believe no one really knows, that's part of the faith you have to have in science based on all that you do know.*

This informed code loses some of its strength, however, when you weigh it against her conception that the primary way scientific knowledge changes is through adding more discoveries. Since she does not clearly express the understanding that scientific knowledge is continually corrected (or disproved), her confidence in science may be a naïve confidence. After viewing all of her statements regarding the tentative nature of science, her pre-intervention conception of the tenet was classified as transitional/informed. No evidence of change in her conception of the tentative nature of science was detected in her post-intervention data.

Dana – Empirical

Dana began the two-week workshop with a transitional conception of the empirical nature of science. She made one informed statement indicating that science must be based on empirical evidence [*Must have a basis in empirical evidence*]:

> *It [scientific knowledge] has to have something fact-based, tangible. Otherwise it's just pure faith.*

However in a subsequent transitional statement she admitted that she was not sure that all science had roots in empirical data [*Leans toward needing empirical evidence, but lacks confidence*]:

> *I leave a little wiggle room because there are still things…but I don't know because I haven't studied them, like the great bang theory that I have no idea what empirical evidence they have for that.*

And in a final naïve statement regarding the empirical nature of science, she conveys the conception that some science lacks any empirical basis whatsoever [*No empirical evidence needed*]:

> *But I still think you have to have some tiny amount of faith in the unseen when you're dealing with science because you can't see it, but you know it's there. It's there and that's what we're trying to prove the whole time. How it got there, why it's there, you go to. That's why people are searching after the Loch Ness Monster. That's why people keep going to the bottom of the ocean. That's why people keep trying to go to the Moon and to Mars because we know there's things out there.*

Her overall pre-intervention conception of the empirical nature of science was classified as transitional.

After the two-week workshop, however, her conception of this tenet appeared to have improved. In her VNOS response to "how is science different from other subjects you have studied?" she replied:

Science is based on empirical data and "facts". It looks at the how and what and stays away from beliefs and "why" things happen which is more common in other content areas.

This informed statement was given the code [*Must have a basis in empirical evidence]* and clearly indicated that she recognized the importance of some basis in empirical data. She further emphasized this idea in her interview with several statements that such as:

it's not science until you have evidence.

And later when discussing teaching evolution to her students, she stated:

I'm not as worried about what I teach my kids because I teach them what I believe and I think it's science, it's factual, it's got evidence, it has empirical basis.

These statements, along with the absence of any naïve or transitional statements in her post-intervention data, demonstrated an informed view of the empirical nature of science.

Dana – Subjective

At the outset of the workshop, Dana possessed a transitional/naïve conception of the subjective nature of science. She recognized that subjectivity existed but attributed it to different backgrounds of the observer and made no reference to theory-laden perspectives through which the data is observed. This statement, coded [*Different backgrounds cause subjectivity*] demonstrated that she lacked a sophisticated view of this tenet:

It's your past experiences and your interpretation of it. It's all the other experiences you've had and the filters you use to interpret that information, so you carry a lot of your baggage with you in your filters and what you've experienced. So that comes through when you're interpreting things.

In the following excerpt from her interview, she conveyed a naïve view of subjectivity in science which was coded [*Subjectivity is bad for science*] and [*Science is objective*]:

Dana – So there is some subjectivity, but there shouldn't be because we should all be able to replicate it and do it the same time that's why we have the scientific method.

Mark – What is the scientific method?

Dana – It's the same way of duplicating procedures, with a hypothesis and steps and coming up with analysis and data and a conclusion that's consistent.

Mark – Is that scientific method how scientists around the globe proceed, standard, is that the standard?

Dana – Pretty much yes.

Mark – Ok. So you indicate there is some subjectivity? Then am I interpreting you correctly that that is sort of a flaw in science?

Dana – Yes. I want it [science] to be objective. It's mostly objective, but it's not completely objective… 'Cause you want it to be and it should be, but it's not.

Her post-intervention conception did not appear to have improved. The only change observed was her naïve interview statement coded [*Does not understand "subjective"*] which indicated she was confusing the subjectivity with personal interest and creativity:

Mark – Ok. Would you characterize subjectivity as being a flaw to science or is it…?

Dana – Oh no. I don't think it's a flaw because also part of science is, I have to communicate what I know and to me it has to be replicable. Somebody else has to come up with what I come up with or it could have been a fluke. It could have been something that I'm not seeing that accounted for it other than what I think accounted for it 'cause I'm the only one that got it. So, subjectivity is what I think peaks people's curiosity because they already…why go some way until somebody tells you to try something else or they want to go after what they believe the truth to be or believe the occurrence to be.

While in this statement she asserts that subjectivity is not bad for science, what she describes as subjectivity is not related to the theory-laden, intended, meaning of it as used in this research. Her post-intervention conception of the subjective nature of science remained classified as transitional/naïve.

Dana – Creative

Dana's pre-intervention conception of creativity in science was classified as transitional/naïve. In her VNOS response to the question of the role of creativity in science, she stated:

> *Yes, the imagination comes in with the planning of the investigation. Like the questioning and the curiosity and when the hypothesis is not proven then the imagination kicks in and you come up with other ideas.*

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*]. In her interview, she did mention that perhaps creativity could be used in other aspects of science, but could not clearly explain how:

> *Creativity… making your observations, it shouldn't come in because you want to be as clear cut and precise as you want and you shouldn't be creative in observations, I don't think. And you don't really want to be too creative with your analysis of data but you gotta be a little creative.*

This statement, although allowing for "a little" creativity, actually reinforces her prior assertion that creativity was useful only in developing questions or setting up experiments.

In her post-intervention data, however, much improvement was discovered. In her VNOS response to the question about the role of creativity, this time, she replied:

> *Yes, because part of science is the creation of new knowledge. It is coming up with new creative questions and hypotheses to be testing. We use creativity in interpreting our conclusions and findings and making inferences of our observations. The facts and evidence are empirical and lack the subjectivity of creativity, but designing, and interpreting depend upon it.*

This statement was given the informed code [*Scientists create new knowledge*] and demonstrated that her conception of this tenet had moved a great deal and was classified as informed.

Dana – Social and Cultural

Dana began the workshop with a transitional conception of the social and cultural nature of science. When asked how much social and cultural values affected the direction of science, she responded;

> *Dana – Actually, I don't think so. It might influence the direction we go at the time, but I really think science is so universal.*
>
> *Mark – Can you explain what you mean by it might influence…?*
>
> *Dana – What we look for, what we want to go for. Cultural, it might say we want to go look at our ancestors versus we wanna go to the Moon. But I don't think it would…it might say we won't do genetic replication, but we will go to the Moon. I think that's where it might influence it, but I don't think it would have any affect on how we would do it or the outcome of research 'cause I think science across the board is very, speaks the same language in every country, in every language. So I'd have to say…I disagree.*

Since she seemed to realize that culture could have some effect, but failed to clearly articulate what role it played. This statement was given the transitional code [*Social and cultural values can have an effect but cannot explain*] and with this being the only evidence of her conception of this tenet, her overall conception was classified as transitional. No change was detected in the post-intervention data and her conception of the social and cultural nature of science remained classified as transitional.

Dana – Observations and Inferences

Dana's conception of the role that observations and inferences play in science remained classified as transitional/informed throughout the two-week intervention. In her answers to the VNOS question about dinosaurs and how scientists knew they existed and how sure they were of their external appearance, she not only described that they use fossil evidence, but went on to explain the role of observations and inferences in determining what they must have looked like:

> *They believe based on what we know of animals and genetics today, what we have found fossilized in rock or amber, drawings in caves believed to be of prehistoric times. We believe because of carbon dating and theories on age of earth and rock. We have found not only fossils but some actual "animals" well preserved in tar, ash and ice. They have various bones, eggs, teeth, and even footprints.*
>
> *They are not 100 certain except for the few that they may have found intact. Even when they have found complete skeletons they have to base the "look" on what they believe the animal would have been like according to what we know about animals today. They know certain things about walking on two or four legs based on bones and animals today, or type of teeth, or being reptiles so they have certain skin types. But I believe no one really knows, that's part of the faith you have to have in science based on all that you do know.*

Although the idea that there are prehistoric cave drawings of dinosaurs is indeed naïve, Dana's conception of how observations and inferences are used is clear; scientists use extant species and knowledge of heritable traits to retrodict how dinosaurs must have appeared. This statement was given the informed code [*Use of current knowledge and theory to make inferences*]. The only other evidence of Dana's understanding of observations and inferences that was detected in the pre-intervention data was in relation to how sure meteorologists are of their predictions. In her response to this VNOS question, Dana stated:

> *No way, I think it is all about probability and a lot of math and patterns. I also think we as humans are continuously changing and interfering or affecting the pattern such as global warming and over population which ultimately affects the weather. They are only using math to predict what they know the laws of physics will do in given situations based on what they have observed over their recorded history.*

This statement indicated that although Dana understood the process of using observations to make inferences, she doubted the reliability of the inferences when in context of weather. This statement was given the transitional code [*Less confident in context of weather*]. Dana's overall pre-intervention conception of this tenet was classified as transitional/informed.

At the conclusion of the two-week workshop, it appeared that Dana's conception of observations had changed slightly. She no longer expressed the uncertainty in weather predictions that she did in the pre-intervention data as seen in her post-VNOS response:

> *Not sure, but based on math and patterns and time and repeated data and observations, they find it more or less likely.*

Despite this improvement, Dana still did not convey a fully informed understanding of the confidence that can be placed on scientific inferences and was not able to relate how inferences were used outside the context of weather. Dana's overall post-intervention conception of this tenet was classified as informed.

Dana – Theories and Laws

Dana was able to give an example of theories and laws, but could not articulate well what characterized them. When asked to describe a theory, she gave the following explanation:

> *Scientific theory… I have no idea. [Laughs]. Scientific theory… well, it's taking all of those observations and inferences and facts and coming up with a theory of how the Grand Canyon was created or evolution. A scientific theory is what we generally accept as fact, truth until proven otherwise.*

Her description of a law was equally vague although it also referenced actual examples of scientific laws:

> *A scientific law is like for every force there's an equal and opposite force, that's a scientific law. It's something that exists that we take for a fact as is. Newton's Law of Gravity, we accept that gravity is what holds us here on earth. We accept that it is a scientific law. That gravity holds this earth in place and holds us on the earth. And that for every force there's an equal and opposite force. That's why a computer sits there. But I guess that's all I can figure out.*

Both of Dana's explanations of theories and laws relied upon using the stereotypical examples such as evolution or gravity, but both lacked an informed nature in describing what made them theories or laws. These statements were given the transitional code [*Describes theories and laws but lacks confidence*]. She contrasted theories and laws by relating the naïve conception that theories were tentative and laws were not:

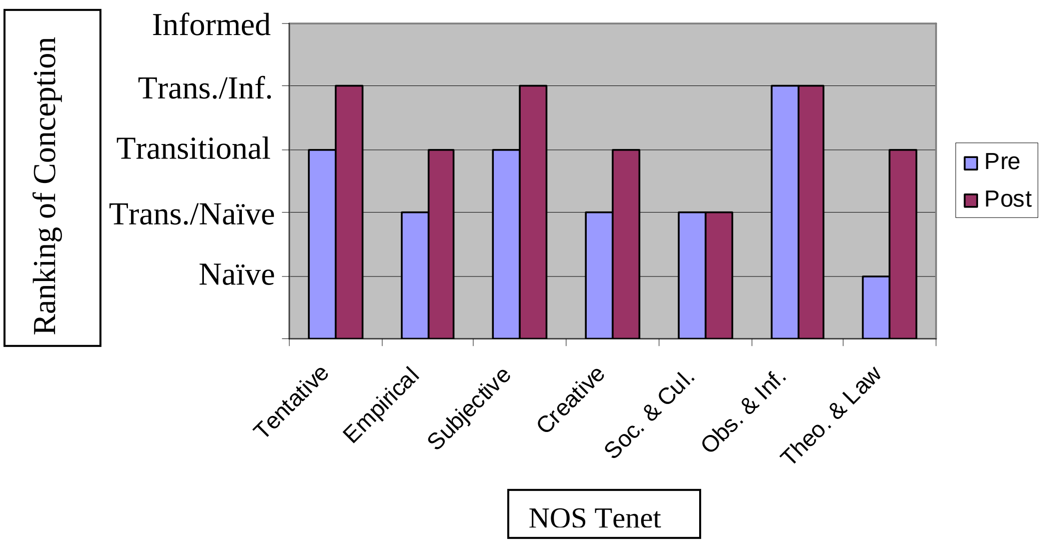
> *And there is a relationship, 'cause the hypothesis is the anticipated outcome, but if I get something different when I do my experiment, my investigation, then I may have to change my theory. What has been thought to be my theory forever. So I think theories could change. At this point, I don't think that laws can change. I think theories can change. They have changed. So, yeah they're related.*

This statement was given the naïve code [*Theory is tentative*, *Law is permanent*]. Dana's overall pre-intervention conception of theories and laws was classified as transitional/naïve. No evidence of change in her conception was identified in the post-intervention data and her conception of this tenet remained classified as transitional/naïve.

Case Study #5 – Elise

Elise is a 9th grade science teacher who has four years experience teaching science. Her educational background includes Bachelor's degree in interdisciplinary studies with emphasis in biology and French. She is certified through the ExCET test. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure V. Examples of Elise's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure V. Elise's Pre- and Post-Intervention Rankings



Elise – Tentative

Elise began the workshop with a transitional conception of the tentative nature of science. She willingly acknowledged that scientific knowledge would change but only described the change as discovering new things or increasing our understanding of phenomena and never recognized that some current science knowledge will later be deemed incorrect and be disproved. She demonstrated this idea clearly in this statement which was given the naïve code [*New scientific knowledge will be added*]:

Elise – Well what we already know is going to be there from now on, it may be changed because we learn some new things, but I think there's gonna be some new knowledge with our capabilities to go farther like the space, for example. Right now we know what scientific material allow us to go and see, but I'm sure one day we'll bring back, they're talking on tv living in Mars, and we're gonna learn some new stuff about Mars that we don't know now.

Mark – So in 50 years will the text books be twice as big as they are today because new knowledge?

Elise – I don't know about that. I hope not, not for our students. There maybe some revised version of what we know and maybe they'll eliminate stuff that will be common knowledge by the time they get to high school or university.

The first line in the above interview statement most clearly demonstrates the naivety of her conception. She stated that the current knowledge would "be there from now on" which fails to recognize the way in which scientific knowledge is corrected over time. This statement was given the naïve code [*Some knowledge becomes permanent*]. Later in the interview she demonstrated a slightly "less permanent" view of science knowledge when she described a theory:

Something that scientists are going to agree on, but it's not a complete fact, it could be changed. That make sense? With time, maybe somebody will come up with a better answer to something we know. Like the Big Bang Theory, some of the scientists agree on this, some don't, but it's been accepted so now that's what most people talk about, but one day maybe it will change.

This statement was given the transitional code [*Scientific knowledge "may" be corrected*]. In this statement she admits there could be some changing in scientific knowledge, but confines this change to theoretical knowledge. While this does allow for her conception of the tentative nature of science to be viewed as less-naïve, it also demonstrates some of her naivety regarding theories (discussed later). The last code identified in her pre-intervention data dealt with the reliability of scientific knowledge. In the following statement, she conveys a sense of satisfaction with the reliability of scientific data despite the fact that it is never certain:

> *Except if one scientist was able to invent some type of time-traveling device, I do not think that there is any 100% certainty. Scientists can probably get close to what the dinosaurs looked like, again by looking at what we find in the remains and common characteristics and present day living organisms.*

This statement was given the informed code [*Scientific knowledge isn't 100% sure, but it is still reliable*], however it had to be weighed against her naïve conception of the relative permanence of the scientific knowledge we now have. After reviewing all statements made regarding the tentative nature of science, her conception was classified as transitional.

After the workshop, her conception seemed to have improved. In two statements (one on the VNOS and one in her interview), she indicated that scientific knowledge was not as permanent as she once believed:

> *Well before the workshop, tentativeness was there, but after the workshop I definitely think it's definitely there. It increased my perception of that science is tentative. That it's not set in stone and it's definitely changing. Yes, knowledge will be changing as we get new technologies or new empirical evidence which will support or change what we know science to be today.*

This view that science was not set in stone demonstrated that she now understood science to be changing in both ways described by the informed definition used in this research. This statement was given the informed code [*New knowledge grows AND is corrected*]. After reviewing all statements regarding the tentative nature of science, her post-intervention conception of this tenet was classified as transitional/informed.

Elise – Empirical

Elise had a transitional/naïve conception of the empirical nature of science at the beginning of the workshop. Very little evidence of her conception was revealed in the data, which by itself is a sign of naivety considering the explicit questions asked during the interview. One statement indicated that she appeared to hold empirical evidence as important in science, but was unsure of her opinion:

> *Mark – My question is, is there any science that exists completely in absence of any empirical evidence?*
>
> *Elise – I don't know. I really can't answer that question right now without thinking really hard. Science that doesn't have any physical knowledge? I don't know. I guess you have to think about something before you actually try to put it together, something physical that we know. I'm thinking space right now because we don't really know what's going on over there, but scientists do know about it without physically touching it or seeing it. I don't know.*

These statements were given the transitional code [*Leans toward needing empirical evidence, but lacks confidence*]. Later in her interview, she revealed a naïve conception regarding empirical which was coded [*Hypotheses require no empirical evidence*].

> *Not all the time, so I would disagree… A lot of the time you would have to have physical evidence, but in order to form your hypothesis, you don't necessarily have to see something or hear or smell or touch, have physical evidence, so probably have to use some of our imagination.*

Her statements indicate that while she understands empirical evidence is important, she also is not comfortable with the opinion that empirical evidence is required. When Elise references that scientists still know about space without physically touching it, she is revealing that her understanding of the word empirical is limited to what can be physically touched. She fails to realize that the way scientists know about space is through other forms of empirically derived data. Were she to make this connection, her conception would have been viewed as more sophisticated. As she did not make this connection, her conception of the empirical nature of science was classified as transitional/naïve.

At the conclusion of the workshop, Elise's conception of empirical had only slightly improved. When asked if there was any science that had no empirical evidence, she replied with a somewhat more definite stance that some empirical evidence was needed, but still failed to articulate her position:

> *Elise – I don't think we can have science without having some background knowledge. I don't know if that makes sense or not?*
>
> *Mark – Sure. So if there is no empirical evidence at all, you would…?*
>
> *Elise – You have to build on something that you have at the moment. Like if we had to come up with a new science branch, they would have to come up with some statement that everybody would have to agree on and build from that point on.*

This statement was given the informed code [*Must have a basis in empirical evidence*]. Because this statement indicated a definite need for some sort of empirical evidence, her post-intervention conception was classified as transitional.

Elise – Subjective

Elise began with a transitional conception of the subjective nature of science. She seemed to confuse subjectivity (due to theory-laden perspective) with general backgrounds and personal opinions. She demonstrated this in her VNOS response to the question which asked why scientists could disagree about the cause of dinosaur extinctions when they had the same data. Her response was:

> *All scientists have the same information but can produce several hypotheses because they all have different backgrounds and expertise.*

In this statement, which was given the transitional code [*Different backgrounds cause subjectivity*], Elise recognizes that scientists can have different opinions, but attributes it to their area of study, not to the theories they have been taught and have accepted.

In the post-intervention data, Elise's conception of this tenet had improved. While she did reiterate that a person's background could cause subjectivity, this time she referenced how background, education, and culture all influenced the subjectivity in any one persons' interpretation:

> *Before the workshop, I thought science was subjective because everybody has a different background and this is why I didn't have too much of an understanding when you said subjectivity and in culture and background, you remember we had that section? I think they go together because you have your personal belief and then your personal education and what you know about and then you add your culture and it's another. I think it goes together.*

This statement was given the informed code [*Educational background can influence interpretation*]. This more informed post-intervention conception of subjectivity was classified as transitional/informed because it still did not include reference to theory influencing interpretation.

Elise – Creative

Elise began the workshop with the commonly held naïve view that creativity was primarily useful at the outset of an experiment in designing an experiment or in developing questions. Despite her assertion that creativity should be used in all aspects of science (per her VNOS response), in her description of how it is useful, she only referenced developing new questions and did not identify scientists as creating new knowledge with their creativity and imagination.

> *In all steps, if you're looking at all the steps of the scientific method. Planning and experimenting, ok. What I tell my students, when they do a scientific lab, for example, most of the time there is no wrong answer as*

long as they explain what they've done. For example, one of the labs I give them to do is growing beans in salt water and fresh water. I give them the beginning and they do the rest of the experiment. They have to think of what else could go wrong or what else would make it work better. So I think it, all the parts, even when they read their results, they still have to think "ok, what if…could I have done this different?" When they write a conclusion, I still think they should think "what if?" and start thinking about other steps further and that's how we end up with different science because there's always somebody that's gonna say "What if?"

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*]. This strength of this naïve view was weighed in context of her transitional response to the VNOS question about the role of creativity in science. Elise responded:

I think a scientist need to use their imagination and creativity during all parts of their experiments. They have to keep an open mind and keep questioning their results and think of alternatives for each parts.

This response was coded [*Creative in all aspects of science, but no explanation*]. After reviewing all statements regarding creativity, Elise's pre-intervention conception of this tenet was classified as transitional/naïve.

After the workshop, Elise's view seemed to have slightly shifted to a more informed view. She referenced in her interview the need to be creative in all aspects of science as she did in the pre-interview, but this time described its role better:

I knew from the start. I don't know if you wrote it down somewhere. I think it was on my questions at the beginning…I said that you had to be creative in all portion of the research, even the reading of the data. The writing of the data you have to read what you have, but you still have to keep in mind that you may be interpreting it a different way than somebody else. I think creativity has to be everywhere in every step of the science.

In this statement she alludes to using creativity in interpreting the data but seems to be confusing creativity with subjectivity. This statement was given the transitional code

[*Conflates creativity and subjectivity but realizes its import*]. Despite the apparent confusion, her conception had moved closer to the informed view of creating new ideas that is viewed as informed for this research. Because this relatively small change has large implications, Elise's post-intervention conception of creativity was classified as transitional.

Elise – Social and Cultural

There was little evidence of Elise's conception of the social and cultural nature of science in any of her VNOS responses or in her interviews despite direct questions about this tenet. The only influence of social or cultural values on science that she was able to articulate was that personal interest in ones environment might generate interest in it for personal motivation. While this is true, it fails to incorporate the influence that a society has on the field of science in guiding the questions that are asked and the research that is done:

> *…somebody that lives on a tropical island will want to see the coral reef preserved, they don't want it to die. But somebody that lives in the middle of the prairies in central United States, they don't really care about what's happening in the tropical island because it doesn't touch them. So yeah, the background is important.*

This transitional statement was coded [*Conflates personal values with social and cultural values*]. Since this was the only statement related to social and cultural values, and so many facets of the influence they have on science were left out, Elise's overall pre-intervention conception of this tenet was classified as transitional/naïve. No evidence of change was observed in her post-intervention data.

Elise – Observation and Inferences

Elise's conception of observations and inferences and their role in science was classified as transitional/informed. She explained how observations and inferences were used to infer how dinosaurs looked in her answers to the VNOS:

> *Probably by first looking at fossils/trace fossils but also looking at common characteristics and common ancestors of present day living organisms. Scientists can probably get close to what the dinosaurs looked like, again by looking at what we find in the remains and common characteristics and present day living organisms.*

And in her interview discussing how she teaches this to her students:

> *When I talk about evolution with my students, I talk about fossils and they can picture a dinosaur, they can relate to this. And I say, "now that you know this, what does that remind you of?" And then we start talking about present day animals and we look at the characteristics they have in common, so that's where the common characters came. And then we look at a phylogenetic tree and say ok, you have the dinosaur and we talked about reptile, for example, how do those 2 look the same but they are different, and then we talk about a common ancestor.*

These statements convey a sophisticated understanding of how observations and inferences are used in science to retrodict and were given the informed code [*Use of current knowledge and theory to make inferences*]. However, when she discussed weatherpersons making forecasts, her confidence in inferences faded:

> *Elise – They don't know too much. [Laughs]*
>
> *Mark – Ok. Can you explain what you mean?*
>
> *Elise – Well, I think more and more they're relying on computer models, what the computer's gonna tell them versus looking at what has been the pattern over the last 2 or 3 days and ok, if it's been sunny for the last 2 or 3 days maybe the computer's gonna tell us it's raining for the last 2 or 3 days and it hasn't rained. They should, I don't know, go a little farther and make an hypothesis based on what they already know versus what the computer's gonna predict, which is just a machine that goes with number and number can be good sometimes but as far as weather, they haven't been good [laughs] in the last few months.*

Mark – Do you think they're more certain about some predictions than others?

Elise – If we're talking about the weather, yeah if there is a hurricane that's coming down close to Florida, they know it's gonna come through Florida or close to Florida. But as far as predicting what's gonna happen 10 days from the time it's born, I don't think…

Her doubt in weatherpersons' forecasts indicates a lack of sophisticated understanding in how computer models are using past information to predict future occurrences. This statement was given the transitional code [*Less confident in context of weather*]. After reviewing all statements related to observations and inferences, Elise's pre-intervention conception of this tenet was classified as transitional/informed. No evidence of change was observed in her post-intervention data.

Elise – Theories and Laws

Elise began the workshop with a naïve conception of theories and laws. Two naïve codes were identified in her pre-intervention data. In her interview she described theories and laws and contrasted them by describing theories as being tentative and subject to change and laws as being unchanging. Her description of a law was:

I don't know. [laughs] Well, if you want definition from the book, it would be something that everybody's gonna agree on.

And her description of a theory:

Something that scientists are going to agree on, but it's not a complete fact, it could be changed.

When asked if there was a relationship between theories, laws, and hypotheses, she responded:

Well they all started as a hypothesis. They've all been accepted by everybody in the science community, theory's accepted, but subject to change. They relate to each other, they all started as a hypothesis, possible answer to a problem. I don't know what else to say.

These statements were given the naïve codes [*Theory is tentative, Law is permanent*] and [*Hierarchical view*].

Elise's overall conception of theories and laws was classified as naïve.

After the workshop, Elise's conception of theories and laws had changed in two ways. She was able to articulate that theories and laws served two different purposes and referenced that one explained the "how" and the other the "what" as was described during the instruction. These descriptions were given the informed codes [*Theories are explanatory*] and [*Laws are descriptive*]. However, in the same statement in which she revealed these informed views, she also maintained that theories were not fully accepted while laws were and implied that a theory becomes a law after being fully accepted:

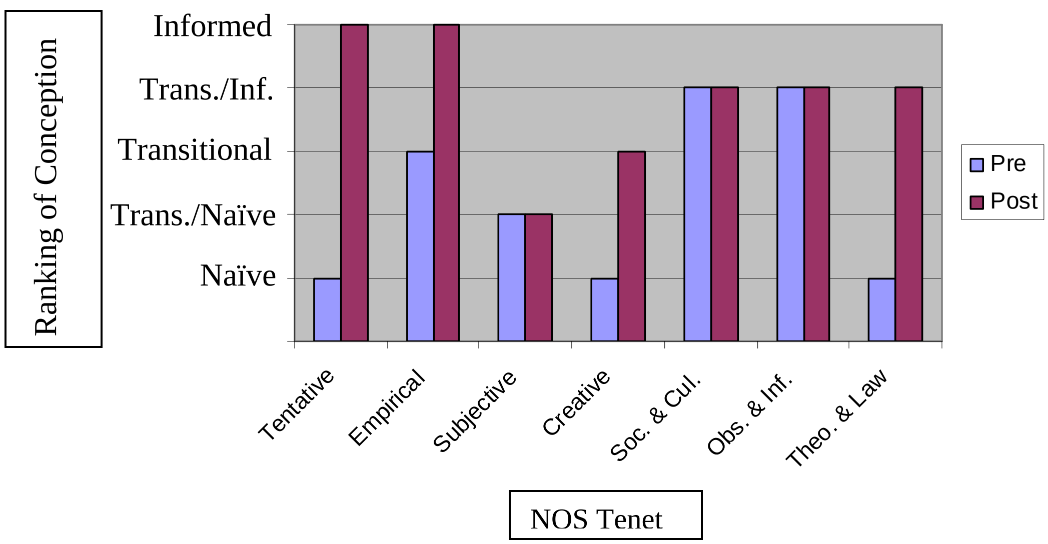
> *When you wrote down that one explained the "what" and the other one explained the "how," that was, well that makes sense now, kind of a little light bulb. I was thinking like here like the theory is an explanation that it is accepted, but not everybody agrees on, versus the law, everybody agrees on it. It becomes a law. That has changed my perception.*

Also in this statement was the phrase "It becomes a law" which indicates that once agreement has been reached "it" becomes a law. This conveys a naïve conception that it is the degree of acceptance that characterizes a scientific statement as either theory or law and that a theory becomes a law once it is fully accepted by the scientific community. This statement was given the naïve codes [*Theory is tentative, Law is permanent*] and [*Hierarchical view*]. After reviewing all statements related to theories and laws, her conceptions were classified as transitional.

Case Study #6 – Flora

Flora is a 4th grade teacher who has 19 years experience teaching science. Her educational background includes Masters Degree in Earth Science and is certified to teach through the ExCET exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure VI. Examples of Flora's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure VI. Flora's Pre- and Post-Intervention Rankings



Flora – Tentative

Flora began the workshop with a naïve conception of the tentative nature of science. Four codes, all naïve, were identified in her VNOS responses and subsequent interview. When asked how scientific knowledge might change in the future, she responded to the VNOS with:

> *It definitely will change as we gain more knowledge and understanding. Example: Pluto was Earth's ninth planet. Because of more sophisticated instruments, it has been reclassified as a dwarf planet based on the understanding of its characteristics.*

And in her interview she explained further:

Flora – Yeah, and I used that example of Pluto. There goes all our nice little games. In 4th grade we do games and activities. There goes My Very Educated Mother Just Served Us Nine Pizzas, because now they're saying Pluto is a dwarf planet. So, we've got to update our knowledge and just refine it.

Mark – Is there any other way that scientific knowledge that a textbook that we have today, that that knowledge won't look the same 50 years from now, other than reclassifying things?

Flora – Of course, you know when you just said textbook, I'm thinking 50 years from now we probably won't have a textbook. We'll probably have a CD in your car or something like that.

Mark – So then the information on the CD would be different. How…would it be different?

Flora – You know what? Yes, because…right now when you look at a textbook you at least see a lot of careers. We want to show students, "You have this knowledge, look at all these people and their careers," and every chapter's gotta a career, which is excellent. 50 years ago you wouldn't seen that.

These statements were given the naïve codes [*Classification and Terminology*] and [*Only change in science textbooks is in the presentation*]. Later in her interview she described how scientific knowledge is so complex that it would have to change, but described the change as being in the learners understanding, not in the knowledge itself:

There are certain things, gravity, I don't think gravity's gonna change. We think we understand it. But we think we understand time, and now we're thinking time is relative. So life is complex and science is the study of life. When the kids ask me questions, especially about creation and evolution and they get troubled, and I just tell them, "think about this is all the knowledge in the world and my brain can hold that much, so there are some things out there I just can't understand. But it doesn't mean that it's right, that it is or it isn't, it just means I can't understand it. So I think as scientist study we just understanding more of life, it's complex.

This statement was given the code [*Scientific knowledge is so complex it must change*]. The last naïve code assigned to Flora's data was [*Proof unclarified*] and was assigned to all statements in which she used a form of the verb prove to describe how science claims are made. After reviewing all statements regarding the tentative nature of science, Flora's pre-intervention conception was classified as naïve.

After the workshop, Flora's conception of this tenet had improved. She clearly recognized that using the word proof was an inappropriate way to present science and stated she had even shared this idea with her fellow teachers:

> *…the main thing that stuck in my head was when we say, "Can you prove that?" That was a big thing to me. In fact, in our teacher training I was supposed to share some things to science teachers and that's one of the things that I brought up. The two things I brought up were we don't prove things, we show evidence because what we thought was for sure 100 years ago is not for sure today.*

This statement was given the informed codes [*Won't use "proof" anymore*] and [*New knowledge grows AND is corrected*]. After reviewing all statements regarding the tentative nature of science, Flora's post-intervention conception of this tenet was classified as informed.

Flora – Empirical

Flora's pre-intervention conception of the empirical nature of science was classified as transitional. She made a statement which was given the informed code [*Must have a basis in empirical evidence*] which indicated that empirical evidence was a requirement of science:

> *Yeah, it should be logical; it should be what we can see it should be based on evidence.*

While this statement indicates an informed view of the empirical nature of science, another statement in her interview indicated that if a claim was not directly testable, it was not scientific:

> *Sometimes the absence of information… I want to say like detectives, sometimes when something's not there it can tell you something. But true*

> *science is 'you're testing it' and you can't test something that's not there. I think when something's not there, it can help you pose a question. But I don't think it could be real science, it would be philosophy, if it wasn't there. I'd think it'd be philosophy. I'd think it'd be wondering. Then I think you get back into literature. To write about what could be, what should be, what I'd like it to be, but if something's not there, no, I don't think it can be science.*

This statement was given the naïve code [*Must have empirical evidence (no inferences)*] and conveyed the naïve view that all scientific claims must be supported by evidence directly accessible to the senses and that all scientific claims must be, likewise, directly testable. After reviewing all statements related to the empirical nature of science, Flora's pre-intervention conception of this tenet was classified as transitional.

After the workshop, Flora's conception of the empirical nature of science appeared to have improved. She made one statement which indicated that she felt that scientific claims must have some basis in empirical evidence, but her stance was not as strong as in her pre-intervention data where she indicated that directly-observable evidence was required of all scientific claims:

> *Mark – …can you have something that is called science that has no empirical evidence whatsoever. How would you answer that now?*
>
> *Flora – I almost want to say no because you have to have some kind of data, otherwise it's just hearsay or it's just legend or it's just because my momma told me. So I'm gonna say it has to have some kind of data.*

By using the phrase, "some kind of data", Flora indicates that she has moved from her absolutist view of the need for empirical data to a more realistic view that scientific claims must have some sort of evidence to support them. This view accommodates inferential scientific claims and, therefore, was given the informed code [*Some scientific knowledge lacks "hard data"*]. Flora clarified her position on the empirical nature of science by contrasting science with other disciplines:

> *…the why is for the theologians and the philosophers to discuss because that's the supernatural.*

This statement was given the informed code [*Science doesn't study supernatural*]. After reviewing all statements regarding the empirical nature of science, Flora's post-intervention conception of this tenet was classified as informed.

Flora – Subjective

Flora recognized subjectivity in science but could not clearly articulate the source of the subjectivity. She did allude to personal backgrounds and experiences, and even mentioned what school or teacher a person may have had, but never clearly related that a scientist can view her observations through a theory-laden perspective which could influence her interpretation:

> *What I said about their own experiences, I think you can't get away from the fact that you're a human-being with your opinions and your thoughts. And if this person went to this school and had these professors who they admired and sat under their teaching and these people traveled the world and read books and they start gaining opinions, they have the same information, but they just see it different and I think that's why we never can be pure scientists when you talk about the past because somebody gives an argument and that makes perfectly good sense and then someone else gives an argument and that makes perfectly good sense and then so well let's test it.*

This statement was given the transitional code [*Different backgrounds cause subjectivity*]. Flora also made less-informed statements which indicated that she believed science should be a purely objective endeavor, both in her VNOS responses:

> *Science is looking at the world objectively and trying to understand it by observations and tests.*

And in her interview:

> *I guess it's the like the opposite of art and literature. Where's it's like "I feel, I get this impression." Where science, you have to step back and be objective so everyone's talking the same language.*

These statements were assigned the naïve code [*Science is objective*]. After reviewing all of her statements regarding the subjective nature of science, her overall pre-intervention conception was classified as transitional/naïve.

After the two-week workshop, her conception of this tenet had changed somewhat. She made no new references to science being objective, but actually acknowledged that subjectivity was not actually bad for science, but that an awareness of the subjectivity is important:

> *Knowing that we have biases, so I think we can't take away our biases, but we have to acknowledge them and work through that.*

Although she describes the subjectivity as bias, her conception has improved in that she recognizes that being aware of ones subjectivity is important. This statement was given the transitional code [*Subjectivity isn't bad, but we need to be aware of it*]. Flora also discussed the source of subjectivity and came closer to attributing it to accepted theory learned in education than she did in her pre-intervention data:

> *I would think they come from our culture, from our education, from our religion. I think culture has the biggest thing, well religion has a big part too and sometimes just our limited education, just what we're exposed to.*

Although Flora did mention education as being a potential source of subjectivity, it was included with culture and religion in a "shotgun" style and did not demonstrate a fully sophisticated conception. The statement was given the informed code [*Educational background can influence interpretation*] but was weighed against less informed codes like [*Subjectivity "just a human thing"*] which were also identified in her post-data:

> *I think in science it can almost be a bad thing, but I think you can't take it awa…I think it can interfere, but I think if we ever try to take all our subjectivity away, we would take away what makes us people, so I don't think you could ever totally take it away because that's just who we are.*

After reviewing all of her statements relating to subjectivity in science, Flora's post-intervention conception of this tenet remained classified as transitional/naive.

Flora – Creative

Flora's conception of the creative nature of science was naïve at the beginning of the workshop. When asked where creativity should play a role in science, she replied:

> *Imagination and creativity are utilized in deciding what needs to be investigated and what questions to ask. Once the investigation has begun, a scientist must become objective and follow standard scientific procedures.*

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*]. She also compared creativity to curiosity and demonstrated some unease in allowing creativity to play a role in scientific methodology:

> *I know? I feel like I'm contradicting myself. You know, I think creativity and curiosity are close… I'm gonna go right down the middle of the road. I think about non-examples. I know some people that are not curious and so I don't think they go about being creat…and I think about creative also as entertaining a lot of ideas. If you're not curious, you're not gonna entertain a lot of ideas.*

This statement was given the naïve code [*Creativity equals curiosity*]. None of her statements about creativity in science conveyed an understanding that by using the imagination, scientists actually create new knowledge and so her pre-intervention conception of the creative nature of science was classified as naïve.

Flora's felt she had changed her conception of the creative nature of science quite a bit over the course of the two-week workshop. She related this change in her interview:

> *That's the one I've changed the most because I remember in the pre-interview I said "oh, you can be creative with your initial thoughts, but then no creativity." And I'm going change that based on all the stuff we learned. Being creative, thinking out of the box, trying to find new solutions, but still you can't be creative in…if you think of creative is following no rules, more like artistic creative, I say you have to limit it,*

> *you have to be able to document and have a systematic way of recording your evidence so that other people can build it from it. But as far as approaching a problem, is not be in a box, being able to look at it from this side and that side and this perspective or try tools that weren't used before… So that's one thing I really have changed on.*

Flora felt she had developed a sophisticated understanding of the creative nature of science, however, she still was thinking of creativity as a way of developing questions, designing experiments, and thinking 'outside the box'. She did reference using creativity to "find new solutions" and so it appears she is beginning to realize that scientists create these solutions. This statement was given the transitional code [*Creative in finding solutions*] and her overall post-intervention conception of this tenet was classified as transitional.

Flora – Social and Cultural

Flora had a somewhat sophisticated understanding of the influence that social and cultural values have on science. She clearly referenced how they could influence different societies and cultures to ask different scientific questions in her interview response:

> *Mark – Ok. How much do you agree or disagree with the statement that social and cultural values influence the advancement of science and the processes of science?*
>
> *S – Ooh. It shouldn't, but I think it does. So, I'm gonna say 6 [on a scale of 1-10] and my example there is in Japan, don't they eat whales? So they're not so prone to study them to save them. They might study them to eat them. But we're just like "oh no, we need to let them be free and save the whales." Well, they have a different value system on that. Some people over in Africa, you know they mine the diamonds so they're not so concerned about keeping that land untouched because they want the diamonds. I think your own interests, your own economy comes into play about those things.*
>
> *I – And you said you thought it shouldn't?*

> *S – It shouldn't, but we're not gonna study something we don't care about. We're not gonna to stop something that I don't think is wrong.*

This passage from her interview indicates that she recognizes the influence societal and cultural values can have on science, but that she does not believe they should. These statements were given the informed code [*Social and cultural values direct science*] and the naïve code [*Social and cultural values SHOULD NOT influence science*]. Her overall pre-intervention conception of this tenet was classified as transitional/informed. No change was observed in her post-intervention data.

Flora – Observations and Inferences

Before the workshop, Flora was able to give a good description of how observations and inferences were used by scientists to retrodict the physical appearance of dinosaurs. In her VNOS response, she wrote:

> *Scientists speculate how dinosaurs looked by studying their bone fossils. From studying the bones, scientist can speculate their muscle formations which indicate how the animal moved. Fossils of teeth can give clues as to what types of food was eaten. Scientists then compare what they know about these extinct animals to animals that live today and make assumptions as to how they may have looked.*

Although she does use terms like speculate and assume to describe the inferences, the overall description is appropriate to explain how observations and inferences play a role in science. This statement was given the informed code [*Use of current knowledge and theory to make inferences*]. Flora did, however, make one statement which was given a naïve code. She indicated that without being able to directly test a claim, it could never be a scientific fact:

> *To become a fact, a scientist would need to test his hypothesis. When working with animals that have become extinct so long ago, a scientist cannot recreate, observe and test a hypothesis using standard scientific methods.*

This statement was coded [*MUST have hard data or just speculating*], and while indicating a lack of confidence in retrodictions, was weighed against the previous informed statements and Flora's pre-intervention conception of observations and inferences was classified as transitional/informed.

At the conclusion of the two-week workshop, her conception of this tenet had only slightly changed. She indicated in the post-interview that confidence increases with more observations; an informed view which was given the code [*Confidence in inferences increases with more data*].

> *…the more observations we have the more accurate our inference is to kind of figure out why that happened, excuse me how that happened.*

Flora's post-intervention conception of observations and inferences was classified as transitional/informed.

Flora – Theories and Laws

Flora's conception of theories and laws was naïve at the outset of the workshop. She held the common, naïve view that theories were tentative while laws were not. She first describes laws as:

> *…something we don't even argue about anymore, because it's just agreed upon. It's already been proven, it's just part of us, it's… Gravity? I'm not gonna argue there's no gravity because I fell off my horse, you know. So I would say it's just something someone's already proved it, we agreed… I think it's something that has been proven beyond a shadow of a doubt and people have just, that's it, period.*

And she contrasts laws with theories:

> *Ok, a theory is, a lot of people agree on it, but it hasn't totally been proven. I think, you know you hear all the time, "well that's your theory." Some people might say evolution, some people say "oh that's a proven fact," and other people go "no, it's not, that's just a theory." As opposed to a law, which is undisputable.*

These statements were given the naïve code [*Theory is tentative, Law is permanent*]. Flora also demonstrated the naïve conception that a hierarchical relationship existed between hypotheses, theories and laws that was given the naïve code [*Hierarchical view*]:

> *Hypothesis is the very beginning of the ladder. A hypothesis, I question something. I make a statement about it. I want to test it out. Then after more and more study, and reading other people's papers and other people testing, and then we've got pretty much a theory. And then as years go by and it's been tested and tested and then it becomes a law. So it's a stepping, it's a ladder.*

After examining all of the statements Flora made about theories and laws, her conception of this tenet was classified as naïve.

At the end of the workshop, Flora's conception of theories and laws had improved. She clearly conveyed that she understood a difference existed between the types of claims made by theories and laws;

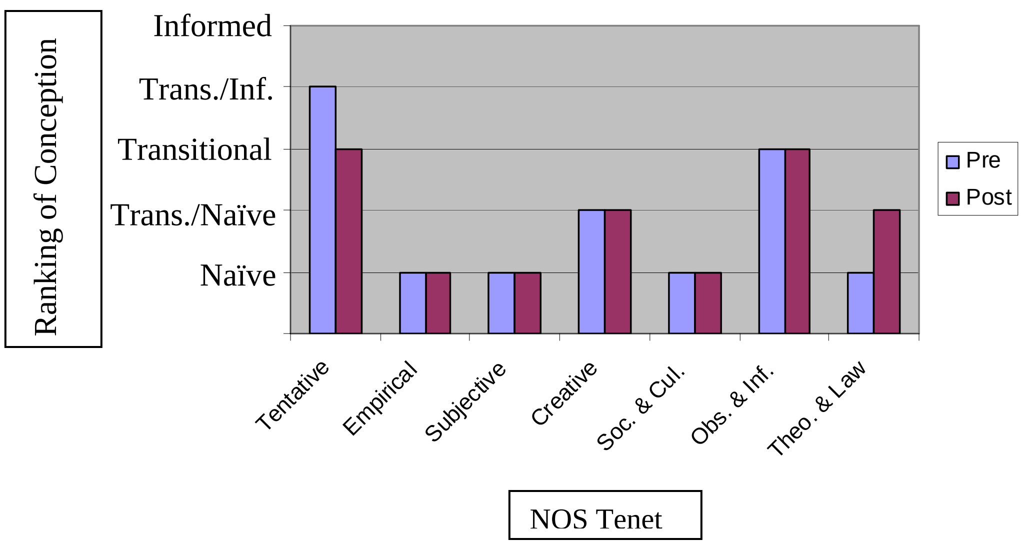
> *…so now I'm still trying to get in my head is that the laws are kind of like a generality or is a pattern of things that happen, but theories try to explain why they happen. I was reading that article again about the hypothesis, the way we using them in school, they're really predictions. And I'm still kind of fuzzy on the other way when they said one is like speculating a law and the other one is like speculating a theory, it's not quite there yet. So maybe I might need a little more help on that one. But the big thing is that laws and theories are totally different things.*

While she clearly understood that theories and laws served different purposes in science and could identify fairly well what those purposes were, she lacked confidence in this new understanding. These statements were given the informed codes [*Laws are descriptive*] and [*Theories are explanatory*] as well as the transitional codes [*Recognizes difference between theory and law*] and [*Lacks confidence in new understanding*]. Flora's overall post-intervention conception of theories and laws was classified as transitional/informed.

Case Study #7 – Gina

Gina is a first grade and kindergarten teacher who has 12 years experience teaching. Her educational background includes Bachelors of Science in Interdisciplinary Studies and she is certified to teach through the ExCET test. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure VII. Examples of Gina's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure VII. Gina's Pre- and Post-Intervention Rankings



Gina – Tentative

Gina began the workshop with a transitional/informed conception of the tentative nature of science. She described how scientific knowledge in textbooks might change in the future:

> *… you know scientists think this is the exact answer, this is the right answer for a question that they maybe had even 10 to 50 years ago, but as they experiment and investigate more though maybe it's changing… more modern technology has come up with a better way to investigate it so this information might not be so prevalent and so they can just kind of drop that out of a text.*

And gives an example of this type of change in scientific knowledge:

> *Like I said science changes second by second. All science is investigative and experimental. New ideas and information are always changing. An example is coronary bypass surgery. Now stints are placed in veins instead of major surgery.*

With these two informed statements which were coded [*New knowledge grows AND is corrected*], Gina demonstrated a fairly sophisticated view of the tentative nature of science. She did, however, convey one naïve conception in her use of the word proof;

> *Mark – And when you use the word "prove" what do you mean by prove? I hear that word bubble up quite a bit.*
>
> *Gina – Ok, prove using experimentations and evaluating. Doing a lot of experiments over and over again, not just once but maybe 5, 10, 15, maybe 20 times to prove that the idea is true*

This statement was given the naïve code [*Proof unclarified*] and indicated the naïve conception that scientific knowledge is relatively certain and unchanging. Because of this seemingly contradictory view of scientific knowledge, her overall pre-intervention conception of this tenet was classified as transitional/informed.

After the workshop, Gina made another statement that further accentuated her view that some knowledge was relatively permanent. While recognizing the tentativeness of scientific claims, she indicates that with enough data, it might become certain. When asked to describe the tenet tentative, she responded:

> *That everything is tentative until you explore it further. Does that make sense?*

This statement was given the naïve code [*Some knowledge becomes permanent*]. After considering this naïve view along with her informed views, her overall post-intervention conception of the tentative nature of science was classified as transitional.

Gina – Empirical

Gina held a naïve view of the empirical nature of science at the beginning of the workshop. When asked if there could be science without any empirical evidence she replied:

> *I would think so because you have to, you had asked a question I think about creativity and imagination I think that would go hand in hand with that because they didn't really know that was a dinosaur I guess when the first bones were found or even plant life or even with when they opened up the mummy's tombs in Egypt. You know I think you don't have to have concrete evidence that science is happening.*

This answer revealed that Gina did not have a good working knowledge of the meaning of the word empirical and was given the naive code [*Misunderstands the meaning of empirical*]. While stating that no empirical evidence was needed, she referenced empirical data. With this being the only evidence of her understanding of this tenet, her overall pre-intervention conception of the empirical nature of science was classified as naïve.

After the workshop, Gina's conception of empirical had not improved. She still did not understand what was meant by the word empirical:

> *Mark – What about empirical?*
>
> *Gina – I still get that…I'm not sure…I think I know what it is, but I'm not sure of the word. Empirical means that it's absolutely right?*
>
> *Mark – No, empirical had to do with that it is observable, or measurable and the tenant was that science is based at least partly on empirical evidence.*
>
> *Gina – I understand it but I don't have my vocabulary paper in front of me [laughs]. I understand what it is, but to attach the words to it…*
>
> *Mark – Ok, when I first did the meeting with you that I'm still wondering about. It was can you have something called science that has no empirical evidence at all?*

Gina – Yes, I think so.

Mark – Can you give me an example?

Gina – And empirical means?

Mark – Observable or measurable?

Gina – It's not measurable or it is?

Mark – It is measurable, empirical is, so can you have something called science that has no empirical evidence?

Gina – No, there is none. I think science is measurable. Because I think we talked about the dinosaurs and stuff, right?

After finally clarifying the meaning of the word 'empirical', Gina asserts that you must have empirical evidence in science. This statement was given the naïve codes [*Misunderstands the meaning of empirical*] and [*Must have empirical evidence (no inferences)*]. Gina's reliance on empirical evidence was further seen in a VNOS response to the question of how sure weatherpersons are of their prediction:

Weather people can only be as certain at the satellites in space are to show them the weather patterns.

Gina's post-intervention conception of the empirical nature of science was classified as naïve.

Gina – Subjective

Gina's pre-intervention conception of subjective was classified as naïve. The only evidence in her data was in response to an interview question which asked her how subjective scientific knowledge was. Her response indicated little understanding of the word subjective:

It can be both subjective and concrete at the same time I think.

This statement was given the naïve code [*Does not understand "subjective"*] and her overall pre-intervention conception of this tenet was classified as naïve.

In her post-intervention interview, her conception of the subjective nature of science had not improved. When asked about the subjective nature of science, she responded:

> *That means that everybody has their own opinion, right? [Laughs] I need to go through my workbook, my material. [Laughs] I know, I just kind of…subjectivity. Yes, I think the nature of science has subjectivity because people have a different view or a different way of coming to an idea. Subjectivity is your opinion or my opinion, right?*

In this statement she conflated subjectivity with personal opinion and in no way related subjectivity to the theory-laden paradigm through which scientists interpret their data. These statements were coded [*Does not understand "subjective"*]. Gina's post-intervention conception of the subjective nature of science was classified as naïve.

Gina – Creative

Gina conveyed a transitional/naïve conception of the creative nature of science in her pre-intervention data. She made statements which indicated that creativity was synonymous with curiosity:

> *Mark – To what degree do you believe creativity plays a role in the process of science?*
>
> *Gina – I'd say a 10.*
>
> *Mark – 10? I guessed you would go there from what we have talked about.*
>
> *Gina – I'd say it's a 10. You have to be curious. You have to be creative to find different ways to do things. If you did the same ole' same ole' you're not getting anywhere, you know.*

This statement was given the naïve code [*Creativity equals curiosity*] and indicated that creativity played a role in formulating questions and stimulating interest, but not in creating new scientific knowledge. Gina made one reference to using creativity in explaining phenomena in context of dinosaurs and their extinction:

> *Mark – I'm wondering what accounts for trained educated scientists having different explanations of dinosaur extinctions when they're using the same evidence?*
>
> *Gina – See, I think that's where the imagination and creativity comes in because some people believe that there was a big ice age came and of course we got the glaciers and such but I don't know.*

This statement was given the transitional code [*Creative in developing new theories*]. This code was classified as transitional because it was only alluding to creating new theories and Gina's conception of theory was synonymous with an 'idea' or a 'guess' and not representative of a scientific explanation based on evidence that is created using imagination and creativity. After reviewing all statements made by Gina relating to creativity in science, her overall pre-intervention conception of this tenet was classified as transitional/naïve.

After the two-week workshop, Gina stated that creativity should play a role in all aspects of scientific research but could not articulate what role it played:

> *I believe scientist use creativity in all aspects of their research.*

This statement was given the transitional code [*Creative in all aspects of science, but no explanation*]. She also alluded to using creativity to "find" solutions:

> *Gina – I think there's a lot of creativity in science. You have to be creative in science to get to where a lot of…for instance like when we watched the movie about the Congo again…*
>
> *Mark – "The Origin of AIDS"?*
>
> *Gina – Yeah, that and the Polio vaccine. Those people were very creative in what they were using to fight the Polio, although it could have created the AIDS problem. I just think that scientists have to be creative because if they keep pounding and pounding their heads on the block, thinking this*

> *is gonna work, this is gonna work and it never works. They have to branch out. They have to be creative.*

This statement was given the transitional code [*Creative in finding solutions*]. After reviewing all statements related to the creative nature of science, Gina's overall conception of this tenet was classified as transitional/naïve.

Gina – Social and Cultural

No evidence of any understanding of the social and cultural aspects of science was observed in Gina's data either before the intervention or after. Her conception of this tenet of nature of science was classified as naïve both pre-intervention and post-intervention.

Gina – Observations and Inferences

Gina's conception of the role of observations and inferences in science was classified as transitional at the beginning of the workshop. When asked how scientists know what dinosaurs looked like, she responded:

> *Gina – …they can put the bones together and model the clay or you know whatever kind of substance they have to get a general idea.*
>
> *Mark – …how do they know how much clay to add?*
>
> *Gina – Maybe from using the species that are still living, like the alligator, and snakes, and the Komodo dragon, knowing that they're reptiles that maybe reptile has a certain thickness of skin depending on where it lived. If it lived in water was it thick or not, if it was a land animal maybe this or that… but skin color I think they, I don't know, I think that's part of the imagination. But looking at the crocodile and the alligator and the Komodo dragon, or even lizards, they might have come up with they probably generally looked like this.*

This statement was given the informed code [*Use of current knowledge and theory to make inferences*]. Despite this informed view of how observations and inferences could be used to retrodict, Gina lacked confidence in her answer and so the statement was also given the transitional code [*Lacks confidence in inferences*]. Furthermore, Gina could not clearly describe observations and inferences when taken out of context of dinosaurs:

> *Mark – Ok. Can you describe the role of observations and inferences in the advancement of scientific knowledge?*
>
> *Gina – Oh, you have to observe, you have to observe the most very tiny, tiny thing because you could miss something very important. What was the other part?*
>
> *Mark – inferences*
>
> *Gina – And you have to infer, well why did this happen? Where are you going with this? What was the reason that this happened anyway beforehand?*

This lack of ability to describe observations and inferences indicated that her conception of this tenet of nature of science was not highly sophisticated and this statement was given the naïve code [*Poor description of observations and inferences*]. Her overall pre-intervention conception of observations and inferences was classified as transitional. No change in Gina's conception was observed in the post-intervention data.

Gina – Theories and Laws

Gina began the workshop with a naïve conception of theories and laws. The only evidence of her conception of theories and laws came from the interview questions which directly asked her to define what they were and give examples. She described theories as:

> *…a theory is an idea that someone comes up with that they try to prove to be true.*

And a law as:

> *It's a rule, maybe, of science that will always be the same no matter what you do or how you try to change it?*

These statements indicated a lack of understanding of these two distinct kinds of scientific knowledge and exhibited a belief that laws were more permanent and theories were more tentative. They were given the naïve code [*Theory is tentative, Law is permanent*].

After the workshop, Gina's conception of theories and laws had improved slightly. While she continued to indicate that theories were more tentative than laws, she distinguished them by identifying theories as being explanatory:

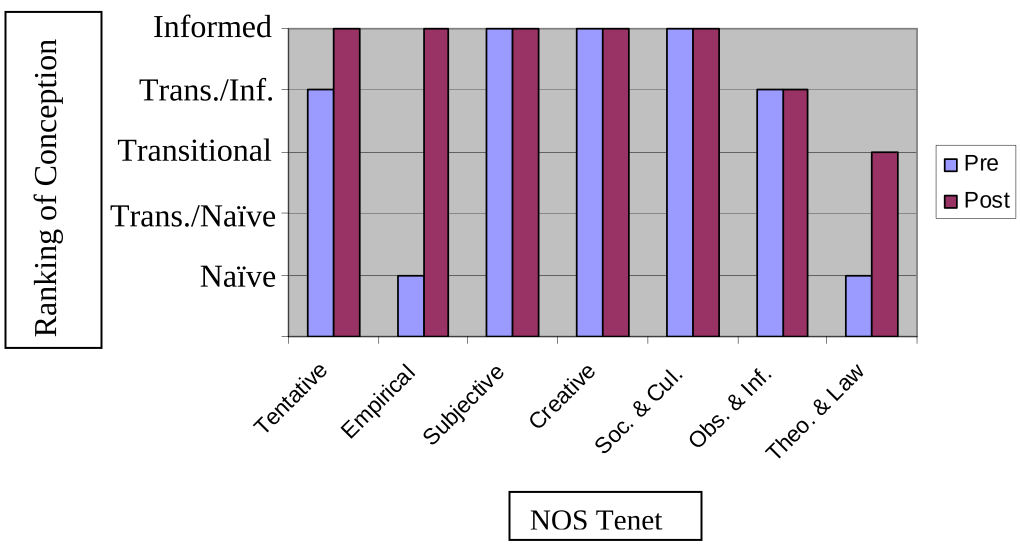
> *…you have a theory, it's more of an inference, maybe, and laws are already set, so to speak.*

By recognizing that theories were inferred explanations she demonstrated that she was beginning to develop a more sophisticated view of theories and laws. This statement was given the informed code [*Theories are explanatory*]. Her post-intervention conception of theories and laws was classified as transitional/naïve.

Case Study #8 – Hannah

Hannah is a seventh and eighth grade teacher who has seven years experience teaching science. Her educational background includes Bachelors of Science in Movement Science and she is alternatively certified through the ExCET exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure VIII. Examples of Hannah's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure VIII. Hannah's Pre- and Post-Intervention Rankings



Hannah – Tentative

Hannah began the workshop with a transitional/informed view of the tentative nature of science. She clearly indicated in her VNOS response that we have had to modify our perception of the planet with new discoveries:

> *Scientific knowledge should always be changing and improving if we are doing our job as scientists. Originally people thought the world was flat. If no one pushed the limits of the knowledge at that time and took risks to further expand our understanding of the physical world, we might all still live in the same region of the world and have missed many of the wonders and resources that our planet has to offer.*

While Hannah demonstrates the informed view that scientific claims can be revised over time, coded [*New knowledge grows AND is corrected*], she limits her examples of the changes in science to the stereotypical flat-Earth to sphere-Earth argument. The only other place she mentions 'correcting' in science is in disproving hypotheses and makes no reference to contemporary changes in current scientific claims. This limited view of the tentativeness of science reduces the strength of her informed view. Further weakening her view, whenever asked how scientific knowledge changes, she consistently refers to the addition of new knowledge. This indicates that unless she was directed to discuss how current knowledge would change, she only recognizes the growing characteristic of science.

> *…in science we're always trying to find what we don't know instead of trying to remember what we did know or do… I guess just the understanding of the unknown, being able to figure out what we don't know and try to investigate so it becomes known, I guess.*

And when asked how science textbooks would be different in fifty years, she responded:

> *I think the knowledge base will just be expanded. Like right now, we're still teaching in our books that you have protons, electrons, and neutrons. We know there's research now that says those can be broken down into smaller pieces. So I think we're gonna find things that we never even knew. We're gonna find more on the human genome project and all of the research that, things are gonna be smaller. We're gonna know more details than they know now. That's my main thing, is what's inside. I don't know if we're gonna have big vast new knowledge, but we're gonna find new knowledge inside of what we already know, I think.*

These statements were given the naïve code [*New scientific knowledge will be added*].

The last code identified in Hannah's pre-intervention data was in her use of the word 'proof' throughout her interview; coded [*Proof unclarified*]. An explanation of her use of the word 'proof' is found in her interview:

> *Hannah – Well like any research you do, you should do background research on what people already know and then you try to go that next*

step. What is the next thing you should find out? Cause you don't want to just repeat the same things. That basic information, once it becomes scientific law and proven, then what's the next step? What can we learn from that, so we just continue to build upon those behind us and continue trying to find something new.

Mark – Ok. You just said "proven something." What do you mean by the word "prove?"

Hannah – That's difficult to say 'cause they thought they proved that the earth was flat originally. So when enough scientific research has been done to show validity, that it happens over and over again to get the same results, then I guess we can assume that we can go that next step.

This statement indicates that Hannah holds the naïve view that with enough evidence, scientific claims become certain and are no longer tentative. After reviewing all statements regarding the tentative nature of science, Hannah's pre-intervention conception of this tenet was classified as transitional/informed.

By the end of the workshop, Hannah's view of the tentative nature of science had improved. When asked to describe tentativeness in science, she responded:

I think I always thought that, but I think I feel more validated in it now. Science is always changing. Some people want it so dogmatic that this is the way it always is, but now I just feel better to be able to say, it's always tentative.

She further expressed this sentiment by asserting that she would not use the word 'proof' anymore:

You really can't prove anything, you really just support it.

These statements were given the informed code [*Won't Use Proof Anymore*]. She further expanded on her view that scientific knowledge would be corrected over time with new data collected:

I think (and hope) that the knowledge of today will change in the future as further research and technology allows (and compels) scientists to question what we think is correct at the present time.

With this statement, Hannah opens up the realm of scientific knowledge that is subject to change from her previous, more-narrow, realm of hypotheses or historical inaccuracies to encompass currently held scientific claims as well. This statement was given the informed code [*New Knowledge grows AND is corrected*]. After reviewing all post-intervention data relating to the tentative nature of science, her overall conception was classified as informed.

Hannah – Empirical

Hannah's pre-intervention conception of the empirical nature of science was classified as naïve. She held the view that without direct, empirical data, scientists were speculating:

> *I think you have to have empirical…if you don't then you're just speculating and that's not true to science. Science is trying to find a hard and fast answer and then build upon that, but if you don't have empirical data or empirical evidence to build your understanding on then I think you're just speculating.*

In another statement in her interview she again alluded to the need for empirical evidence to 'prove' scientific claims:

> *If you don't have objective data then you can't prove anything.*

These statements were given the naïve code [*Must have empirical evidence (no inferences)*]. This absolutist view of the need for direct, observable evidence, led to her pre-intervention conception of the empirical nature of science to be classified as naïve.

After the workshop, Hannah's conception of this tenet had improved. In her discussion of the empirical nature of science, she expressed a much more informed view:

> *Hmm…I guess the beginnings of a science investigation, the beginnings of a science concept could begin that way, but I think that truly without empirical evidence at some point within the investigation or the study of that, then I think you wouldn't call it science. I think you would have to*

> *call it something else… I think in you're creativity and you're 'thinking outside the box' and you're 'figuring out just what is the question I want to look at', all of that yes, but I think eventually you have to bring it back to have some empirical evidence to move to the next step.*

This was a change from her prior view that empirical evidence was critical to directly support any scientific claim. In this passage she indicated that all scientific claims must be somehow tied back to empirical evidence indicating that as long as there was some empirical support, the claim could be made. This statement was given the informed code [*Must have a basis in empirical evidence*]. Hannah's overall post-intervention conception of the empirical nature of science was classified as informed.

Hannah – Subjective

Hannah began and ended the workshop with a sophisticated conception of the subjective nature of science. In her VNOS response to how scientists could disagree about the extinction of dinosaurs, she replied:

> *In the case of the mass extinction, I believe that there is still enough missing evidence that allows room for speculation as to what actually caused it. Scientists are humans too and each come at evidence with some sort of bias or preconceived notion of what they think is the right answer. Further research is the only correct way to change the mind of those who interpret the evidence in a false manner. If all scientists thought exactly the same way we would never have new discoveries.*

In this statement, Hannah clearly addresses that scientists approach data with a preconceived notion, but fails to attribute it to a theory-laden perspective. This statement was given the naïve code [*Subjectivity is "just a human thing"*]. In a later statement, she identifies the source of the preconceived notions as being their theoretical lenses that were put in place during their educational background:

> *I'm just thinking maybe if you had spent your whole life researching it this direction, thinking that maybe they were killed by something different…then your data starts skewing you the other way, do you look at it differently if you believe something to be the case instead of totally*

> *scrapping your idea and going another direction? …Maybe you already have some idea of what you thought, maybe you just learned it at school, maybe that's what some teacher taught you and you believed that that was the case and then you have to tell yourself, well that's not what the data's telling me…*

These views are consistent with the informed description of subjectivity in science used in this study. Not only does Hannah attribute the personal bias to education and theoretical lenses, but she also addresses the problems faced when one's theory fails to accommodate the data and paradigm shifts are being faced. These statements were given the informed codes [*Theory laden*] and [*Educational background can influence interpretation*]. Hannah's overall pre-intervention conception of the subjective nature of science was classified as informed.

The only additional evidence found in the post data involved the need to be aware of one's subjectivity. Hannah described subjectivity as being a potential problem and a potential source of new discovery in science:

> *I think there's always going to be subjectivity in science, whether it's good or bad. Because we all come at it from different areas of study, different areas of where you were trained, to what their opinion was. So in the real world you would hope that would be limited as much as possible, but I think there's always subjectivity. But then sometimes, your subjectivity may also help your creativity and take you a different direction that other people aren't going, so it may not always be a bad thing. I think it's just something we have to be aware of and we all bring some subjectivity to the chair, whatever we're doing.*

These statements were given the transitional code [*Subjectivity isn't bad, but we need to be aware of it*] and the informed code [*Subjectivity fuels discovery*]. Hannah's post-intervention conception of the subjective nature of science was classified as informed.

Hannah – Creative

Hannah's pre-intervention conception of the creative nature of science was classified as informed. In one statement she acknowledges that objectivity can be important, but then explains how creativity is equally important:

> *I think it's necessary to have objectivity, but I think if you don't at least when you see this data try to figure out what it could be telling you. I think you've got to have some creativity thinking of trying to figure out what that means to you. I think if you have this whole pool of data and you have these trends you're seeing, but what does that mean? What do you get from that? I think if you're totally cut and dry and have no creativity, something's gonna miss you. You might run off on a tangent and you may not even think "well maybe I should go that direction" because you're just looking right down the barrel in one direction. You may not know what that next question is, so if you hit a dead end with your data and that didn't work, do you stop? Or do you use creativity to try to figure another way to go at it again? That's kind of what I'm thinking.*

In her description of creativity as formulating 'what that means to you', she clearly attributes creativity to the creation of new knowledge. Later in her interview, she expands further on this relating creativity to the development of inferences:

> *And again, I think an inference almost has to have some creativity with that to infer what you think that evidence means and then you make an inference and then usually if you're going the next step, you take that inference and turn it into a hypothesis, what do you think?, and then you try to retest that. So I think just because you take data, if you don't infer what it means it doesn't do anything, it just sits there. If you infer what you think it means, and you test that further to see what you can get from that, then I think that's it, I think that's creativity again. I think inferences have to have some creative thinking to look at all the different possible ways that that data could tell you something.*

These statements were given the informed code [*Scientists create new knowledge*] which is consistent with the informed view used in this research. Hannah's pre-intervention conception of this tenet was classified as informed. No change was observed in her post-intervention data.

Hannah – Social and Cultural

Hannah also exhibited an informed view of the social and cultural nature of science both before and after the workshop. She described how social and cultural values can influence the direction of science in her interview as follows:

> *I would think things that are socially seen as problems or maybe like looking for a cure for AIDS. That is a social problem that the world is facing, so we're trying to throw resources behind it. I guess more what I'm thinking is where do we throw our resources behind? What do we study? What do we expand upon as science? Where do we pick to put our money? Because really money is a big part of where our research goes. So if you're looking at that or you're looking at things with the human genome problem. What can we do with genetic research? Well people are having problems. People are born with problems who are dying from diseases. We're looking for ways there because, again, we put value on human life, so maybe that gets more research than what planet is outside of our universe. There's funding for that, but I think we put our money where our heart is as a society, that's what I think.*

This description was given the informed code [*Social and cultural values direct science*] and is consistent with the informed view of the social and cultural nature of science being used in this research and Hannah's pre-intervention conception of this tenet was classified as informed. No change was observed in her post-intervention data.

Hannah – Observations and Inferences

Hannah began the workshop with a transitional/informed view of the role of observations and inferences in science. She could adequately describe how observations and inferences were used to make predictions in context of weather:

> *A good weather person gathers as much information as possible and compares it to weather patterns in the past to predict what will happen. Weather people "predict" the weather to the best of their knowledge with the data and resources available.*

She also describes how current data can be used to retrodict the physical appearance of dinosaurs:

> *I think they would think well an orange dinosaur would be eaten because he'd show up against the trees, so they're probably more camouflaged coloration. I really don't know. They would just look at things now-a-days to try to figure out what might have happened then. And that's a lot of what we do right now. If you look at…we look at things back then to try to predict that's why they still happen like they do now, but I guess that can go in reverse.*

Both of these descriptions show a sophisticated understanding of how inferences are made, but she lacks confidence in her answer when describing retrodictions. These statements were given the informed code [*Use of current knowledge and theory to make inferences*] and the transitional code [*Lacks confidence in inferences*]. She further demonstrated a less-than-sophisticated view of observations and inferences when she was discussing retrodiction:

> *Hannah – Did the first guy just throw his picture out there and everybody liked it. That I don't know. There's this new TV show on, I don't even remember the name of it, but they're showing all of these dinosaurs and how they're interacting and all that and they talk about it like it's happening like they have this evidence, this dinosaur got wounded by this one and fell down and was caught in this trap, how do they know that? Just 'cause you have a skeleton, you don't even know what the thing looked like necessarily. You don't know if it was fat on that skeleton or if it was very slender, how do you know? I really don't know how they predict all that.*
>
> *Mark – So what you wrote was "they understand the skeletal structures of the dinosaurs that have been found." And I guess that's…*
>
> *Hannah – That's about all I know. You can tell how tall it was, you can tell how long it was, you can tell what the feet looked like, but what the whole dinosaur looked like? If you see human skeletons, you're not gonna know if it was a beautiful woman or, you don't know. I don't know how they predict, but in their mind they know, they think.*

This interview segment shows a lack of confidence in inferences if no directly observable data is available. These statements were given the naïve code [*MUST have hard data or just speculating*]. Hannah's overall pre-intervention conception of observations and inferences was classified as transitional/informed. No change was observed in her post-intervention data.

Hannah – Theories and Laws

Hannah began the workshop with a naïve conception of theories and laws. She held two naïve conceptions of theories and laws which were revealed in her interview. She believed that theories were tentative while laws were fixed and permanent:

> *My understanding of a scientific law is just something that has been proven. A theory is something you've seen happen a couple of times, maybe many times, but not enough in enough varied situations to be considered a scientific law at this point.*

These statements both display a naïve conception of theories and laws [*Theory is tentative*, *Law is permanent*] but, furthermore, begin to expose her conception of a hierarchical relationship existing between them *[Hierarchical* View]. The conception that a hierarchical relationship existed between hypotheses, theories and laws was further indicated in another statement:

> *I think they are all just steps in the same process. I think you begin with a hypothesis, trying to find an answer to a question. You find that answer time and time again and in different varied situations then you can assume it's a theory and at that point. Then you continue testing it, trying to see if you have validity, and then if enough people can do that same thing and get the same results time and time again, then I think it can become a scientific law.*

After reviewing all statements regarding theories and laws, Hannah's pre-intervention conception of this tenet was classified as naïve.

At the conclusion of the workshop, Hannah's conception of theories and laws had improved. She indicated that she now understood her previous conception of theories and laws was incorrect and that a definite difference existed between them. She further attempted to explain theories and laws and met with some difficulty:

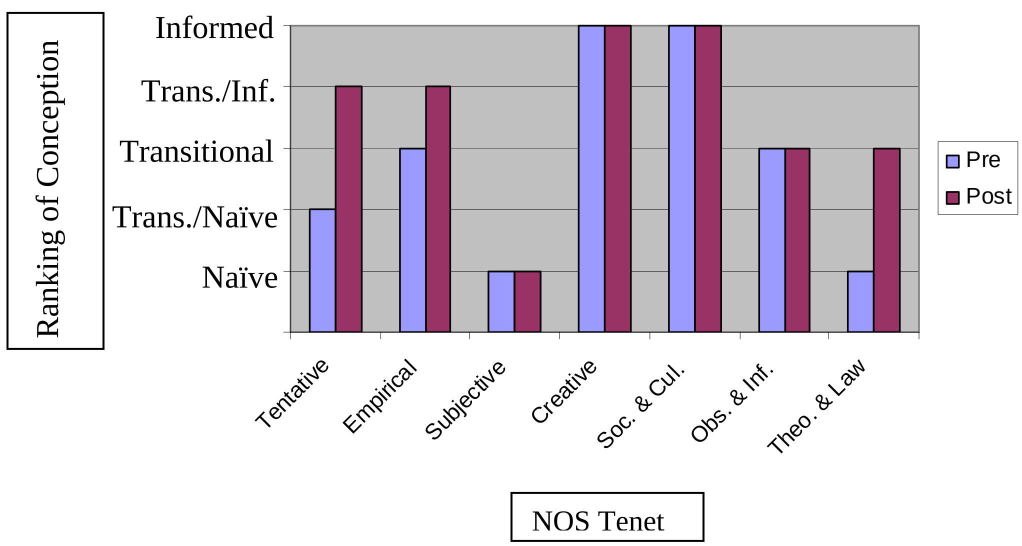
> *I think I had the standard science teaching that a theory is beyond a hypothesis, but not a law and a law is something that has been proven. Now we're saying that we never really prove anything, you just believe the knowledge at the time. The how and the why, that kind of…I'm still toying with that one. Which one is how, which one is why. I'm trying to get a better grasp of that but I do understand the concept that there's no such thing as a law being what I would have thought because you really don't prove anything. You just support that theory at the time… that idea at the time. Still toying with that one, but I do have a different feeling for it. I just don't have it all conceptualized in my head yet.*

Clearly, Hannah identified that her prior conception was incorrect and was working at developing a more informed understanding but had not quite reached that goal. These statements were coded [*Recognizes difference between theory and law*] and [*Lacks confidence in new understanding*] and her overall post-intervention conception of theories and laws was classified as transitional.

Case Study #9 – Irene

Irene is a ninth through twelfth grade teacher who has two years experience teaching science. Her educational background includes Bachelors degree in secondary education with an emphasis in life science. She is certified to teach through the TExES exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure IX. Examples of Irene's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure IX. Irene's Pre- and Post-Intervention Rankings



Irene – Tentative

Irene began the workshop with a transitional/naïve conception of the tentative nature of science. The most sophisticated statement she made about tentative was given the transitional code [*Knowledge will change with new technology, but no explanation of how*]:

> *…I know biology is always changing, especially with medical fields and the oceanography is really pushing forward right now. With all the global warming stuff, all that is coming into play, so I think people are really*

getting more into studying what's going on around them, as far as the affect that we are having.

Two naïve codes were identified in her data. When asked how scientific knowledge in textbooks would change in the future, she responded:

> *I think a lot of the ways that they change is how they're able to make it easier for people to understand it. …there's like a zoology book from the 50's and there's no pictures in it. It's just…read about zoology, which is fine. I'm interested in that, but now I just got the new 7th edition of Campbell's, the brand new one, and that is just so different than some of the older ones I've seen because the old Campbell books, there's a lot of words and not quite so many pictures. This one is all color pictures, diagrams, models. When you flip through it and I think adding that in helps as well.*

This indicated that, at the very least, the content changes that will occur were not at the forefront of her mind, but rather the appearance of the content in textbooks. This statement was given the naïve code [*Only change in science textbooks is in the presentation*]. When asked to further describe how science knowledge might change, she described the changing classification scheme for the kingdoms of life:

> *Mark – Is there anything in textbooks from 10 years ago that you would not find in textbooks today?*
>
> *Irene – The differences in the kingdoms…trying to think…maybe some of the way the information is presented rather than being…I don't know about 10 years ago, but I know originally kingdoms is a big one that always changes. I can't think of anything else right now. Maybe stuff with bacteria and everything, but I think that kingdoms is really the big one that's always back and forth.*

This statement further indicated that her conception of the tentative nature of science did not encompass correcting and revising incorrect scientific claims but rather just in the way current knowledge is presented or described. This statement was given the naïve code [*Classification and Terminology*]. After reviewing all statements regarding the tentative nature of science, Irene's pre-intervention conception of this tenet was classified as transitional/naïve.

At the conclusion of the workshop, her conception of tentative had improved. When describing how scientific knowledge may change in the future, she replied on the VNOS with the following statement:

> *Since once of the basic principles of the nature of science is the fact that there is tentativeness involved, yes I do feel that knowledge may change in the future. One example is based on the current accepted idea of how AIDS originated in humans (the cut hunter hypothesis). Yet there is another idea that is beginning to surface based on the polio vaccine given to millions in Africa and how this may be a better explanation for the origins of AIDS.*

This description of how currently-held theory may be discarded if new discoveries support an alternative theory was given the informed code [*New Knowledge grows AND is corrected*] and indicates that Irene had improved her conception of the tentative nature of science and her post-intervention conception more closely matched the informed view used in this study. Her overall post-intervention conception of tentative was classified as transitional/informed.

Irene – Empirical

Irene began the workshop with a transitional conception of the empirical nature of science. While she indicated that empirical evidence was needed in science which exemplifies an informed view [*MUST have a basis in empirical evidence*], her description also implied an over-importance placed on empirical evidence which indicated the naïve view that without direct, concrete, evidence, claims were not scientific and was also given the naïve code [*MUST have empirical (no inferences)*]:

> *You have to have something that's observable, you have to have something that is measurable just to have and experiment in the first place. If you*

> *don't have that, your hypothesis is not testable. So, I think you have to really have something concrete. There's always maybe with astronomy or something, since it's more abstract in what they're looking at to begin with. I don't know anything really about astronomy, but for all of the other subject areas I've dealt with, you have to have something to start off with that you can even ask a question about, observe something.*

With these statements being the only evidence of Irene's conception of the empirical nature of science, her conception was classified as transitional.

After the workshop, her conception showed some change. When asked if there could be science with no empirical evidence, she responded:

> *I think there is some way of looking at science without having any empirical evidence, but then again for me, I would put that on the less science spectrum. So things like astrology that obviously the empirical evidence is not there but some people consider it pseudo-science, some people are just "I believe that" and stuff. I think for me I still feel there has to be some empirical knowledge for me to accept that and I think it's important to have empirical knowledge. I've always taught my students that we have to have the qualitative and the quantitative to be able to formulate a well-rounded conclusion or analysis or evaluation of something that we have done. We can't just focus on one because you may not come up with the best conclusion that you could have if you had looked at both sides of the spectrum. So, I think there does have to be some empirical knowledge there. How much? It just depends, but I don't know that I would ever really accept something that was just based on something that wasn't empirical.*

This statement was given the informed code [*Must have a basis in empirical evidence*] and indicated that her stance on the need for empirical evidence had lessened to some degree, but that she still believed that a basis in empirical knowledge was necessary. After reviewing all of her statements related to the empirical nature of science, her post-intervention conception of this tenet was described as transitional/informed.

Irene – Subjective

Irene began and ended the workshop with a naïve conception of the subjective nature of science. She began by indicating that subjectivity in science was caused by personal backgrounds:

> *I think it's background…, I think it's your personal experiences, maybe your research… I think a lot of it has to do with where your background comes from and how you take that and apply it to what's being presented to you.*

She further described subjectivity as being just a human characteristic with no reference to its source:

> *Because as humans, we can take the same information and all interpret it differently.*

These statements were given the transitional code [*Different backgrounds cause subjectivity*] and the naïve code [*Subjectivity "just a human thing"*]. Neither of these statements connected subjectivity to theoretical lenses of the observer. Irene's overall conception of subjectivity was classified as naïve. No change was observed in the post-intervention data.

Irene – Creative

Irene demonstrated an informed conception of the creative nature of science both before and after the workshop. The following interview segment demonstrates her informed view well:

> *I think it takes a creative person to really step out of the box and figure out something new…a lot of the medical stuff that comes up, being able to figure out ways to cure diseases and things like that. That's not stuff that we already have readily available knowledge to do…basically, sometimes they have to come up with things out of thin air. There's no knowledge there to begin with and they really have to use the knowledge they have to step out there and do something new…You think about Darwin; people thought he was crazy. He couldn't have come up with that just with the*

background knowledge that was given to him. He had to go out there and look at all these things and say "Oh, wait, I think this way." People didn't understand Darwin's stuff until way after he was dead. That's really, I think, when the creativity comes in. Choosing to take a step further than what's given to you.

This interview segment demonstrates that Irene understood that scientists actually create new knowledge which is consistent with the informed view of creative nature of science being used in this study and was given the informed code [*Scientists create new knowledge*]. Irene's overall pre-intervention conception of this tenet was classified as informed. No change was detected in the post-intervention data.

Irene – Social and Cultural

Irene also demonstrated an informed view of the role that social and cultural values have in science. She described their influence in the following interview segment:

Irene – Big things will come out, like the big blockbuster movie "Day After Tomorrow" and when that was thrown out there and then with Al Gore's "An Inconvenient Truth," I think that throwing that stuff more into main stream culture has helped a lot. Because if that movie hadn't come about, if Al Gore hadn't decided to tour and do his big PowerPoint slide thing, whatever, I don't think as many people would be out there. Al Gore was a blip on the map a couple of years ago, and now you see him at the Oscars, all these international film festivals, and he's won an academy award, and he's…they did the Live Earth Concert, which he basically got going, all that stuff. A couple of years ago, you never heard about anything like that.

Mark – And that social change will impact science?

Irene – I think it will because the general public feeds a lot off of things that affect their personal lives. Whether it's their grandmother had cancer or their cousin has AIDS, or for younger people, the group that I teach, what is Cameron Diaz so excited about. What is Tom Cruise, whatever, celebrities, what are they getting into and celebrities are really getting into global warming. I had the opportunity to show "An Inconvenient Truth" to my classes this year. Now, they've seen probably the Live Earth and all these celebrities that are trading in their Hummers and getting a Prius, doing all that. That affects the younger crowd, which is really the crowd that's moving up to do the next round of research. So I really think what's socially acceptable, it's culturally acceptable, has a lot to do with

> *where the change in science comes and what gets focused on and things like that.*

This description clearly shows how social and cultural values and even the media (responding to social and cultural values) can influence the direction that science moves. This statement was given the informed code [*Social and cultural values direct science*]. Irene's overall pre-intervention conception of this tenet was classified as informed. No change was observed in the post-intervention data.

Irene – Observations and Inferences

Irene was able to describe how scientists use observations and inferences to determine the physical appearance of dinosaurs as seen in the following interview segment:

> *Well, if you look at bone structures of certain animals, they've taken and they've compared like the bones structure of like the leg of an alligator to bone structures that they found in fossils to see if the number of bones are the same. They may not be the same size, but the number are the same and they're placed in the same way to when you look at the bone structure, it's so similar that they're able to take that and connect as that's some type of relationship there. They've done that a lot I know with birds and like alligators and some of the older reptiles and stuff. They've taken and looked at bone structure of the animals and compare them to be able to see if there's any similarities there to how the bones are arranged.*

This statement was given the informed code [*Use of current knowledge and theory to make inferences*] and indicated that Irene understands how scientists are using extant animals to determine the general appearance of extinct dinosaurs. However, when asked how sure they were of superficial appearances such as skin color her confidence declined:

> *I think they've gotten more clear on some of the basic structure. I don't think as far as bone structure and how that shapes some of the outside characteristics, but things like color and maybe texture of skin and stuff, I think is harder to really get a good idea of that unless they maybe found something somewhere.*

Clearly, her confidence in the inferences made by scientists was dependant on physical data. This statement was given the transitional code [*Lacks confidence in inferences*]. She further demonstrated a lack of confidence in inferences when discussing them in context of weather predictions.

> *…I think on day-to-day weather, we're a clear example here in Ft. Worth. They'll tell us it's gonna rain, 80% chance, and we won't see rain. Then the next day it's 20% chance and it rains half the day. A lot of it you can't really know until probably half an hour, hour before because, especially with thunderstorms and things like that around here. There's so many components that have to go together, temperature, the right air masses have to meet at the right time, the humidity has to be there and all those things…I kind of feel sorry for the weather people, they get a bad rap because you can't predict that several days ahead. You can give percentages as you think it's going to rain, but if the right components don't come together, it's not going to happen.*

This passage from her interview conveys a general lack of confidence in inferences related to weather predictions. This statement was given the transitional code [*Less confident in context of weather*]. Irene's overall pre-intervention conception of observations and inferences was classified as transitional. No change was detected in her post-intervention data.

Irene – Theories and Laws

Irene's conception of theories and laws was naïve at the beginning of the workshop. She made one informed statement about laws which was coded [*Laws are descriptive*] which adequately described laws as being descriptive (formulaic) in nature:

> *Whereas a scientific law is usually more of a formula. You don't really see a lot of scientific laws in biology. You see them more in chemistry and physics because it usually has a formula…force equals mass times acceleration. That's one of Newton's Laws.*

However, this one informed statement was followed by several that indicated several naïve views. The following statement given the naïve code [*Theory is tentative, Law is permanent*] demonstrated the view that theories can change while laws are permanent;

> *Yeah, well a law really is accepted fact. 10 commandments put in stone, type of thing. Where a theory is always tentative.*

And this statement, given the naïve code [*"just a theory"*] demonstrates her lack of confidence and overly-tentative view of theories:

> *Well right now, the theory of evolution is still considered a theory. It's not accepted as fact. It's not accepted as this is the way it's gonna be forever in science. It's still considered a theory.*

After viewing all statements regarding theories and laws, Irene's pre-intervention conception of this tenet was classified as naïve.

At the conclusion of the workshop, her conception of theories and laws had improved. Irene was adequately able to describe theories as being explanatory in nature and laws being descriptive, statements which were coded [*Theories are explanatory*] and [*Laws are descriptive*]:

> *The law is the what and the theory is the how. I said that right, didn't I?*

She did, however, lack confidence in her answer so the statement was also given the transitional code [*Lacks confidence in new understanding*]. Irene also demonstrated again the notion that a theory is highly tentative in how she described her teaching evolution to her students:

> *I always tell them right off "This is a theory, this is what I'm telling you, ok. This is what many scientists think is true." But then I always say to them " Does that mean that you yourself have to believe that it's true?" And they say "Well, no," and I'm like "Good, then we're clear?"*

By describing 'theory' in this way, Irene demonstrates a persistent naïve view of theoretical knowledge in science. This statement was given the naïve code [*"just a* *theory"*]. The last statement relating to theories and laws in Irene's post-intervention data revealed that she was using her new knowledge of NOS in a way not intended by the workshop:

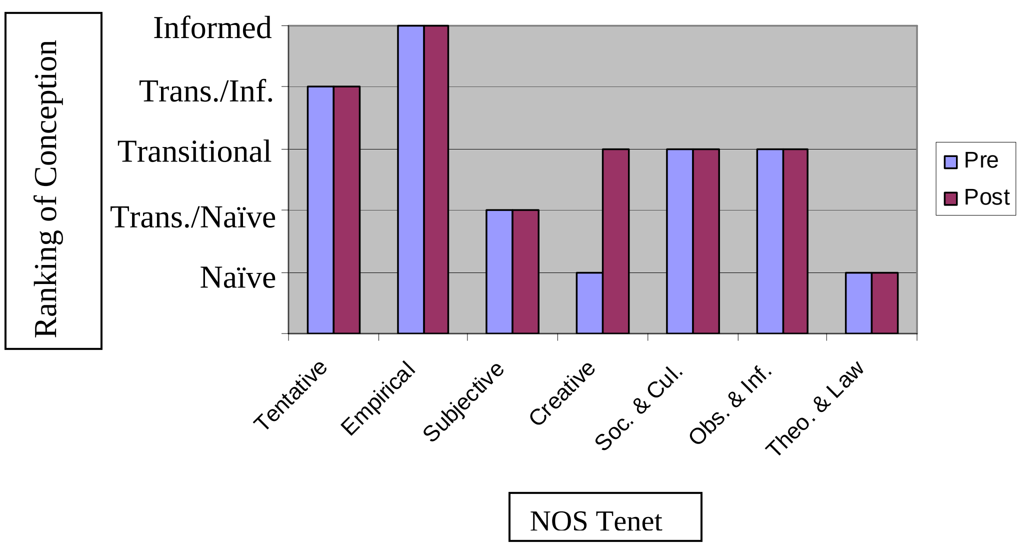
> *You don't want to offend anybody and of course you don't want to have parents coming up and yelling at you and things like that. But I think the nature of science just helps you present all the aspects of something and then still allow the students to make their own decision about the idea that's presented.*

This statement revealed that despite her improved view of theories and laws, she believed it was still up to her students to 'make their own decisions' about scientific theories; a naïve view at best. Irene's conception of theories and laws had definitely improved, but was not consistent with the informed view as defined in this research. After reviewing all of her statements regarding theories and laws, her post-intervention conception of this tenet was classified as transitional.

Case Study #10 – Jeri

Jeri is a ninth grade teacher who has two years experience teaching science. Her educational background includes Masters Degree which included 12 hours of college science. She is certified to teach through the ExCET exam. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure X. Examples of Jeri's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure X. Jeri's Pre- and Post-Intervention Rankings



Jeri – Tentative

Jeri began the workshop with a transitional/informed conception of the tentative nature of science. She was clearly willing to admit that scientific claims might need to be adjusted or be judged incorrect with new discoveries:

> *…we talked about making adjustments, maybe something changes, we have to add it, say it's something different, or just say "oh what we thought before was just completely wrong because now we just discovered something else."*

This statement was given the informed code [*New knowledge grows AND is corrected*] and was consistent with the informed view used in this research. However, she also demonstrated some naïve views as well. She repeatedly, in her interview, used the word proof in describing scientific advances which indicated a naïve view that science advances by proving statements true. These statements were given the naïve code [*Proof unclarified*]. After reviewing all statements made in the pre-intervention data, however, Jeri's overall pre-intervention conception of the tentative nature of science was classified as transitional/informed. No change was observed in her post-intervention data.

Jeri – Empirical

Jeri began and ended the workshop with an informed conception of the empirical nature of science. In the pre-intervention interview, Jeri adequately described the basis in empirical evidence which is characteristic of scientific knowledge:

> *I don't know. I might say, I'm not thinking of all the different examples, but I might say that no, because then how do you know something exists scientifically, let me preface that scientifically, how do you know something exists if you don't have any evidence of it. So then how can you study it, if you're talking about in a science world? I don't know…Even with let's say about in astronomy, even though you cannot see it, you see the evidence of it because it skews when they're reading scientific stuff. The numbers change. Something happens and they go "we can't see it but we know it some kind of gravitational pull or something that makes our statistics do something." So again, even though you cannot see it, it's affecting something.*

Jeri's unwillingness to allow for science in the complete absence of empirical data, yet her willingness to realize that not all scientific claims have directly observable evidence demonstrates the sophisticated view consistent with that proposed for this research. These statements were coded [*Must have a basis in empirical evidence*] and her overall pre-intervention conception of this tenet was classified as informed. No change was detected in her post-intervention data.

Jeri – Subjective

Jeri did not begin the workshop with as sophisticated a conception of the subjective nature of science. Jeri seemed to conflate subjectivity with tentativeness:

> *As new discoveries are made, it is more subjective and as the more you can replicate that, then you can hone in on the part that is more objective, not subjective. That kind of part, I would think, kind of falls away. You go, "ok, sometimes that part changes, but here's the real part that remains the same." So probably on a gradual thing. New knowledge probably more subjective, but then as people keep experimenting with it, it gets less subjective.*

This statement was given the naïve code [*Does not understand "subjective"*]. She did make reference to how scientists must incorporate new knowledge into prior knowledge in response to the VNOS question of how scientists can disagree on the cause of the dinosaur extinction; a statement which hints at the theory-laden nature of science, but she fails to identify if as such:

> *It might be how that information is applied, interpreted, and integrated into the known body of knowledge.*

This statement was given the transitional code [*Incorporates new knowledge into prior knowledge*]. Jeri's overall pre-intervention conception of the subjective nature of science was classified as transitional/naïve. No change was detected in her post-intervention data.

Jeri – Creative

Jeri began the workshop with a naïve conception of the creative nature of science. She demonstrated this in her VNOS response to the question of what role creativity played in science:

> *Thinking of a new way to do something is creativity. It takes imagination to do so. Planning-designing. Experimenting-changing variables.*

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*]. No other evidence of her conception of the creative nature of science was found in her data and her pre-intervention conception of this tenet was classified as naïve.

In her post-intervention interview, Jeri described creativity in science in a different way:

> *I had said creativity in like design, but you use creativity about what new information do we get from different studies we might do or different experiments, so I hadn't looked at it that way.*

This statement implied that creativity was useful in determining what to conclude from the experiments results, not just in designing the experiments. This statement was given the transitional code [*Creative in finding solutions*]. Jeri's post-intervention conception of creativity was classified as transitional.

Jeri – Social and Cultural

Jeri started and finished the workshop with a transitional conception of the social and cultural nature of science. She related her views of the influence of society and culture on science in the following interview segment:

> *Mark – to what degree do you believe that social and cultural values influence the advancements of science and/or the processes of science.*
>
> *Jeri – Maybe 8, or like 80%. [Pause] You're waiting for me to explain why, I don't know. Let's go with India, because of their culture and religious beliefs, they're not going to be doing experiments on cows. So that's going to affect different scientific studies they do.*

Jeri obviously was not confident in her answer, but she was able to identify a way in which social and cultural values could limit the progress of science. This statement was given the transitional code [*Social and cultural values can limit science*] and her overall pre-intervention conception of this tenet was classified as transitional. No change was observed in her post-intervention data.

Jeri – Observations and Inferences

Jeri's conception of observations and inferences was transitional both before and after the workshop. She was able to describe how scientists use past observations to make inferences about weather patterns:

> *I think weather persons can only be certain to the degree that the previous data collected, and predicted outcomes, then actual weather patterns occurred have been reliable then studied then applied to make those next predictions. A caveat is usually given, if these conditions continue...because weather patterns are subject to change.*

But when asked to describe how scientists could retrodict the physical appearance of dinosaurs, her confidence decreased:

> *Bones and teeth can give a framework of the shape and size of dinosaurs. I believe the drawings of the exterior of the dinosaurs are at the artists'/scientists' discretion and imagination.*

And in her interview:

> *I don't know. If they could figure out texture of skin and how thick it is, but they thought they knew what the weather was, or something like that. I think they're relying on what they called the descendants of those animals is probably where they get some of their color from, but I don't know. I don't know how they determine that.*

These statements were given the informed code [*Use of current knowledge and theory to make inferences*] and [*Confidence in inferences increases with more dat*a] in relation to weather predictions and [*Does not know how inferences are made*] in relation to dinosaur retrodictions. Jeri's overall pre-intervention conception of observations and inferences was classified as transitional. No change was observed in her post-intervention data.

Jeri – Theories and Laws

At the beginning of the workshop, Jeri demonstrated a naïve view of theories and laws. She held the common naïve view that theories were tentative and laws were certain. She made the following statements which were coded [*Theory is tentative, Law is permanent*]. She described a theory as:

> *…what you think and either it has not been proved or you're unable to prove it. For example, here's a hot button, the Theory, I emphasize the Theory of Evolution because we cannot put into experimental form something that the evolutionists say happened over hundreds, thousand, millions of years. How can you replicate that? So it's a theory that they used based on data that they collected and inferred that this is what happened, so it's a theory.*

And she described a law as:

> *I consider a scientific law something that can be proven and replicated and it always is, unless there's some other variable, like gravity.*

She also demonstrated that she held the naïve view that a hierarchical relationship existed between hypotheses, theories, and laws. She describes this relationship in her interview as:

> *…it starts with a hypothesis and I would say while you're still in the proving stage, that's a theory. But then after you've done all the experiments that you can and the scientific world of that field have given their input, they've judged it, they've evaluated, they said "ok, that's true, but what about this?" and then we start it all over again. And then once you've meshed all that and get to the law, so it's kind of like a continuum.*

This statement was given the naïve code [*Hierarchical view*] and Jeri's overall pre-intervention conception of theories and laws was classified as naïve.

After the workshop, Jeri's conception of this tenet had changed slightly. In her interview, she tried to describe her new understanding of theories and laws as:

> *I changed on that because I always thought it was hypothesis, theory, and laws. But then we talked about how you can make a hypothesis, you can*

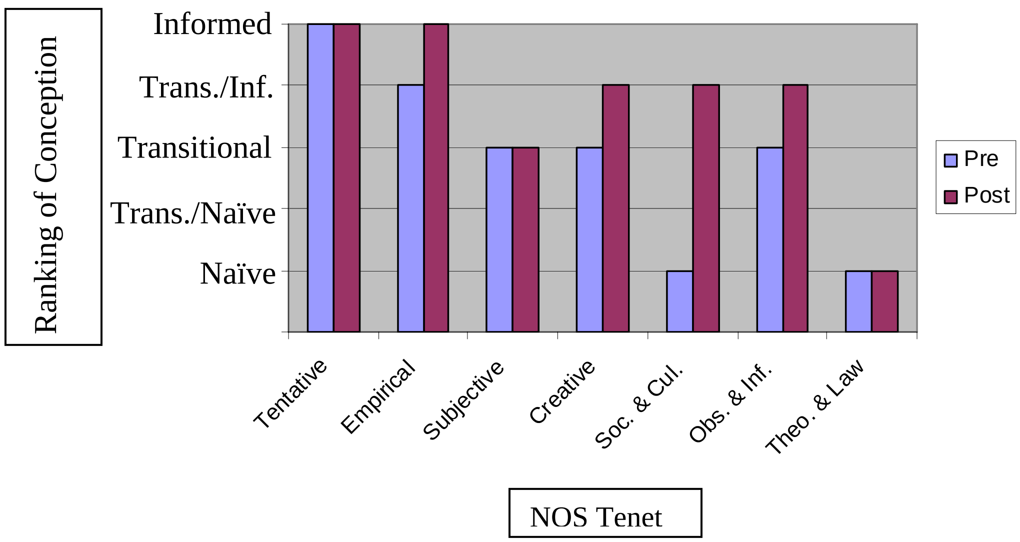
> *go to theories, or you can go to laws, or it can go to a theory to a law. It doesn't always have to be a linear process. I hadn't thought about that before.*

Jeri was clearly still uncertain about theories and laws, but had realized that they were not related to each other in the hierarchical way she once believed. This statement was given the naïve code [*Unsure of theories and laws*]. As this was the only change observed in her post-intervention data, Jeri's conception of this tenet remained classified as naïve.

Case Study #11 – Keren

Keren is an 8th grade teacher who has eleven years experience teaching science. Her educational background includes a Bachelor's Degree in interdisciplinary studies and she is alternatively certified. Her pre- and post-intervention conceptions of the seven tenets of NOS are shown in Figure XI. Examples of Keren's statements which earned her the rankings awarded to her are given below for each tenet of NOS.

Figure XI. Keren's Pre- and Post-Intervention Rankings



Keren – Tentative

Keren started the workshop with an informed view of the tentative nature of science. In her description of how certain scientists are of how dinosaurs looked, she replied:

> *We can study similar animals that live today. This however does not mean we do not make mistakes sometimes. In the beginning of finding the dinosaurs some of the bones were assembled wrong. As we grow in knowledge and technology, we are able to better predict outcomes.*

This statement clearly showed that Keren was comfortable with the idea that scientists sometimes come to incorrect conclusions. She further explains how she can be comfortable with this tentativeness by stating that the corrections in scientific knowledge result from better technology and an improved knowledge base. Her answer was given the informed codes [*New knowledge grows AND is corrected*] and [*Scientific knowledge isn't 100% sure, but it is still reliable*]. This conception clearly matches the informed view used in this study and her pre-intervention conception of tentative was classified as informed. No change was detected in her post-intervention data.

Keren – Empirical

Keren began the workshop with a transitional/informed view of the empirical nature of science. In response to the interview question "can there be science without any empirical evidence?" she replied:

> *That's a good question. I haven't thought about. All the shows that I've watched have talked about, tied it into observable things. For long time there was a question on were dinosaurs warm blooded or were they cold blooded? And as they've gotten more and more evidence, I think the majority of them have gone to that they were warm blooded because they've been able to see how the heart pumps and how the blood flow went and it's very similar to the warm blooded as opposed to the cold blooded type things. I don't know. That would be a good question.*

This answer indicates that although she seems to feel that empirical evidence is important, she lacks confidence in her opinion. This statement was given the transitional code [*Leans toward needing empirical evidence, but lacks confidence*]. She later conveyed further insight into her ideas of the empirical nature of science when she referenced the lack of direct, observable evidence to support theories:

> *Theories are not necessarily all based on empirical things. I think you can observe something and then make an intuitive leap and then that's where you would start testing to see if it actually goes that direction.*

Although she states that theories "…are not necessarily all based on empirical things.", she then references the use of empirical evidence to make intuitive leaps. She does not realize that she is describing how theories *are based* on empirical evidence, but lack direct observable support for the explanations they provide. Despite her lack of sophisticated language, her conception was very close to the informed understanding used in this research. This statement was, therefore, given the informed code [*Some scientific knowledge lacks "hard data" but is based on empirical evidence*]. Her overall pre-intervention conception of the empirical nature of science was classified as transitional/informed.

In the post-intervention interview, Keren demonstrated an informed view of the empirical nature of science in response to the question of how important empirical evidence was to science:

> *Mark – With empirical, remember in the first interview, I said 'is there any science that exists without empirical evidence?' What we presented [in the workshop] was that empirical was an important aspect there…*
>
> *Keren – Well it is, but not in all science. The String theory, where's our empirical evidence for the String theory? This is something that people have taken information from and put together and now they're trying to find it, but they didn't start out with the evidence first. They started out with their inferences and their observations and they put it together. So, I don't think we always have empirical evidence, no.*

This statement was given the informed code [*Must have a basis in empirical evidence*] and [*Some scientific knowledge lacks "hard data" but is based on empirical evidence*]. These statements indicated that Keren's conception of the empirical nature of science had improved. Her post-intervention conception of this tenet was classified as informed.

Keren – Subjective

Keren began the workshop with a transitional conception of the subjective nature of science. She recognized subjectivity in science as being derived from a person's personal background, but alludes to educational background:

Keren – Part of it [subjectivity] comes from their training, what college, things that they have, their professor's things. Part of it comes from their background, such as, I grew up being outside a lot, so a lot of the things that I see, I see through that thing. How can I do this outside for the kids? Get them involved that way.

Mark – Whereas if someone had not grown up in the outdoors…

Keren – No, they'd probably want to stay inside all the time. They might be more of a book person instead as opposed to let's get out and do type thing. It might also go with if…there are some of the Paleontologists who just stay in Montana or just stay in Wyoming and there are just certain animals that are there. So maybe that would influence them as opposed to ones that go over to China and see different kinds or go down to Antartica and see different kinds, who have a bigger picture of what was going on.

While she references prior training and college learning, she never clearly indicates that theories held by scientists influence their interpretation and more-directly attributes the subjectivity to personal past experiences. This statement was given the transitional code [*Different backgrounds cause subjectivity*]. She, again, alluded to preconceived ideas as influencing interpretation of data but still did not clearly articulate the theory-laden nature of science:

It involves prior knowledge skills, but also a disconnect from your opinions. A person must be able to observe and analyze--put the pieces of the puzzle together without being directed by personal opinion.

Here she, again, indicates the influence that 'prior knowledge' can have, but goes on to express that scientists must be objective and 'disconnect' from their 'opinions' indicating that subjectivity has a negative influence on science. This statement was given the transitional code [*Incorporates new knowledge into prior knowledge*] as well as the naïve code [*Subjectivity is bad for science*]. After reviewing all of her statements related to subjectivity her overall, pre-intervention conception of this tenet was classified as transitional. No change was detected in her post-intervention data.

Keren – Creative

Karen's pre-intervention conception of the creative nature of science was classified as transitional. She expressed the naïve view that creativity was only useful in setting up experiments. When asked (in the VNOS) if creativity played a role in science, she responded:

> *Yes and no. A scientist must stay detached from the outcome of an investigation, but sometimes creativity and imagination help in designing how to accurately investigate something. Part of planning maybe--but a scientist must remain detached from the results in order to fully understand the item being investigated.*

This statement was given the naïve code [*Creativity in setting up experiments or developing questions*]. Later, however she made statements that seemed to contradict her idea that creativity should be relegated to the planning phase of scientific research. In the following passage from her interview, Keren describes how scientists need to be open to new ideas and allow themselves to use their creativity to discover new knowledge and come up with new solutions to problems:

> *I think of Albert Einstein and his wife. I think they had to be terribly creative people because if they weren't, he would've not been open enough to see the things that he's seen. And when you talk about string theory, you have to be really open too…and that's what I think creativity is. You're very open to lots of information and things that come in and how they come together. So yeah…there's a lot of room for creativity in scientific things and research. Think of cancer researchers. They have to be really creativity and, what was the thing they were talking about last night, they've discovered that the hormones… Is it the hormones in cancer? It's a new level on understanding what cancer is and it has to do with, I want to say, some kind of switch that they've discovered. And if they can find what the thing is that turns the switch to reproduce the cells so crazily then they'll know how to turn it off.*

Although she seems to be attributing creativity to the way scientists create solutions and develop new theories, she does not clearly identify this process as *creating* new knowledge. Instead, she describes it as 'being open' to new information that is waiting to be discovered. These statements were given the transitional codes [*Creativity means open to new ideas*] and [*Creative in finding solutions*]. Keren's overall pre-intervention conception of the creative nature of science was classified as transitional.

After the two-week workshop, Keren's view of creativity in science had improved. In response to the VNOS question regarding the role of creativity in science, she still responded with the naïve view that creativity only plays a role in planning experiments [*Creativity in setting up experiments or developing questions*]:

> *Planning is where the creativity usually comes in. A scientist has to figure out how to measure what they are investigating.*

But then, in her post-intervention interview, she compared creativity in science to the development of new technology that would have been considered fantasy or science fiction until very recently:

> *… and then you read science fiction and fantasy and now some of that stuff is coming true. Years ago, back in the 60's, they talked about building a little submarine with people in it and injecting it into a person's blood and sending it on its way to do the surgery or whatever. And now we can put in little targets for cancer, piggy-back on viruses and we can target it. How much different is that?*

In this statement she reveals the idea that scientists create new knowledge that previously did not exist which is consistent with the informed view put forth in this research. This statement was given the informed code [*Scientists create new knowledge*] and her overall post-intervention conception of this tenet was classified as transitional/informed.

Keren – Social and Cultural

When asked about the influence of social and cultural values on science, Keren was unable to describe how they could direct or impede scientific research. Her only answer to this question was to reference how in the American culture scientific knowledge 'flows freely' and contrasted that with other cultures where knowledge is suppressed. She in no way indicated how the values held by a culture or society could influence the questions asked by science. Her pre-intervention conception of this tenet was classified as naïve.

At the conclusion of the workshop, however, her conception of the social and cultural nature of science had improved. In the following passage, Keren discusses how social and cultural values could have an effect on how scientists conduct experiments which jeopardize the health of those involved:

> *…and some of the tests that they did during WWI I on the blacks in the south, what was it, they injected them with syphilis? …and then during WWII they exposed people in the Army to radiation. …So I think science sometimes has to work with stuff like that. I think this is hard because a lot of this is so subtle we don't even think about this.*

This statement, although only referencing negative aspects of society's influence on science, does indicate that Keren understands that the value (or lack thereof) that society placed on 'illegals' and WWII African Americans allowed them to be objectified by the scientific community. This statement was given the informed code [*Social and cultural values direct science*]. Later in her interview she described science as serving to counterbalance the controlling forces of religious culture:

> *…if you look at the way history developed with religion, at least in the western world, religion taking over what people, controlling what people believed and how their lives were. Science to me developed as a counter-point to making sure people learn to think for themselves and in a way being responsible for themselves instead of somebody telling them everything.*

This statement was given the transitional code [*Social and cultural values can limit science*]. Keren's overall, post-intervention conception of the social and cultural nature of science was classified as transitional/informed.

Keren – Observations and Inferences

Keren started the workshop with a transitional conception of observations and inferences. When asked to describe the roles of observations and inferences she could not clearly articulate their meaning or how they are used in science:

> *We have to observe to see what we think is gonna go on is gonna go on. And the inference is, I guess, is it gonna go to this next step, or is it gonna go off in another direction? I think inferences you have to be careful and again, maybe it's semantics, because if you infer something you really have to have your evidence to back up that's what is gonna happen. You can think "well I think we're gonna go from B to C," but then you have to make sure that you show, did it really go to C or did it jump off to D?*

This passage was given the naïve code [*Poor description of observations and inferences*]. Despite her poor description of observations and inferences, she was able to describe how they were used by scientists to retrodict the physical appearance of dinosaurs:

> *So they now they know with the computers they can see the jaw strength and the structure and stuff. Computers are really good for doing that kind of stuff. But we look at the modern animals and we look at how they move and like the dinosaurs stood with their feet underneath them, whereas lizards and stuff stood with their feet like that. So we've learned different structural things just by watching the animals of today.*

In this statement, Keren indicates that scientists use current knowledge of extant animals (observations) along with the phylogenetic relationship between them and dinosaurs (theory) to retrodict what the dinosaurs most likely looked like (inference). This statement was given the informed code [*Use of current knowledge and theory to make inferences*]. Keren was less able to describe the role of observations and inferences in weather forecasting and lacked confidence in the ability of weatherpersons to do so. When asked how confident weatherpersons were in their predictions, she replied:

> *Not completely--Mother Nature has a way of staying independent. The computer only takes the information it is given and shows possible trends. Weather can change its trend (energy flow) suddenly.*

This statement was given the transitional code [*Less confident in context of weather*]. After reviewing all statements regarding observations and inferences, Keren's pre-intervention conception of this tenet was described as transitional.

After the workshop, Keren's conception of this tenet had improved. She reiterated how scientists make inferences about dinosaurs appearances and but was still unable to express the same confidence in weather predictions. She did indicate that with more experience, weatherpersons become better able to make predictions:

> *With more experience in weather prediction and more experience in a certain area (such as Fort Worth), weather people become more proficient in knowing which computer model is more likely to happen. This does not mean that they will be right every time--weather patterns can change very quickly and not always as predicted.*

This statement was given the informed code [*Confidence in inferences increases with more data*]. Keren's overall, post-intervention conception of observations and inferences was classified as transitional/informed.

Keren – Theories and Laws

Keren's conception of theories and laws was classified as naïve at the beginning of the workshop. She expressed the naïve view that theories were tentative while laws were not. She described theories as:

> *A theory means that we've got all these pieces of the puzzle here and this is the way we think they go together, but we're not locked into that because tomorrow we may get another piece and then we'll have to start all over again to fit it again. If we stay open to the fact that this is what we know today, but tomorrow may be different.*

And she described a law as:

> *I would say that [a law is] one that we are very sure that, through observation and trial, that it's going to happen this way all the time.*

These statements were given the naïve code [*Theory is tentative, Law is permanent*]. She also conveyed that she held the naïve view that a hierarchical relationship existed between hypotheses, theories, and laws:

> *I think they go into an order. You talk about your hypothesis, what you think is gonna happen. Then you take all those pieces that you've discovered and you put them into a theory and if they hold true for a while, then you say that that's a law.*

This statement was given the naïve code [*Hierarchical View*]. Keren's overall, pre-intervention conception of theories and laws was classified as naïve. No improvement was detected in her post-intervention data.

CHAPTER 5

RESULTS BY TENET

Overview of Pre- and Post-Intervention Profiles

The primary goal of the study was to determine in what ways inservice science teachers' conceptions of nature of science change by engaging in an explicit, professional development. Following the methodology described in chapter 3, each participant's VNOS questionnaire responses and interview transcriptions were unitized based upon the tenets that were addressed and the data units were classified as informed, transitional or naïve based upon their agreement with or deviation from the working description of each tenet put forth in this research. Each participant's data units for each tenet of concern were compiled into seven groups (one per tenet) to create participant profiles. Once the participant profiles were created, all data units related to each tenet were evaluated and the participants' overall conceptions of each tenet was ranked as informed, transitional/informed, transitional, transitional/naïve, or naïve. Pre-intervention profile results for the 11 participants are found in Table III.

Table III

Pre-Intervention Profile Results for Each Tenet

	Tentative	Empirical	Subjective	Creative	Social/ Cultural	Observations/ Inferences	Theories/ Laws
Informed	2 (18%)	1 (9%)	2 (18%)	2 (18%)	2 (18%)		
Transitional/informed	6 (55%)	1 (9%)			1 (9%)	6 (55%)	
Transitional	1 (9%)	5 (45%)	2 (18%)	1 (9%)	4 (36%)	4 (36%)	
Transitional/Naïve	1 (9%)	1 (9%)	4 (36%)	4 (36%)	1 (9%)	1 (9%)	1 (9%)
Naïve	1 (9%)	3 (27%)	3 (27%)	4 (36%)	3 (27%)		10 (91%)

Five of the participants began the workshop with no informed views of any of the seven tenets of NOS being studied in this research. Six participants began the workshop with informed views related to at least one of the tenets; tentative (two participants), empirical (one participant), subjective (two participants), creative (two participants) and social and cultural (two participants). Four of the participants who demonstrated informed views, only did so in relation to one tenet. Angela and Keren conveyed an informed understanding of the tentative nature of science, but not for any other tenet being studied. Jeri's conception of the empirical nature of science was classified as informed as was Brenda's conception of subjectivity. Irene conveyed informed views of both the creative and the socially and culturally embedded natures of science. Hannah demonstrated three informed views; namely the subjective, creative, and the socially and culturally embedded natures of science.

In contrast to the informed views detected in the pre-intervention data, numerous naïve views were identified. Ten of the participants began the workshop with naïve conceptions of some of the tenets of NOS. Brenda and Elise only demonstrated one naïve view; namely, theories and laws. Five participants began with two naïve views. They held naïve views of theories and laws and one other tenet; empirical (Hannah), subjective (Irene), creative (Angela and Jeri), and socially/culturally embedded (Keren). Flora conveyed naïve views of three tenets; tentative, creative, and theories and laws. Gina began with naïve views of four tenets; empirical, subjective, social and cultural, and theories and laws. Christina began with conceptions of five tenets of NOS that were classified as naïve; empirical, subjective, creative, social and cultural, and theories and laws.

The same methodology was used to create post-intervention profiles based on the participants' post-VNOS and post-interview. A visual representation of the post-intervention data analysis is found in Table IV.

Table IV

Post-Intervention Profile Results for Each Tenet

	Tentative	Empirical	Subjective	Creative	Social & Cultural	Observations & Inferences	Theories & Laws
Informed	5 (45%)	5 (45%)	1 (9%)	3 (27%)	2 (18%)		
Transitional/informed	5 (45%)	2 (18%)	2 (18%)	1 (9%)	2 (18%)	7 (64%)	1 (9%)
Transitional	1 (9%)	2 (18%)	1 (9%)	6 (55%)	4 (36%)	4 (36%)	4 (36%)
Transitional/Naïve			5 (45%)	1 (9%)	1 (9%)		3 (27%)
Naïve		2 (18%)	2 (18%)		2 (18%)		3 (27%)

Improvement was detected in the post-intervention data for all tenets of NOS being studied and among all participants in varying degrees. At the conclusion of the workshop, eight participants conveyed informed views of one or more of the seven tenets. Some of these informed views were repeated demonstration of informed views already possessed at the outset of the study, while others were newly detected informed views which suggests that the workshop interventions could have affected positive change. Newly detected informed views were identified in five participants. Christina began the workshop with no informed conceptions of any of the seven tenets but conveyed in her post-intervention data a sophisticated understanding of the tentative nature of science. Keren began and ended the workshop with an informed view of tentative but also conveyed a post-intervention conception of the empirical nature of science that was consistent with an informed view. Two participants began the workshop with no informed views of any of the seven tenets, but ended the workshop with a sophisticated understanding of two of them; Flora conveyed informed views of tentative and empirical and Dana conveyed informed views of empirical and creative. Hannah's post-intervention data revealed informed views not detected in the pre-intervention data. She began with informed views of three tenets (subjective, creative, and social and cultural) which persisted through the study but also revealed, in her post-intervention data, informed views of two more (tentative and empirical).

Definite improvement was also seen among all ten participants who began the workshop with naïve views. Christina began with naïve conceptions of five of the tenets (empirical, subjective, creative, social and cultural, and theories and laws) but her post-intervention data revealed improvement in her understanding of the creative and subjective natures of science. No change was detected, however in her understanding of empirical, social and cultural, or theories and laws. Three participants began with naïve conceptions of two tenets and ended with only one. All three began the workshop with naïve views of theories and laws and all three also had naïve views of one other tenet. Two participants' naïve view of theories and laws persisted throughout the workshop, but their naïve conception of another tenet appeared to have improved. Keren improved her understanding of the socially and culturally embedded nature of science and Jeri improved her understanding of the creative nature of science. Irene improved her understanding of theories and laws, but maintained her naïve conception of the subjective nature of science. Brenda and Elise both began with a naïve conception of theories and laws and both ended the workshop with improved understandings of this tenet. Gina also improved her understanding of theories and laws, but her naïve conceptions of the empirical, subjective, and socially and culturally embedded natures of science persisted.

Results by Tenet

In the following sections, I first give the definition used by Lederman (2006) and then describe the working description of each tenet put forth for this study. These working descriptions are based upon Lederman's, but may be somewhat modified. The modifications to Lederman's descriptions were made to accommodate limitations in their ability to account for the many informed, transitional, and naïve conceptions found in my prior research (Bloom & Weinburgh, 2007; Bloom, Sawey, Holden & Weinburgh, 2007). These descriptions will articulate what is considered to be an informed view of each tenet of NOS and all participants' conceptions will be evaluated against them. After describing the informed view of each tenet put forth by this research, I then identify the informed, transitional, and naïve codes that emerged for each of the seven tenets of NOS both before and after the two-week intervention. This more clearly demonstrate how I assigned the various scores for the participants' conceptions of each tenet. After describing the major codes that were identified within this set of data for each tenet, I then show the overall pre and post-intervention rankings of all participants for that tenet. After all tenets have been described, I then present each participant's conception of each tenet in a short case study. This allows me to describe how each person's conceptions of each tenet changed over the course of the two-week intervention.

Tentative

When describing the tentative nature of science, it is important to clearly articulate several major aspects in order to represent an informed view. Lederman (2006b) describes this tenet as follows:

> Scientific knowledge is never absolute or certain. This knowledge, including “facts,” theories, and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs.

After preliminary analysis of this set of data, I felt it important to modify this description so that it more explicitly addresses some subtle aspects to this tenet which were observed during this study. The revised description of the tentative NOS is;

> The body of scientific knowledge, including “facts,” theories, and laws, changes in two ways; it grows as new knowledge is discovered and it improves as old knowledge is revised and corrected. While scientific knowledge is tentative, there is also much reliability in scientific knowledge because it is based on empirical evidence.

This modification of the definition ensures that in order to get an informed score, the participant must recognize both the growing nature of scientific knowledge as well as the way scientific knowledge improves and corrects as old knowledge is deemed insufficient or incorrect. It also ensures that respondents do not hold a simplistic, overly tentative view of science as it emphasizes the reliability of scientific knowledge along with its tentativeness.

The participants were given opportunities to address the tentative nature of science in both the VNOS as well as in the interview. While some VNOS questions generally give the participant an opportunity to address tentativeness, others very overtly guide the participant to address it. Questions which directly address tentativeness include (question numbers are from VNOS-D):

3. Scientists produce scientific knowledge. Some of this knowledge is found in science books. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. b. How certain are scientists about the way dinosaurs looked?

5. a. Do you think weather persons are certain (sure) about these weather patterns?

The participants were also directly asked to offer their opinion about the tentative nature of science during their interviews when they were asked to rank on a scale of 1-10 how much they believed scientific knowledge to be tentative and were then asked to explain their answer. Also during the interview, all VNOS responses were reviewed and discussed which many times offered further opportunities for the participant to reveal their conceptions of this tenet.

Pre-Intervention Codes Identified for Tentative

Ten codes were identified in the pre-intervention data that related to the tentative nature of science. Later, two codes were classified as informed, two were classified as transitional, and six were classified as naïve.

Tentative – informed.

The more common informed code found in the data was [*Scientific knowledge grows AND is corrected*]. This code was given to statements that clearly demonstrated the two distinct ways in which scientific knowledge can change and most closely matched the definition of tentative being used in this research. Eight of the 11 participants conveyed this idea in either their VNOS responses or in their interview. Although this indicated informed views of tentative in these eight participants, only two of them were given an overall score of informed for this tenet. This is due to conflicting naïve statements found elsewhere in their dataset which lowered their scores. Three participants made informed statements which were coded [*Scientific knowledge is not 100% sure, but it is still reliable*]. This code indicated that the participants' statements addressed that scientific knowledge is subject to change, but that the knowledge was reliable due to the methodologies that generated it and its basis in empirical data.

Tentative – transitional.

One participant conveyed a conception which was classified as transitional and was coded [*Scientific knowledge will change with new technology, but no explanation of how or why*]. This statement demonstrated an understanding that new technology and discoveries would alter the body of knowledge, but did not reference that some claims could be disproved and corrected due to the new discoveries. Two of the participants made statements which indicated that they realized that scientific knowledge would change but they were cautious and uncertain in stating that knowledge would be corrected stating, instead, that it "may" or "might" change. These statements were coded with a transitional [*Scientific knowledge "may" be corrected*]. These statements indicate a willingness to recognize some change may occur, but also demonstrate the participants may believe that scientific knowledge is relatively permanent.

Tentative – naïve.

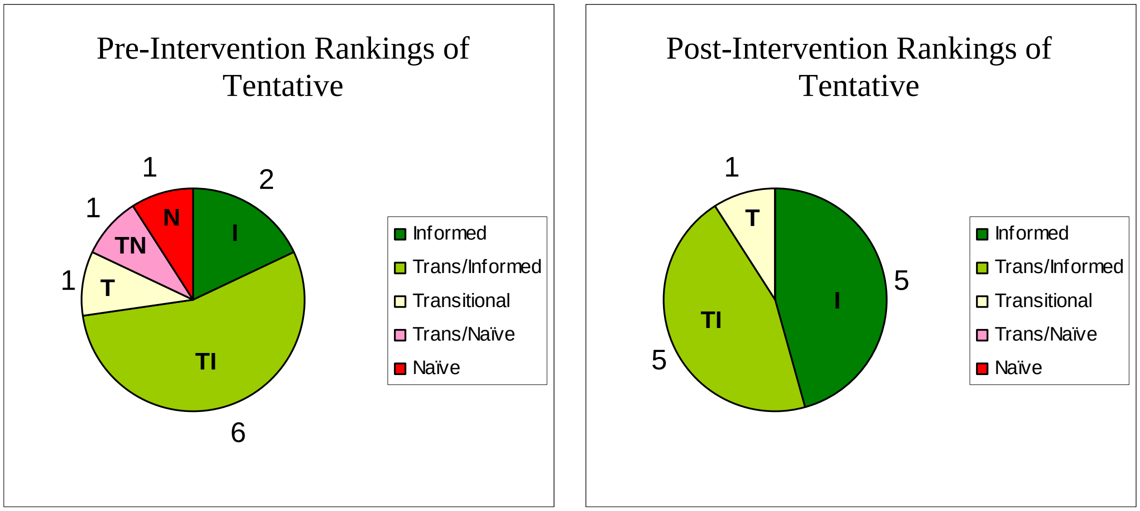
Four of the 11 participants made statements which included the words “proof”, “proven”, or “proved” in reference to scientific findings with no indication elsewhere in their data that they were using the word in its colloquial sense. These statements were coded [*Proof unclarified*] indicating a potential conception that science categorically proves statements with incontrovertible evidence; a conception diametrically opposed to the informed view of the tentative nature of science. Numerous naïve references were made regarding how scientific knowledge could be different in the future. Five participants made statements indicating that the body of scientific knowledge would grow which were coded [*New scientific knowledge will be added*]. Four participants referenced the changing classification systems for the kingdoms of life or the classification of Pluto as a planet. These statements indicate a naïve conception that the only change in scientific knowledge is in how we refer to the physical objects (no change in our understanding of them). These statements were coded [*Classification and Terminology*]. In an attempt to elucidate a more informed view that was not being articulated, the participants were asked during interviews, “how will science textbooks be different 20 years from now?” While some indicated that what is in textbooks today might be different because we learn more and modify our current understanding (indicating a more informed view than was being detected), two participants responded the only difference would be in the presentation of the material (using digital media to eliminate the need for textbooks or books including more information on careers in science); these statements were coded [*Only change in science textbooks is in the presentation*]. Another participant described some scientific knowledge as being so complex that it would "have" to change but gave no explanation of how or why it would change. This statement was coded [*Scientific knowledge is so complex it must change*]. One last naïve code identified was [*Some knowledge becomes permanent*]. One participant described scientific knowledge as becoming certain with enough data.

Post-Intervention Codes Identified for Tentative

In the post-intervention data, one additional code was identified. Four participants made clear reference to how they would not use the word proof to describe scientific discoveries anymore in order to more authentically represent the findings of science. This informed view was coded [*"Won't use proof" anymore*].

These codes were used to rank participants overall conception of the tentative nature of science. When determining overall scores, all codes identified for tentative within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XII shows the distribution of overall rankings among the participants both prior to and after the intervention.

Figure XII. Participants' Conceptions of the Tentative NOS



Change Detected in Participants' Conceptions of the Tentative NOS

Improvement was detected in the participants' conceptions of the tentative nature of science. Flora began with a naïve conception of the tentative nature of science but ended with an informed view of this tenet. This movement from the least informed category to the most informed category indicates a four-step improvement. Irene began with a transitional/naïve view and ended with a transitional/informed view indicating a two-step improvement. Elise began with a transitional view and ended with a transitional/informed view (a one-step improvement), but Gina's post-intervention data indicated a decrease in her understanding which moved her from the transitional/informed category to the transitional (a one-step digression). Christina and Hannah both began with views of tentative classified as transitional/informed and ended with informed views (a one-step improvement for each). No change was detected in the transitional/informed views held by Brenda, Dana, and Jerri or in the informed views held by Angela and Keren.

Nine participants began the workshop with conceptions of the tentative nature of science that were classified as less than informed. Of these nine, five appeared to have developed more informed views by the end of the workshop. A range of change was detected; one-step improvement in three participants, two-step improvement in one participant, and four-step improvement in one participant. One participant demonstrated a movement away from an informed view (a one-step digression). Two participants began and ended the workshop with an informed view. The total number of participants who began or ended the workshop with a conception classified as less than informed was nine. The overall percent change, based upon these nine, was five improved (55%) and one digressed (11%). The average categorical change across all eleven participants (including one four-step change and a negative one-step change) was +0.89 indicating that appreciable improvement was detected.

Empirical

The empirical nature of science refers to the view that all scientific knowledge must be at least partially based on empirical evidence. Lederman (2006b) describes the empirical nature of science as:

> Scientific knowledge is, at least partially, based on and/or derived from observations of the natural world.

In a personal correspondence with Abd-El-Khalick (2007), a contemporary of and co-researcher with Lederman, I identified another potential area of concern when using the definitions put forth by these researchers. Abd-El-Khalick referenced the response a student made to the VNOS question, "how does science differ from other subjects you have studied?" The student replied, "Science collects data, art collects dust". Abd-El-

Khalick joked that this simple answer actually conveyed that the student understood the empirical nature of science. This answer, although witty, failed to address a critical aspect to the empirical nature of science; *in what way and to what degree does science rely upon empirical evidence?* While much of scientific knowledge is directly supported by empirical evidence, scientific inferences and theories are not always directly testable with empirical evidence. If one oversimplifies the need for empirical evidence and does not clarify that scientific knowledge must be *based* on empirical evidence (not wholly supported by it), then the risk is there to discount any scientific claims that are not directly supported by hard data. To accommodate this subtlety, the definition of the empirical nature of science used in this study is:

> Scientific knowledge is based on and/or derived from observations of the natural world. Although all scientific knowledge is based upon empirical evidence, much scientific knowledge (i.e. inferences and theories) lacks hard data to overtly demonstrate it. While a basis in empirical evidence is important, empirical data is not required as a primary source of validation of scientific claims.

Making this modification to the definition of the empirical nature of science will ensure that participants who are given a ranking of informed for empirical nature of science will truly recognize the importance of empirical evidence as a basis in scientific knowledge, but will also recognize that all scientific claims do not have full support of empirical data. The participants were offered numerous opportunities to reveal their conceptions regarding the empirical nature of science. The VNOS questions which directly addressed this tenet included:

4. a. How do scientists know that dinosaurs really existed?

4. b. How certain are scientists about the way dinosaurs looked?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

5. a. Do you think weather persons are certain (sure) about these weather patterns?

Other questions in the VNOS also gave them opportunities to address the empirical nature of science as did direct questioning during the interview. While all participants conveyed that scientists knew about dinosaurs because of fossil evidence (empirical evidence), these statements were not used to identify their conceptions of the empirical nature of science for two reasons. First, the answer "they know because they have fossils" is far to simplistic an answer because the likelihood of finding a science teacher who has not at least seen dinosaur fossils in a textbook is so remote, that this answer would be expected. Furthermore, this simplistic answer does not convey to any degree if the respondent understands in what way scientific claims are sometimes directly supported by empirical evidence and sometimes not in the case of inferences or theories.

Pre-Intervention Codes Identified for Empirical

Seven codes were identified in the pre-intervention data that related to the empirical nature of science. Later, two were classified as informed, one was classified as transitional, and four were classified as naïve.

Empirical – informed.

Four of the 11 participants made statements that indicated they understood the importance of empirical evidence as a basis for scientific knowledge. These statements were coded [*Must have a basis in empirical evidence*]. Only two participants, however, also conveyed the conception that some scientific claims are not directly supported by hard data. These statements were coded [*Some scientific knowledge lacks "hard data" but is based on empirical evidence*] and indicated an understanding that inferences and theories lack observable data despite being based upon observable data.

Empirical – transitional.

One transitional code was identified in the data. Three of the 11 participants indicated that they felt there was a need for empirical data, but seemed to lack confidence in their answer and/or could not confidently say that science must have some degree of empirical evidence. These statements were coded [*Leans toward needing empirical evidence, but lacks confidence*]. Without the confidence in a basis in empirical evidence, these statements could not be labeled informed.

Empirical – naïve.

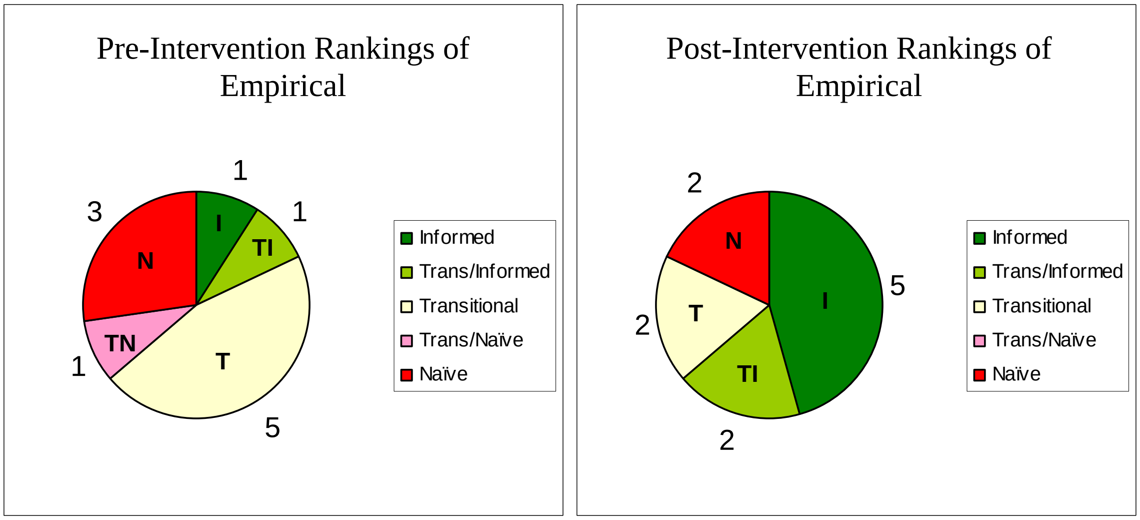
The most common naïve view found among the participants was that empirical data was a requirement in all scientific statements and that if empirical evidence did not directly support the claim, then it was pure conjecture. These statements were coded [*Must have empirical evidence (no inferences)*]. Six of the 11 participants made statements which fell within this code. At first glance these statements might appear informed in nature, but they fail to address the critical importance of inferences as a way of knowing. One participant made statements which indicated that no empirical evidence was needed. These statements were coded [*No empirical evidence needed*]. One also made a contradictory informed statement that there must be some basis in empirical evidence. Another participant made a distinction between types of scientific claims and their need for empirical evidence. She claimed that empirical evidence is not needed when generating hypotheses, but only in supporting them. This statement was coded [*Hypotheses require no empirical evidence*]. One participant stated that empirical data was not always necessary, but then gave an example which was based on the use of empirical data. This indicated that she did not have a clear understanding of what empirical meant. Her statement was coded [*Misunderstands the meaning of empirical*].

Post-Intervention Codes Identified for Empirical

One additional code was identified in the post data that related to the empirical nature of science. Two participants described how natural science does not address supernatural phenomena and that things of this nature would fall outside the realm of science. These statements were assigned the informed code [*Science doesn't study supernatural*].

These codes were used to rank participants overall conception of the empirical nature of science. When determining overall scores, all codes identified for empirical within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XIII shows the distribution of overall rankings among the participants.

Figure XIII. Participants' Conceptions of the Empirical NOS



Change Detected in Participants' Conceptions of the Empirical NOS

Improvement was detected in the participants' conceptions of the empirical nature of science. Christina, Gina, and Hannah all began the workshop with a naïve conception of the empirical nature of science. While Christina's and Gina's naïve view persisted through the study, Hannah's conception improved markedly from naïve to informed (a four-step improvement). Elise's transitional/informed view improved one-step to be classified post-intervention as transitional. Five participants began with transitional views of empirical. Brenda's transitional view did not change, but Angela's and Irene's transitional views both improved one-step to be post-intervention classified as transitional/informed. Dana's and Flora's transitional views improved two-steps to be classified as informed at the conclusion of the study. Keren's conception of the empirical nature of science improved one-step from transitional/informed to informed.

Ten participants began the workshop with conceptions of the tentative nature of science that were classified as less than informed. Of these ten, seven appeared to have developed more informed views by the end of the workshop. A range of change was detected; one-step improvement in four participants, two-step improvement in four participants, and four-step improvement in one participant. One participant began and ended the workshop with an informed view. The total number of participants who began or ended the workshop with a conception classified as less than informed was ten. The overall percent change, based upon these ten, was seven improved (70%). The average categorical change across all eleven participants was +1.2 indicating that appreciable improvement was detected.

Subjective

The subjective nature of science refers to the way in which scientists view their data from different perspectives and make conclusions about their research based upon their educational background and what theories they have learned and accepted. This tenet is sometimes referred to as the *theory-laden* nature of science. Lederman (2006b) describes the subjective nature of science as:

> Scientific knowledge is subjective. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work.
> Scientists' observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives (theory-laden).

During prior work with the VNOS, this definition was found to adequately address all responses regarding the subjective nature of science and was, therefore, used in this study. The participants were given opportunities to convey their conceptions of the subjective nature of science through several questions in the VNOS; the most direct question dealing with the subjective nature of science was:

> 4. c. Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?

The participants were given further opportunities to convey their conceptions of the subjective nature of science through direct and indirect questions and discussions during the interview.

Pre-Intervention Codes Identified for Subjective

Eight codes were identified in the pre-intervention data that related to the subjective nature of science. Later, two were classified as informed, two were classified as transitional, and four were classified as naïve.

Subjective – informed.

As seen in figure III, over half of the participants held naïve or transitional/naïve views. There were three different codes which were classified as informed. Two participants indicated that a person's educational background could influence their interpretation of data. These statements alluded to the theoretical framework influencing interpretation (theory-ladenness) and were coded [*Educational background can influence interpretation*]. Only one participant directly addressed the use of theories in the interpretation of observations. This statement was coded [*Theory laden*].

Subjective – transitional.

Six of the 11 participants conveyed the view that personal backgrounds could cause subjectivity but made no reference to how they caused it. There was no reference to educational background to even allude to theoretical perspectives as being the source of the subjectivity. These statements were coded [*Different backgrounds cause subjectivity*]. Two participants conveyed views which were very close to an informed view; they referenced that new discoveries are incorporated into prior knowledge about the subject of the discovery and could change our perception of it. These statements were coded [*Incorporates new knowledge into prior knowledge*]. In both instances, however, the participant failed to connect the prior knowledge with theory and did not show how the current knowledge influenced how the new discoveries were incorporated.

Subjective – naïve.

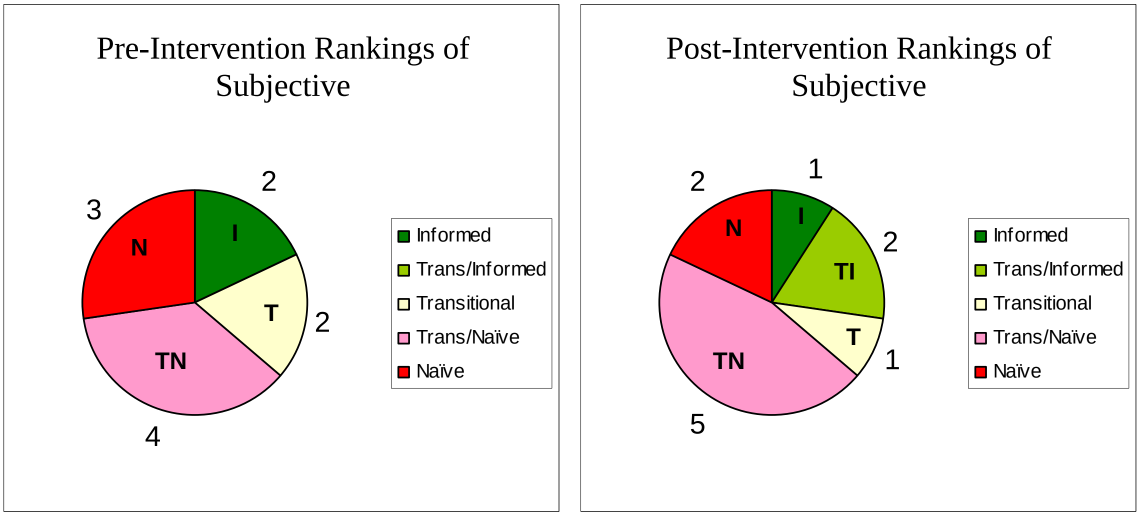
The majority of the participants received an overall ranking of naïve or transitional/naïve for the subjective nature of science. This is largely due to their lack of informed views and their holding the naïve view that subjectivity in science is merely an unavoidable characteristic of any human endeavor. Four of the participants related in their VNOS responses and in the interviews that subjectivity was just a "human" thing. These statements were coded [*Subjectivity "just a human thing"*]. The other common code found among the data was the view held by four participants that subjectivity needed to be avoided if at all possible as it flawed good science. These statements were coded [*Subjectivity is bad for science*]. These two common themes fail to connect the subjectivity to current scientific theory and even viewed such theory-ladenness as bad for science instead of aiding scientists in understanding new phenomena. Two participants held the naïve view that science was purely objective; these statements were coded [*Science is objective*]. Two participants did not seem to understand what was meant by the word subjective and could not explain how subjectivity was a factor in science; these statements were coded [*Does not understand "subjective"*].

Post-Intervention Codes Identified for Subjective

Two additional codes were identified in the post data that related to subjectivity in science. Three participants conveyed a conception of the subjective nature of science that was moving in an informed direction but lacked the sophistication to be called informed. These transitional statements indicated that subjectivity was not bad for science but that care needed to be taken to be aware of it. These statements recognize the way subjectivity can lead to dogma in science which can impede discovery but fails to recognize the importance of the theory-laden approach to interpreting data. These statements were given the transitional code [*Subjectivity isn't bad, but we need to be aware of it*]. One participant indicated that subjectivity could benefit scientists in interpreting their data. This statement was given the informed code [*Subjectivity can fuel discovery*].

These codes were used to rank participants overall conception of the subjective nature of science. When determining overall scores, all codes identified for subjective within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XIV shows the distribution of overall rankings among the participants.

Figure XIV. Participants' Conceptions of the Subjective NOS



Change Detected in Participants' Conceptions of the Subjective NOS

Improvement was detected in the participants' conceptions of the subjective nature of science. Three participants began the workshop with a naïve conception of this tenet. Gina's and Irene's naïve views persisted throughout the study, but Christina's naïve view shifted one-step towards a more-informed view and was classified post-intervention as transitional/naïve. Angela, Dana, Flora, and Jerri all began and ended the workshop with transitional/naïve views of subjectivity indicating no change had occurred. Keren's transitional view of subjective also showed no change. Elise began with a transitional view of this tenet but ended with a conception of subjectivity classified as transitional/informed (indicating a one-step improvement). Brenda's informed conception based on pre-intervention data diminished and was classified as transitional/informed at the conclusion of the study.

Nine participants began the workshop with conceptions of the subjective nature of science that were classified as less than informed. Of these nine, only two appeared to have developed more informed views by the end of the workshop. Furthermore, one participant's view moved in a negative direction. A one-step improvement was detected in two participants and a one-step digression was detected in one participant. One participant began and ended the workshop with an informed view. The total number of participants who began or ended the workshop with a conception classified as less than informed was ten. The overall percent change, based upon these ten, was two improved (20%) and one digressed (10%). The average categorical change across all eleven participants was +0.1 indicating little appreciable improvement was detected.

Creative

The creative nature of science refers to how scientists create new knowledge as they follow scientific methodologies to make inferences and theories to explain scientific phenomena. Lederman (2006b) describes the creative nature of science as:

> Scientific knowledge involves human imagination and creativity. Science involves the invention of explanations and this requires a great deal of creativity by scientists.

During prior work with the VNOS, this definition was found to adequately address all responses regarding creativity in science and is, therefore, used in this study.

The participants were given opportunities to convey their conceptions of the creative nature of science through several questions in the VNOS; the most direct question dealing with the creative nature of science was:

7. Scientists try to find answers to their questions by doing investigations/experiments. Do you think that scientists use their imagination and creativity when they do these investigations/experiments?

Circle one → **YES** **NO**

a. If **NO**, explain why?

b. If **YES**, in what part(s) of their investigation (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

The participants were given further opportunities to convey their conceptions of the creative nature of science through direct and indirect questions and discussions during the interview.

Pre-Intervention Codes Identified for Creative

Seven codes were identified in the pre-intervention data that related to the creative nature of science. Later, one code was classified as informed, four were classified as transitional, and two were classified as naïve.

Creative – informed.

Only two participants held conceptions of the creative nature of science that were classified as informed. They conveyed their informed view by making statements which described scientists using their imagination to create new knowledge that did not previously exist. These statements were coded [*Scientists create new knowledge*].

No other informed views regarding the creative nature of science were detected in the pre-intervention data.

Creative – transitional.

One participant expressed a transitional view of the creative aspect of science by stating that creativity is useful in all steps of scientific processes, but failed to articulate how it was useful. This statement was coded [*Creative in all aspects of science, but no explanation*]. One participant indicated that creativity could play a role in developing new theories; this statement was coded [*Creative in developing new theories*] which showed a somewhat informed view, but lacked an explanation of how creativity played in the development of theories. One participant described creativity as helping scientists “find” solutions which was coded [*Creativity in finding solutions*]. Finally, one participant described creativity as being open to new ideas and thus helping scientists make discoveries. These statements were coded [*Creativity means open to new ideas*] and included references to an “inner nudge” and intuition in coming up with new ideas.

Creative – naïve.

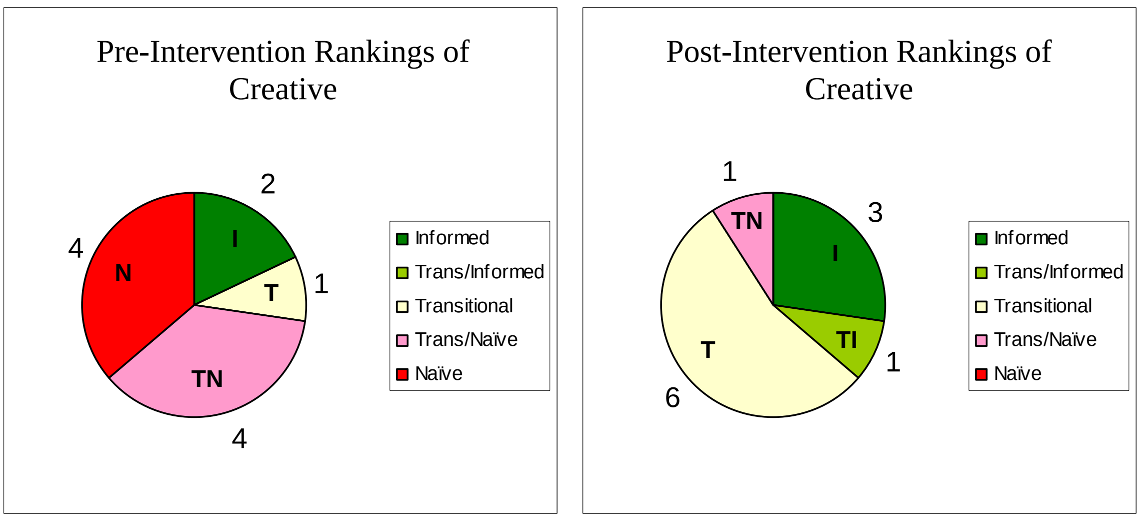
The most dominant idea related to creativity that was found in the data was that creativity was useful in setting up an experiment (with no reference to any other place for creativity to play a role). These comments were coded [*Creativity in Setting up Experiments or Developing Questions*] and were identified in eight of the eleven participants. Three participants also viewed creativity as curiosity and thought the creative aspect of science was what led scientists to ask the questions they ask. These statements were coded [*Creativity Equals Curiosity*].

Post-Intervention Codes Identified for Creative

Two additional codes were identified in the post data. Two participants were able to discuss creativity in a somewhat sophisticated sense and stated that scientists must use creativity when they explain new phenomena. This statement was given the informed code [*Creativity in explaining occurrences*]. Two participants confused the meaning of creativity in science with subjectivity, but recognized its importance. These statements were coded [*Conflates creativity and subjectivity but realizes its import*].

These codes were used to rank participants overall conception of the creative nature of science. When determining overall scores, all codes identified for creative within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XV shows the distribution of overall rankings among the participants.

Figure XV. Participants' Conceptions of the Creative NOS



Change Detected in Participants' Conception of the Creative NOS

Improvement was detected in the participants' conceptions of the creative nature of science. Angela, Christina, Flora, and Jeri all began with naïve conceptions of this tenet and all four demonstrated two-step improvements in their post-intervention data and their views of the creative nature of science was classified as transitional. Brenda, Dana, Elise, and Gina all began with transitional/naïve views of creativity. Gina's transitional/naïve view persisted throughout the study, Brenda and Elise both demonstrated a one-step improvement and were post-intervention classified as transitional for this tenet, and Dana showed a three-step increase from transitional/naïve to informed. Keren began with a conception of creativity classified as transitional but ended with a more informed view of this tenet that was classified as transitional/informed (a one-step improvement).

Two participants began and ended the workshop with an informed view. The total number of participants who began or ended the workshop with a conception classified as less than informed was nine. The overall percent change, based upon these nine, was eight improved (89%). The average categorical change across all eleven participants was +1.56 indicating that appreciable improvement was detected.

Socially and Culturally Embedded

The socially and culturally embedded nature of science refers to influence that society and culture have on the questions that scientists ask, the kinds of scientific research that is conducted, and the way in which scientific progress affects and is affected by both the practitioners as well as the users of scientific discoveries. Lederman (2006b) describes the socially and culturally embedded nature of science as:

> Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion.

During prior work with the VNOS, this definition was found to adequately address all responses regarding social and cultural embeddedness in science and is, therefore, used in this study. The participants were given opportunities to convey their conceptions of the socially and culturally embedded nature of science through the questions in the VNOS; however, none of the VNOS questions addresses this issue directly. In this research as well as prior studies using the VNOS, few participants convey their thoughts of social and cultural influence on science based upon the prompts in the VNOS itself. Only through subsequent interviews do most participants begin to convey these conceptions. During the interviews the participants were directly asked their thoughts about how culture and society influence science. It was through these interview questions that their conceptions were uncovered and the codes identified.

Pre-Intervention Codes Identified for Social and Cultural

Six codes were identified in the pre-intervention data that related to the socially and culturally embedded nature of science. Later, one was classified as informed, three were classified as transitional, and two were classified as naïve.

Socially and culturally embedded – informed.

Four participants articulated views of the social and cultural influence on science that were consistent with the informed view. These statements were coded [*Social and cultural values direct science*]. These statements clearly demonstrated the participants recognized that social and cultural values influenced the direction of scientific progress.

Socially and culturally embedded – transitional.

Four participants expressed views that social and cultural influences could limit the direction science could move. This view, although not incorrect, only exemplifies the stifling effect that social and cultural values can have on science. It fails to incorporate the positive effect that these same influences can have. These statements were coded

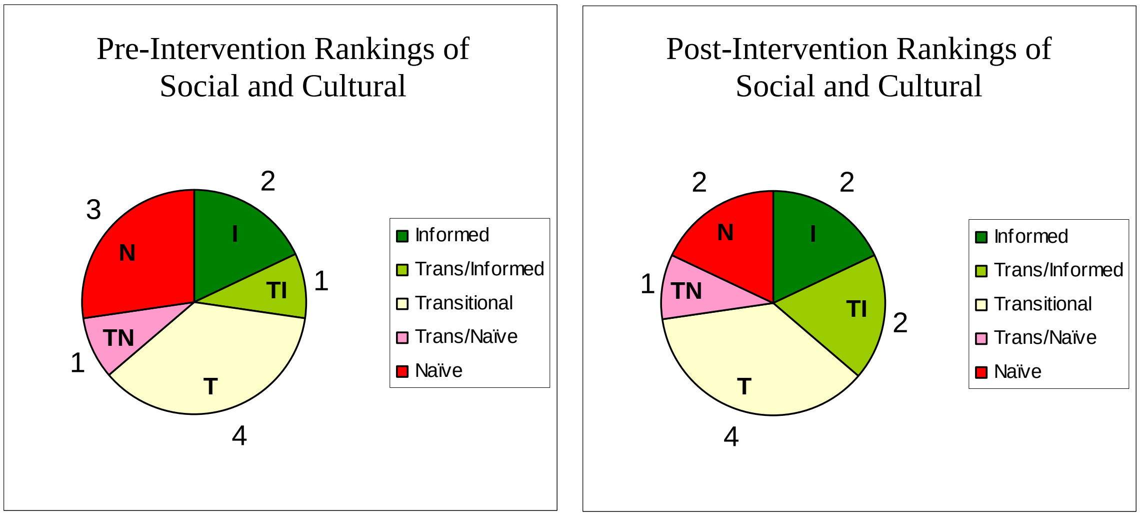
[*Social and cultural values can limit science*]. Another participant conveyed that she knew society and culture had an effect on science but did not explain how they affected science or give examples of their effect. This statement was coded [*Social and cultural values can have an effect but cannot explain*]. The last transitional code that emerged was in a participant's view that social and cultural influence was the same as an individual's personal interest in a subject. She realized that individuals think differently about scientific endeavors but failed to recognize that as a larger body, the society in which science is being practiced also has a collective thought on scientific enterprises and can, therefore, direct scientific research. This statement was coded [*Conflates personal values with social and cultural values*].

Socially and culturally embedded – naïve.

Only two naïve codes were identified in the data. One participant clearly articulated that although social and cultural values can influence science, she felt they should not. She held the naïve conception that science should exist outside the influence of any societal values and that when social and cultural values influenced science, it was to the detriment of "good science". This statement was coded [*Social and cultural values SHOULD NOT influence science*]. The other code which was identified was one in which the subject mistook social and cultural values as being subjective and conditional. This statement was coded [*Conflates social and cultural with subjective and conditional*]. No additional codes were identified in the post-intervention data related to subjectivity.

These codes were used to rank participants overall conception of the socially and culturally embedded nature of science. When determining overall scores, all codes identified for social and cultural embeddedness within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XVI shows the distribution of overall rankings among the participants.

Figure XVI. Participants' Conceptions of the Social and Cultural NOS



Change Detected in Participants' Conceptions of the Social and Cultural NOS

Almost no improvement was detected in the participants' conceptions of the social and cultural nature of science. The only change that was detected was in Keren's data. She began the workshop with a naïve conception of this tenet but her post-intervention data revealed a three-step improvement in her understanding which was classified as transitional/informed. No other changes occurred. Christina and Gina both started and ended the workshop with naïve views and Elise's transitional/naïve view did not change. Angela, Brenda, Dana, and Jeri all started and finished the workshop with a transitional conception, and Flora's transitional/informed view did not improve. Hannah and Irene both began the workshop with informed views which persisted throughout the study. The total number of participants who began or ended the workshop with a conception classified as less than informed was nine. The overall percent change, based upon these nine, was one improved (11%). The average categorical change across all eleven participants was +0.33 indicating that little appreciable improvement was detected.

Observations and Inferences

The role of observations and inferences in nature of science refers to the way that science uses observations of phenomena which are directly accessible to the senses and then makes inferences based upon these observations to explain and predict future events and retrodict past circumstances. The predictions and retrodictions are not directly accessible to the senses but are supported by empirical evidence.

Lederman (2006b) describes the role of observations and inferences in nature of science as:

> Observations are descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses). By contrast, inferences are statements about phenomena that are not "directly" accessible to the senses.

During prior work with the VNOS, this definition was found to adequately address all responses regarding observations and inferences in nature of science and is, therefore, used in this study. The participants were given opportunities to convey their conceptions of the role of observations and inferences in nature of science through the following questions from the VNOS:

4. a. How do scientists know that dinosaurs really existed?
   b. How certain are scientists about the way dinosaurs looked?
   c. Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about

what had caused this to happen. Why do you think they disagree even though they all have the same information?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

   a. Do you think weather persons are certain (sure) about these weather patterns?

   b. Why or why not?

7. Scientists try to find answers to their questions by doing investigations/experiments. Do you think that scientists use their imagination and creativity when they do these investigations/experiments?

The participants also had the opportunity to convey their knowledge of the role of observations and inferences in science through direct and indirect questions and discussions in their interviews.

Pre-Intervention Codes Identified for Observations and Inferences

Eleven codes were identified in the pre-intervention data that related to the role of observations and inferences in the nature of science. Later, three were classified as informed, four were classified as transitional, and four were classified as naïve.

Observations and inferences – informed.

Over half of the participants exhibited views on observations and inferences that were consistent enough with the informed view to earn a ranking of transitional/informed or informed. Nine of the participants were able to convey an understanding of observations and inferences as a way for scientists to apply theory to predict and/or retrodict in context of weather and dinosaur appearances respectively. These statements were coded [*Use of current knowledge and theory to make inferences*]. Two participants also stated that confidence in inferences increase as more evidence is discovered that supports the inferences. These statements were coded [*Confidence in inferences increases with more data*]. The last code identified was [*Describes observations and inferences*] and was given to those statements that were descriptive of these two terms and were reflective of what of what might be read in a science textbook. Two participants made these statements.

Observations and inferences – transitional.

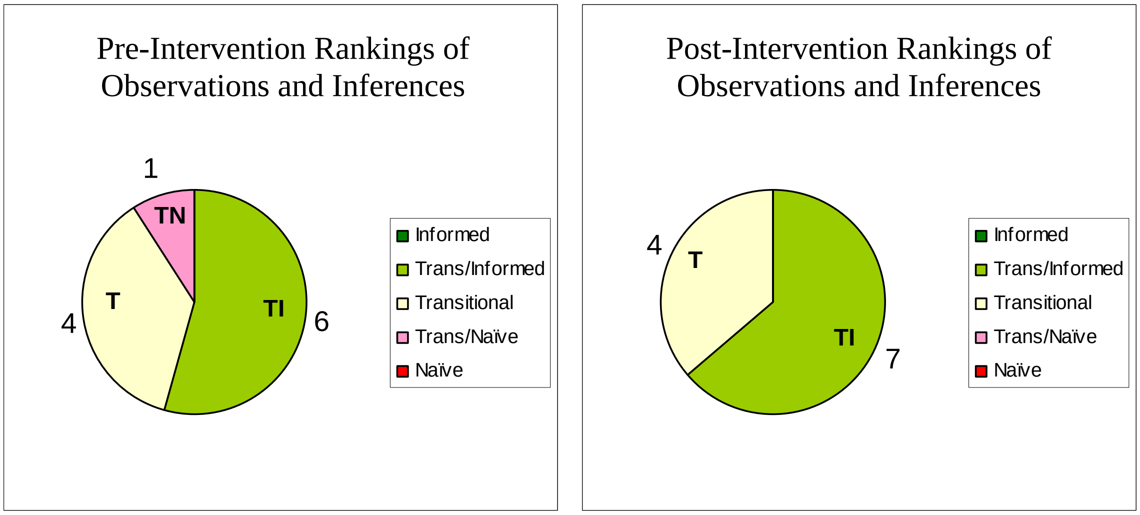
Three participants who described the use of observations and inferences in an informed way also made statements in which they conveyed a lack of confidence in inferences if there was no “hard data”. These statements were coded [*Lacks confidence in inferences*]. One participant stated that inferences were based upon current or past evidence but offered no real explanation how this evidence could be used to make inferences. This statement was coded [*Describes use of past/present evidence, but does not explain*]. Six participants exhibited views of inferences that were inconsistent when viewed in different contexts. One of these conveyed much higher confidence in inferences when in context of weather forecasting, while five others indicated that their confidence in the inferences declined dramatically when in context of weather. These statements were coded [*More confident in context of weather*] and [*Less confident in context of weather*]. Both of these two codes demonstrated that the participants understood how observations and inferences were used in science, but also showed their level of trust in this common scientific methodology was not consistent across subjects.

Observations and inferences – naïve.

One participant expressed a lack of understanding in how inferences were made even though two of them had described well how scientists use current information to retrodict and infer what dinosaurs looked like. Her statements were coded [*Does not know how inferences are made*]. Three participants made statements which demonstrated that they believed that without "hard data" that inferences were pure speculation. Statements which showed this naïve lack-of-confidence in inferences were coded [*MUST have hard data or just speculating*]. One participant expressed naïve views of observations and inferences by conveying a level of trust in technologically developed inferences (i.e. weather forecasts) without being able to explain how the inferences were made. Her statements were coded [*Trust in technology without understanding*]. No additional codes were identified in the post data that related to observations and inferences. The last naïve code found in the pre-intervention data was identified in two participants' data. Both of these participants attempted to describe the role of observations and inferences, but could not give an informed description. These statements were coded [*Poor description of observations and inferences*]. No additional codes were identified in the post-intervention data.

These codes were used to rank participants overall conception of the role of observations and inferences in the nature of science. When determining overall scores, all codes identified for observations and inferences within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XVII shows the distribution of overall rankings among the participants.

Figure XVII. Participants' Conceptions of the Observational and Inferential NOS



Change Detected in Participants' Conceptions of the Observational and Inferential NOS

Almost no improvement was detected in the participants' conceptions of the observational and inferential nature of science. Only two participants demonstrated any change in their conceptions of this tenet of NOS. Christina began with a conception classified as transitional/naïve and ended with her understanding classified as transitional (a one-step improvement). Keren also demonstrated a one-step improvement in her conception which moved from being classified as transitional to transitional/informed. Gina, Irene, and Jeri all began and ended the workshop with transitional views and all other participants maintained a transitional/informed view throughout the workshop. None began the workshop with an informed view and, therefore, all could have experienced growth. The overall percent change, based upon these nine, was two improved (18%). The average categorical change across all eleven participants was +0.18 indicating that little appreciable improvement was detected.

Theories and Laws

The distinction between theories and laws as a feature of nature of science refers to recognizing that laws and theories are two distinct forms of scientific knowledge with laws being descriptive and theories being explanatory. It also emphasizes that there exists no hierarchical relationship between theories and laws and that both forms of scientific knowledge are reliable and enduring. Lederman (2006b) describes the distinction between theories and laws as follows:

> Individuals often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. However, theories and laws are different kinds of knowledge and one can not develop or be transformed into the other. Laws are statements or descriptions of the relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena.

During prior work with the VNOS, this description was found to adequately address all responses regarding theories and laws and is, therefore, used in this study. The participants were given opportunities to convey their conceptions of theories and laws during their interview by responding to direct questions about their meaning and any relationships that they believed existed between them. The VNOS does not directly address the role of theories and laws and little evidence was seen in the VNOS responses regarding them.

Pre-Intervention Codes Identified for Theories and Laws

Seven codes were identified in the pre-intervention data that related to the role of theories and laws in the nature of science. Later, two were classified as informed, one was classified as transitional, and four were classified as naïve.

Theories and laws – informed.

No participant's overall conception of theories and laws was classified as informed. However, two different codes emerged that were of an informed nature. One participant related that theories were explanatory and one (a different participant) related that laws were descriptive. These statements were coded [*Theories are explanatory*] and [*Laws are descriptive*]. When these statements were read in context of all other statements made by these participants regarding theories and laws, the strength of their informed statements was dramatically reduced.

Theories and laws – transitional.

One participant described the role of theories and laws in a way that was close to the informed view, but lacked confidence in her understanding. This statement was coded [*Describes theories and laws but lacks confidence*].

Theories and laws – naïve.

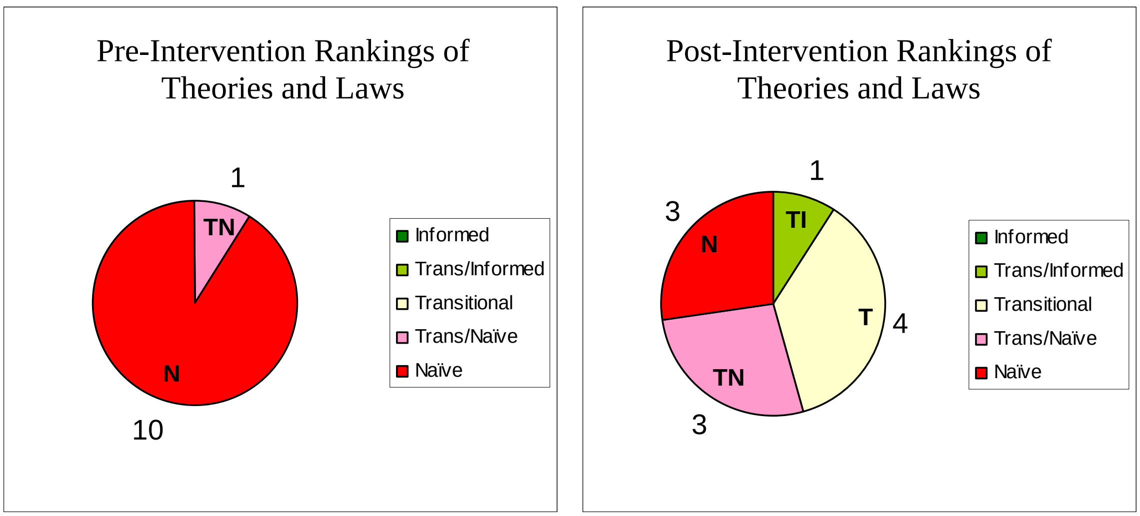
All eleven participants conveyed the naïve view that theories were subject to change over time while laws were permanent and unchanging. These statements were coded [*Theory is tentative, Law is permanent*]. Eight of the participants also held the view that there exists a hierarchical relationship between hypotheses, theories and laws with hypotheses becoming theories once they are supported by evidence and then theories becoming laws once they are adequately tested and supported by evidence. These statements were coded [*Hierarchical view*]. Two participants conflated hypotheses, theories and laws and used them interchangeably in their VNOS responses and/or their interviews. These statements were coded [*Conflates hypotheses, theories and laws*]. Two participants echoed their belief that theories are more tentative than laws by making statements about the strength of theories being much less than laws. These statements were coded [*Just a theory*].

Post-Intervention Codes Identified for Theories and Laws

Three additional codes were identified in the post-intervention data that related to theories and laws. Two transitional codes and one additional naïve code were identified. Four participants indicated that they knew that theories and laws were different but could not clearly articulate what the difference was. Because these statements indicate a prior conception that theory and law might be used interchangeably, these statements were coded [*Recognizes difference between theory and law*] and was classified as transitional. Another transitional code was identified in statements made by five participants who indicated they liked the “new” descriptions of theories and laws and would “try” to use them in their classrooms. These statements conveyed recognition that their prior conceptions of theories and laws were inadequate and that they were working to assimilate the new information presented in the workshop into their working knowledge, but that they lacked the sophistication to confidently do so. These statements were coded [*Lacks confidence in new understanding*]. The one naïve code that was identified in the post data was a general lack of understanding of the terms theory and law. This statement was identified in one participant’s data and was coded [*Unsure of theory and law*].

These codes were used to rank participants overall conception of the role of theories and laws in the nature of science. When determining overall scores, all codes identified for theories and laws within a participant's VNOS responses and interview transcriptions were combined to award them a ranking of informed, transitional/informed, transitional, transitional/naïve, and naïve. Figure XVIII shows the distribution of overall rankings among the participants.

Figure XVIII. Participants' Conceptions of the Theories and Laws NOS



Change Detected in Participants' Conceptions of the Theories and Laws NOS

Much improvement was detected in the participants' conceptions of theories and laws in nature of science, however, none achieved a level of understanding classified as informed. Dana was the only participant who began the workshop with a conception of theories and laws that was not classified as naïve (her conception was classified as transitional/naïve). Her conception of theories and laws did not improve or digress over the course of the workshop. All others began with a naïve conception of theories and laws and demonstrated various amounts of improvement. Brenda and Gina both demonstrated post-intervention conceptions that were classified as transitional/informed which indicates a one-step improvement. Angela, Elise, Hannah, and Irene all demonstrated new understandings of theories and laws that were classified as transitional (indicating a two-step improvement). Flora's post-intervention conception of theories and laws was the most informed of all participants and was classified as transitional/informed which reflects a three-step improvement. Since none of the participants began with an informed conception of this tenet, all had the potential to develop a more informed understanding. The overall percent change, based upon them, was seven improved (64%). The average categorical change across all eleven participants was +1.18 indicating that appreciable improvement was detected.

CHAPTER 6

DISCUSSION

Do scientific biologists [and science teachers] contribute no more to the progress of human society than, for example, the scientific philologists?"

– Henry R. Linville (1907)

The primary goal of the study was to examine eleven inservice science teachers' conceptions of nature of science before and after engaging in an explicit professional development intervention. Consistent with early research on NOS (Anderson, 1950; Behnke, 1950; Carey & Strauss, 1968; Miller, 1963; Schmidt, 1967) and more recent studies (Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Bloom & Weinburgh, 2007; Bloom, Sawey, Holden & Weinburgh, 2007), the teachers who participated in this study demonstrated an unsophisticated overall conception of the philosophical underpinnings of science at the beginning of the professional development workshop. Unlike the early studies referenced above, however, this study examined the teachers' conceptions of NOS in a more detailed way. Many of the early studies examined just one characteristic of science such as the scientific method (Anderson, 1950) or the tentativeness of science (Behnke, 1950). Others examined overarching aspects of science such as "the scientific enterprise", "the scientist", and "scientific methods" failing to address specific tenets of science (Miller, 1963). Recent research by Weinburgh (2003b, 2007) further addresses teachers' conceptions of *the* scientific method. More recent research in NOS has built upon these studies by using an instrument (Views of Nature of Science Questionnaire – VNOS) aimed to reveal conceptions about the individual underlying characteristics of science that form the basis of these larger ideas (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Bloom & Weinburgh, 2007). In these recent studies, however, the teachers' conceptions of each tenet of NOS being studied was classified dichotomously as informed or naïve with less attention given to the broad range of ideas that exist somewhere between the fully informed and fully naïve conceptions. My research used the VNOS questionnaire along with semi-structured interviews in order to elucidate the teachers' conceptions of each individual tenet of NOS and classified their conception of each tenet not as either informed or naïve, but rather on a spectrum ranging from informed, transitional/informed, transitional, transitional/naïve, or naïve. Using five categories for classifying the teachers' conceptions of the seven individual tenets of NOS allows more subtle changes in their understanding of these concepts to be observed before and after instructional interventions and further allowed for any relationships between these tenets to be identified.

Discussion of Each Tenet

My research is based upon the assertion that sophisticated understanding of NOS is necessary for teachers to authentically present scientific knowledge in their classrooms. This assertion is supported by recent research (Bloom & Weinburgh, 2007; Weinburgh, 2003a) as well as by the benchmarks and standards put forth as guidelines for science teachers in America (AAAS, 1993; NSTA, 1982). In the following sections, I first review the informed description of each tenet being studied and describe why an informed understanding is important for authentic science teaching. After describing each tenet, I discuss the improvement observed among the participants' post-intervention data and how that improvement may affect their classroom teaching.

Tentative

The working description of the tentative nature of science put forth in this research was described as;

> The body of scientific knowledge, including "facts," theories, and laws, changes in two ways; it grows as new knowledge is discovered and it improves as old knowledge is revised and corrected. While scientific knowledge is tentative, there is also much reliability in scientific knowledge because it is based on empirical evidence.

This research posits that an informed view of the tentative nature of science is essential for authentic science instruction. This position is supported by recognizing problems that can arise when this representation of science is not achieved. First, students need to realize that current scientific knowledge is not permanent and that new advances in technology or new discoveries could lead to revisions in our understanding of the natural world. This is apparent when viewed in context of medicine. Only a quarter of a century ago, medical scientists around the world held the view that stomach ulcers were caused by stress and diet. With this understanding of ulcers, patients suffering from them resorted to acid-lowering or acid-blocking medications which they would take indefinitely to treat their symptoms. Today, due to advances in medical research, it is understood that ulcers are most commonly caused by the bacterium *H. pylori* and patients may now undergo a treatment of antibiotics and cure their disease (Films for the Humanities and Sciences, 2005). Once students learn that scientific knowledge is tentative, they will know that better-informed answers may well be developed in the future. Another reason that students should understand the tentative nature of science is due to the fact that scientific knowledge does change and without understanding this process of scientific advancement, they could develop serious misconceptions about the reliability of scientific claims. When students lack a sophisticated understanding that changes in scientific knowledge are representative of improvements, when they learn that new discoveries have disproved previously held beliefs in science, they may begin to develop doubt about all scientific claims. Teachers must be able to convey to their students that scientific claims are always tentative and yet because they are based upon empirical evidence and sound scientific methodology, they are at the same time reliable.

Before the professional development, eight of the teachers demonstrated informed (18%) or transitional/informed (55%) conceptions of the tentative nature of science. This number of participants with relatively sophisticated views was inconsistent with prior research that reported low levels of informed views of this tenet among preservice and inservice science teachers (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Behnke, 1961). At the conclusion of the workshop, ten of the participants demonstrated conceptions of this tenet that were classified as informed (45%) or transitional informed (45%). Furthermore, no participant's post-intervention conception of the tentative nature of science was classified as naïve or transitional/naïve (one participant was classified in each of these categories prior to the workshop). It should be noted, that one participant's conception of this tenet did digress one-step and it is unclear if this change was due to her understanding becoming less informed or an artifact of the subjective evaluation of the data. The overall change for tentative was 55% improved conceptions and 11% digression (again, represented by only one participant). These data suggest that the descriptions of the tentative nature of science that were presented throughout the professional development generally had a positive effect for most participants who needed improvement in relation to this tenet. This positive trend was also observed in similar studies with teachers (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007).

The intention of the explicit NOS instruction was based upon the idea that a more sophisticated understanding of this characteristic of NOS will allow these teachers to more authentically describe scientific knowledge in their classrooms and avoid the problems identified earlier in this section.

Empirical

The working description of the empirical nature of science put forth in this research was described as:

> Scientific knowledge is based on and/or derived from observations of the natural world. Although all scientific knowledge is based upon empirical evidence, much scientific knowledge (i.e. inferences and theories) lacks hard data to overtly demonstrate it. While a basis in empirical evidence is important, empirical data are not required as a primary source of validation of scientific claims.

Since an understanding of the empirical basis of scientific claims is an integral aspect of NOS, this tenet must also be well-understood by teachers if they hope to accomplish good science instruction. Students need to understand that scientific claims are based upon empirical evidence that is directly accessible to the senses but also realize that most natural phenomena are not so available for direct observation. Because of this, much scientific knowledge is logically developed explanatory statements that are inferred from the empirical evidence. Naïve conceptions of this tenet can promote a view of science as being a collection of facts that can be directly observed using the five senses. With this view of science, any inferential claims (i.e. theoretical knowledge) could be deemed unreliable because inferences lack direct empirical evidence. Since many scientific claims are inferential in nature, students need to understand how inferences, while not directly observable, are based upon empirical evidence. Without understanding the importance of scientific claims being based upon empirical evidence, students (and teachers) could conflate unscientific claims with credible scientifically-supported knowledge.

Before the professional development, only two participants (18%) conveyed informed (9%) or transitional/informed (9%) views of the empirical nature of science. At the conclusion of the workshop, a marked increase in informed views appeared to have occured; five participants (45%) demonstrating informed views and 2 participants (18%) demonstrating transitional/informed views. This relatively low percentage of informed views prior to instruction and substantial improvement after instruction is consistent with prior research (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007). The overall change for empirical was 70% improved. These data indicate that teachers' conceptions of this tenet can be influenced in a positive way by explicit instruction and can become more informed and supports the notion that the professional development provided was effective at accomplishing appreciable change for most participants who needed improvement in relation to this tenet.

The intention of the instruction was to improve teachers' understanding of this tenet so that they may avoid the problems listed above when presenting science to their students. A clear example of this very problem is the current problem faced by science teachers today when they address whether to include intelligent design in their lessons on evolution and natural selection (Bloom & Weinburgh, 2007). Once teachers realize that a lack of empirical basis excludes a claim from the realm of science, it becomes clear that intelligent design has no place in a science class. Once students understand this same demarcation standard, they will understand why natural selection and evolutionary theory, and not intelligent design, is presented in their science classes.

Subjective

The working description of the subjective nature of science put forth in this research was described as

> Scientific knowledge is subjective. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work.
>
> Scientists' observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives (theory-laden).

Developing an informed conception of the subjective nature of science is important for science teachers when describing how scientists interpret data and make inferences.

When students understand that scientists interpret their findings in context of their prior theoretical commitments, they can begin to appreciate the power of scientific theories. With this understanding the student can begin to realize how the explanatory power of a scientific theory, which may have been created in a particular context, can be useful in multiple other contexts as well. Furthermore, once students recognize the theory-laden nature of science, they can identify how a priori assumptions can help scientists make sense of their data or, sometimes, even prevent them from making new discoveries until their "theoretical lenses" are taken off and they can observe more objectively. Consistent with prior studies (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007), the participants in this research began the workshop with more naïve conceptions of the subjective nature of science than informed conceptions. Only two participants (18%) understood this tenet in an informed way. All other participants' conceptions were classified as transitional, transitional/naïve, or naïve. At the conclusion of the instructional workshop, very little change was detected (unlike the prior studies referenced above which detected much improvement in understanding of subjectivity). The post-intervention data indicated that one participant whose conception had been characterized as informed had, after the workshop, conveyed a less sophisticated understanding and only one participant (9%) still possessed an informed view. Two participants (18%) had conceptions classified as transitional/informed. The overall change for subjective was 20% improved and 10% digressed. These findings support the notion that the workshop interventions failed to adequately address this tenet enough to accomplish appreciable change among the participants' conceptions. With such little change among the participants' understanding of subjectivity, no effect in their classroom practices is expected related to this tenet.

Creative

The working description of the creative nature of science put forth in this research was described as:

> Scientific knowledge involves human imagination and creativity. Science involves the invention of explanations and this requires a great deal of creativity by scientists.

Understanding the creative nature of science is helpful in dispelling the myth that science is purely objective and follows a linear, orderly, single, scientific method (Weinburgh, 2003b). When students understand that scientists creatively ask questions, design experiments, evaluate their data, and formulate conclusions based upon their data, they can begin to realize the important role of imagination and divergent thinking involved in scientific processes. Rather than viewing science as being a strictly methodical and objective formal process, they can better realize how serendipity and wild conjectures can also generate new discoveries in science. Prior to the professional development, only two participants (18%) had an understanding of the creative nature of science that was classified as more than transitional (both were classified as informed). More striking, however, were the four participants (36%) with naïve and four participants (36%) with transitional/naïve conceptions. The overwhelming idea that was conveyed in the data was that creativity was only useful in designing experiments but was not useful in analysis of data or in developing explanations. These findings were consistent with prior studies on NOS (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003;

Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007). At the conclusion of the workshop, appreciable change was detected, but not as much positive improvement as found in the prior studies referenced above. Three participants demonstrated ideas of creativity that were classified as informed (27%) and one (9%) was classified as transitional/informed. Even more substantial were the improved conceptions of the eight participants whose pre-intervention conceptions were classified as naïve or transitional/naïve; only one participant ended the workshop with a conception of creativity that was classified as transitional/naïve and none was classified as naïve. These findings indicate that the naïve conception of creativity as only useful in designing experiments or asking questions (which was held by most of the participants) could be changed to a more informed view. The findings also demonstrate that although positive change occurred, only three participants (27%) were able to construct new conceptual understanding consistent with an informed view. Seven of the participants (64%) never achieved an understanding of creativity that was classified as transitional/informed or informed. The overall change for creative was 89% improvement. These data indicate that while the workshop interventions did not address this tenet sufficiently to accomplish the desired goal of fostering informed views, appreciable improvement did occur.

Social and Cultural

The working description of the socially and culturally embedded nature of science put forth in this research was described as:

> Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual

> spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion.

When science teachers understand that social and cultural values greatly influence the direction of scientific research and that scientific research then influences social and cultural values, a richer understanding of science as a discipline can be conveyed to their students. Once this understanding is gained by students of science, students can identify why some problems are not researched while others are aggressively investigated. For example, until the scientific community discovered that HIV was not solely affecting the four H's (homosexuals, heroin uses, hemophiliacs, and Haitians), there was little public concern, and even less federal funding, to find a treatment or cure. A more current issue is climate change, a theory met with much skepticism until public concern arose due to alarming reports of environmental impact (i.e. melting ice-caps and drowning polar bears), and the influence of celebrity activists (i.e. Leonardo DiCaprio and Al Gore). Understanding the influence that social and cultural values have on science can also allow students to recognize how it can hinder scientific progress. Current social and cultural values (influenced by religious and moral ethics) have halted federal funding for medical research into stem cells and therapeutic cloning. Once students realize the strong influence that society and culture can have on science, they can realize the importance of being informed members of the global community of which they are a part. This understanding can provide a contextual meaning that can invigorate students to become excited about learning (and perhaps pursuing careers in) science.

Prior to the workshop, only three participants demonstrated somewhat sophisticated views of social and cultural NOS; two participants (18%) were classified as informed and one (9%) was classified as transitional/informed. Even more demonstrated less than transitional views; one (9%) was classified as transitional/naïve and three (27%) were classified as naïve. These data are consistent with some prior studies on NOS which also revealed inadequate understandings of this tenet (Akerson & Abd-El-Khalick, 2003; Akerson & Hanuscin, 2007) but was inconsistent with another that revealed 56% of participants demonstrating a sophisticated view prior to instruction (Akerson, Abd-El-Khalick & Lederman, 2000). The post-intervention data were not consistent with the prior research and rather than revealing much-improved views (found in all the aforementioned studies), revealed instead little appreciable change among the participants. The overall change for social and cultural was 11% improvement. These findings indicate that either the workshop interventions did not address this tenet as explicitly as planned or that the participants' conceptions of this tenet were more resistant to change. Although the cause behind this lack of change may not be understood, the paucity of post-intervention data relating to this tenet is evidence that the workshop interventions did not achieve the desired goal. With such little change among the participants' understanding of the influence that social and cultural values have on science, no effect in their classroom practices is expected related to this tenet.

Observations and Inferences

The working description of the observations and inferences put forth in this research was described as:

> Observations are descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses). By contrast, inferences are statements about phenomena that are not "directly" accessible to the senses.

The ability for students of science to be able to understand and differentiate between observations and inferences is, arguably, one of the most important tenets of NOS. Since so much of scientific knowledge is based upon inferences developed after making observations, a sophisticated understanding of how this process works is critical to understanding science in even the most elementary level. Scientists infer to predict (i.e. forecasting weather, determining medical options, evaluating future environmental impact of development) as well as retrodicting (i.e. the origin of species, past climate conditions, causes of past extinctions). Understanding that these predictions and retrodictions are based upon empirical evidence along with theoretical understanding of the natural world, allows students to understand the strength behind scientific theories (such as evolutionary theory and plate tectonics) and to have faith in the reliability of scientific application of those theories (such as in medicine and engineering).

Because this is a fundamental principle of science, it is no surprise that over half of the teachers (six, 55%) who participated in this study began the workshop with transitional/informed conceptions of observations and inferences. Surprisingly, however, was that none was classified as informed. These findings are consistent with the prior studies on NOS that also found inadequate conceptions of observations and inferences (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007). The most common idea expressed by the teachers in this study that prevented their ideas from being classified as informed was that they lacked confidence in inferences if there was no "hard data" to support them. Five of the participants (45%) indicated that they lacked confidence in inferences if there was no direct, observable evidence. This idea supports the notion that they do not fully understand the basic premise of an inference; that they lack directly observable evidence. In the above-referenced studies, the majority of the participants demonstrated informed conceptions of observations and inferences at the conclusion of the instruction. The post-intervention data from this study, however, showed almost no change whatsoever. The only change that occurred among the eleven participants of this research was one participant whose conception was classified as transitional/naïve moved to a classification of transitional, and one participant whose conception was classified as transitional moved to transitional/informed. The overall change for observations and inferences was 18% improved. Such a small degree of change detected in the post data supports the notion that the workshop interventions had no appreciable effect on the participants' ideas about observations and inferences. With such little change among the participants' understanding of observations and inferences, no effect in their classroom practices is expected related to this tenet.

Theories and Laws

The working description of the theories and laws put forth in this research was described as:

> Individuals often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. However, theories and laws are

> different kinds of knowledge and one can not develop or be transformed into the other. Laws are statements or descriptions of the relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena.

Theories and laws are defining characteristics of science and these explanatory and descriptive statements are the basis for scientific hypotheses and inferences. Despite the critically important roles that these knowledge statements play in scientific endeavors, very few science teachers have a sophisticated understanding of them and many demonstrate naïve conceptions of the relationships between them (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Bloom & Weinburgh, 2007). The common misconceptions were found in the pre-intervention data. All eleven participants (100%) conveyed the notion that theories are tentative while laws are permanent. Eight of the participants (72%) believed a hierarchical relationship exists whereby a hypothesis becomes a theory after being "proved" and with enough evidence, the theory becomes a law. All participants' conceptions of theories and laws were classified as either transitional/naïve (9%) or naïve (91%). After the workshop, much improvement was detected. Three of the participants (27%) demonstrated that their naïve views of theories and laws had persisted throughout the workshop interventions, but the other eight participants (72%) demonstrated positive movement towards a more informed conception. Only one participant (9%) conveyed a view of theories and laws that was classified as informed, but seven who had been classified as naïve had moved into the transitional/naïve (27%), transitional (36%), or transitional/informed (9%) categories.

The overall change for theories and laws was 64% improvement. These data support the notion that the workshop interventions affected appreciable change among most of the participants, but that more work remains to be done in order for them to develop informed views.

Summary

This research has followed in the direction of many contemporaries in the field of nature of science and hopefully will help inform future research. The findings of this study support claims made about teachers understanding of NOS and the effectiveness of professional development on teachers' conceptions of NOS. First, the research demonstrates that inservice science teachers can possess inadequate conceptions of the philosophical tenets that characterize science and differentiate it from other "ways of knowing" which is consistent with prior findings (Anderson, 1950; Barufaldi, Bethel & Lamb, 1977; Behnke, 1950; Billeh & Hasan, 1975; Bloom, Sawey, Holden & Weinburgh, 2007; Bloom & Weinburgh, 2007; Carey & Strauss, 1968; Gruber, 1963; Klopfer & Cooley, 1963; Miller, 1963; Riley, 1979; Scharmann & Harris, 1992; Schmidt, 1967; Trembath, 1972; Welch & Walberg, 1967-1968).

Second, these findings clearly demonstrate that positive improvement can be detected in teachers' conceptions of NOS following explicit classroom instruction, also consistent with prior research (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson, Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Akindehin, 1988; Billeh & Hasan, 1975; Bloom, Sawey, Holden & Weinburgh, 2007; Bloom & Weinburgh, 2007).

Third, this research corroborates the findings of similar studies that describe substantial improvement in understanding of some tenets of NOS and less substantial gains in others (Akerson, Abd-El-Khalick and Lederman, 2000; Akerson & Hanuscin, 2007; Bloom, Sawey, Holden & Weinburgh, 2007). This study identified substantial gains in the teachers' understandings of some tenets (tentative, empirical, creative, and theories and laws) and less improvement of their understanding of others (observations and inferences, subjective, and social/cultural).

This study extends the current research by providing a more detailed analysis of teachers' conceptions of NOS tenets. Because the data collected in this study were qualitative in nature, the strategy used to analyze them had to incorporate a qualitative approach. Although it could be argued that the question being asked by this research was far from qualitative in nature, the modification of qualitative methods to work with these data allowed for a richer and more authentic understanding of the teachers conceptual understanding of concepts which have proved difficult to measure quantitatively (Lederman, Wade & Bell, 1998). While many contemporary researchers in NOS are addressing the problems faced by quantitative instruments used in the past to assess teachers' understandings of NOS when using instruments such as the VNOS, many studies have classified the teachers' knowledge into broad categories of adequate (informed) or insufficient (naïve) (Abd-El-Khalick & Akerson, 2007; Akerson, Abd-El-Khalick & Lederman, 2000). These classifications could be interpreted in a variety of ways with a respondent being classified as adequate by some while others would characterize them as less than adequate. The importance of addressing this subjectivity becomes apparent when recognizing the risk of making errors not unlike the alpha or beta errors referenced in traditional experimental designs (to borrow from my biology roots). An alpha error (false positive) would be detecting and reporting an appreciable change when it has not actually occurred. If fewer categories were used such as in the dichotomous schema of adequate versus inadequate, the changes could have been overrepresented when some degree of positive change occurred and a participant's previously inadequate views were reclassified as adequate. While the improvement may have been documented, there could still be room to improve further for the understanding to truly be classified as informed. In this case, the intervention effort (instruction) could be deemed more effective than it actually was. Conversely, a beta error (or false negative) could also occur if the same dichotomous classification scheme was used. In this case, the changes that occur could be underrepresented by a more conservative researcher who deemed them "insufficient" to justify the move from inadequate to adequate and possible improvement in understanding as well as the effectiveness of the intervention may have been missed.

Not to besmirch the highly-regarded predecessors within this line of research, it should be noted that they, too, realize the inherent *loss of fine focus* when broad categories are used. Indeed, several researchers within that community and other researchers following in their direction are working to develop categorization schemes that separate the respondents' views into more narrow categories (Koehler, 2008; Schwartz & Lederman, 2002).

Along this very line, this research attempts to address the issue by *increasing the focus* on the participants' understandings. Using methodologies borrowed from the field of qualitative inquiry, the data were unitized by tenet and subject profiles were created.

The data units were then coded to represent what idea about the tenet was being conveyed. Detailed analysis of the 22 VNOS responses and 22 interview transcriptions resulted in data units which were categorized into 65 separate codes representing informed, transitional, and naïve views of the seven tenets being studied. This detailed description of the data informs the research of the wide variety of informed, transitional, and naïve conceptions teachers may hold regarding these seven tenets of NOS. By dissecting the data in this detailed fashion, each participant's conceptions could be more genuinely classified into one of the five categories which ranged from informed to naïve.

By creating five categories in which to place each participant's conception of each individual tenet, more subtle nuances could be accounted for when determining categorization. By *increasing the focus* in this way, these nuances that were observed could be taken into consideration when looking for change over time and the subtle changes that occurred could be described as improvement, even when the participant never achieved an understanding classified as informed. Furthermore, this richer description of the numerous ways an individual might demonstrate informed or naïve views of any particular tenet may prove useful when attempts are made to create a quantitative instrument for use in assessing understanding of NOS.

Conclusions

Based upon the findings of this research, it appears that the professional development affected change among the participants' views of nature of science. There were varying amounts of change among the participants, but some overarching trends seem to exist among them. It appears that substantial gains were observed in participants' understandings of four of the tenets of nature of science. Of the participants with less than informed views of the tentative nature of science, 55% improved. For empirical, there was a 70% improvement. For creative, there was 89% improvement. Finally, for theories and laws, 72% of those who began with less than informed views showed positive change in their understanding.

By contrast, less significant gains were detected among the other three tenets being researched. Among participants who began with less than informed views of the subjective nature of science, there was only a 20% improvement in their understanding. In relation to the socially and culturally embedded nature of science, only 11% of those beginning with less than informed views appeared to have positive change in their understanding. Finally, those participants beginning with less than informed understanding of observations and inferences, only 18% demonstrated improvement.

It should be noted that while improvement was detected among many participants across many tenets of NOS, the improvements observed do not translate into informed views. Rather, they demonstrate movement in a direction towards an informed view. At the conclusion of the workshop, informed views were not prevalent for any of the tenets of NOS being investigated. Informed views were detected among eight of the participants, but none developed informed views of all tenets that were taught. Hannah ended the workshop with informed views of five tenets. Four participants (Dana, Flora, Irene, and Keren) ended with informed views of only two tenets. Finally, three participants (Angela, Christina, and Jeri) finished the professional development with informed views of only one tenet. This demonstrates that while improvement was detected, more work is left to be done to accomplish the goals of the instruction.

The implications of these findings inform the research on the effectiveness of this professional development on improving these seven tenets of NOS. When planning future professional developments, it appears that more emphasis needs to be placed on improving teachers' understanding of the tenets: subjective, social/cultural, and observations/inferences. Without further research, it cannot be determined which intervention activities were most effective, but if further research reveals this information, time allocation can be redistributed to accommodate more emphasis on those tenets which are less easily taught and less emphasis placed on those tenets which show more improvements. This would allow for more thoughtful planning on how best to use the time of our teacher participants who attend these professional developments.

Limitations of the Research

Interrater reliability and subjectivity of the analysis

The literature states that VNOS interrater reliability has been well-established within research communities (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002), however, the research does not support the notion that cross-community reliability exists. Problems which are faced in gaining interrater reliability are apparent when one examines how it was achieved. Lederman describes the establishment of VNOS validity as;

> Whereas face and content validity of the various versions of the instrument have been determined repeatedly, its principle source of validity evidence stems from the follow-up interviews. (p. 517)

In other words, the validity of the VNOS instrument is supported primarily by the reported consistency between the subjective interpretation of the VNOS and the subjective interpretation of the interviews by the same researcher (which stem from the

VNOS responses). If one truthfully acknowledges the subjectivity inherent in interpreting qualitative data such as this, it is no surprise that an individual grader would find consistency between his interpretation of the VNOS response and the interview which was generated based on those responses. The subjectivity of those analyzing the data cannot be ignored. Even when there are multiple scores within a research community, discrepancies emerge and Lederman advises researchers to address them as follows;

> When several researchers are involved in analyzing VNOS responses, it is crucial to establish interrater reliability. Such agreement could be established by having all researchers independently analyze the same subset of data and then compare their analyses. Discrepancies could be resolved by further consultation of the data (especially interview data) or consensus. (p. 517)

In other words, interrater reliability will be achieved once all members of the research community agree to classify statements as informed or naïve in a consistent manner. Within a single research community such interrater reliability could be established with enough consultation, but without universal agreement on what classifies a conception as adequate or inadequate, cross-community agreement would not be expected. Indeed, discrepancies have been identified in personal communication between myself and a member of the aforementioned community of researchers (Abd-El-Khalick, 2007). This research does not escape this same problem. To address the subjectivity among scorers, all data collected in this study were analyzed only by me. While the subjectivity is present, the lens through which statements were classified as informed, transitional, or naïve remained consistent throughout the analysis.

Subjectivity could arise in other ways as well. Throughout the two-week workshop, I developed relationships with the participants and grew to appreciate some more than others and developed personal opinions about how knowledgeable each was. Knowing that this could have a subconscious influence on how the data were scored, efforts were taken to make the data anonymous during analysis. Names were removed from all data generated and names were replaced with numerical codes. Although every effort was taken to keep the data anonymous during analysis, occasionally the data itself would reveal the participant's identity. In order to reduce this potential effect, the analysis proceeded in an orderly fashion. First all data was unitized according to tenets; anytime a data unit addressed a tenet it was high-lighted a color specific for that tenet. No coding occurred until all data were unitized. After unitization, coding began and the codes were assigned informed, transitional, or naïve classifications. By proceeding in this manner, even if the identity of a participant was revealed, the data unit was already identified and a code was assigned that was consistent with all other data units. In other words, if the personal opinion of the researcher was that a participant was well informed, a data unit that matched a naïve code would clearly be revealed (as it was previously high-lighted) and the researcher would have to incorporate that naïve view into the subject profile.

The last, and perhaps most suspected, way that subjectivity could influence the research is apparent when one considers that I was gauging the effectiveness of my own instruction on the learning of the participants. Some could assert that positive trends would be desired. Again, the only valid argument against this potential source of subjectivity is in the methodology adopted in the analysis. Until the final profiles were created (both pre and post) and they were compared, I did not know what, if any, change would present itself. Indeed, the findings of the research support that I accomplished some success in improving conceptions, failed at accomplishing appreciable change in others, and may even have caused negative change in some participants' understanding of some tenets. In other words, the results do not present my instructional ability in the most appealing way.

What explains negative change (digression)?

While the observed negative changes (digressions) that were detected in the data help support the notion that researcher bias was not artificially creating improvement, it also indicates that participant-conceptions could have been classified as more informed than they actually were. When this occurred, one of two things could have happened. One way this could have occurred would be if the pre-intervention ranking was erroneously classified as more informed than it actually was, and thus, when analyzing the post-intervention data, the more authentic less informed view was identified. The other way this negative change could be detected would be if through the course of the professional development, the participants understanding of a particular tenet actually became less informed. This negative effect of the workshop could be explained in two ways; either the interventions themselves fostered misconceptions or the participants were experiencing cognitive disequilibrium in relation to their understanding of a tenet and until they transcended that disequilibrium and solidified their more informed view, their answers appear less informed. Further research into this phenomenon could, perhaps, answer this question and shed more light on this kind of change.

Were the changes significant?

To anyone accustomed to reading quantitative research, the paucity of statistical data would be quite apparent. While the intention of the research was to gauge the effectiveness of a workshop on teachers' conception of NOS, there is difficulty in identifying statistical significance in the change observed. The problems can be attributed to the limitations sections above. Without having trustworthy interrater reliability with both the assessment instrument and in the classification strategy used by the researcher, statistical significance values would be suspect. Because of this, the methodology has been explained and the findings presented leaving the evaluation of these findings to the reader. Until a validated instrument with trustworthy interrater reliability is developed for measuring understanding of NOS or until successful arguments are made which allow for statistical analysis of data results which are subjectively derived without said interrater reliability, no statistical significance can be assigned to the changes observed in these data that this researcher believes to be "of significance".

Can the findings be generalized to other teacher populations?

Another limitation of this research stems from the wide range of academic backgrounds of the participants in this workshop. Although it has been reported that academic variables such as grade-point average, specific courses, number of math credits, or years of teaching are not significantly related to teachers' conceptions of science" (Carey & Strauss, 1970), more research along this line could support or cause doubt in these findings. Within the participants of this study, there was a range of experience from first-year teachers to veteran teachers with 20 or more year experience in the classroom. Furthermore, the teachers were teaching a range of age levels from kindergarten to high school seniors and teaching subjects from general science to integrated physics and chemistry. Their academic background varied tremendously as well with some holding Masters degrees in biology or related subjects while others had taken few college level science courses. The amount of change (or lack thereof) observed among the participants could be attributed to some or all of these variables, but without statistical analysis, the significance of potential correlations between NOS gains and these variables could not be presented. Were these data able to be manipulated this way, it could be suggested that the interventions worked well with certain demographics and less well with others; in other words could be somewhat generalizable. Without this analysis, generalizability cannot be suggested.

Are improvements lasting?

The last limitation of this research listed in this section involves the length of the workshop. The entire professional development workshop only lasted for two weeks. The design of the research was constrained by the requirements of the agency funding the professional development as well as by the time constraints of the teacher-participants and those conducting the workshop. The initial VNOS survey was administered several weeks prior to the beginning of the workshop and the pre-intervention interviews were conducted in the week before the instruction began. The post-VNOS was administered on the last day of instruction and the post-interviews were conducted by phone during the two weeks after the workshop. Because of this there was only approximately 4-5 weeks between the pre-assessment of their understanding and the post-assessment. Because of the short time frame between the explicit interventions and the post-assessment, the participants' recent experiences could have played a role in the observed improvement that might not have been seen had more time been given between interventions and post-assessment. It could be that short-term memory influenced post-assessment rankings so that they appeared to have improved, but the apparent improvements may not have been retained long-term. Whether a short-term effect was responsible for their improved understandings is currently being studied as we observe the teachers in their classroom settings and listen for informed or naïve views that match or do not match their post-intervention assessment scores. As this less direct measurement requires much time and coordination with teacher schedules, it was outside the limits of what was manageable for this study and this one researcher.

Extending This Research

This research builds the foundation for many future studies. Many questions have been generated by this research and some questions are already being addressed. Among these questions are:

1. Do the gains observed in NOS understanding persist over time?
2. Does the increased understanding of NOS observed in some participants translate into more authentic teaching of science?
3. Do academic variables such as years in teaching, degrees held, college science courses taken, among others, influence how effective professional development is in fostering improved views of NOS?

4. What relationships, if any, exist between the improvements of the seven tenets of NOS studied?
5. Can trustworthy interrater reliability be achieved when working with subjectively “graded” qualitative data such as these?
6. Can statistical analysis be thoughtfully planned to accommodate problems with (or indeed, lack of) interrater reliability so that significance values can be placed on the amount of changes observed?

Appendix A. VNOS-D

Name ____   **Date –**

VNOS-D – TQG Professional Development Training – Summer 2007

Instructions

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.

- Some questions have more than one part. Please make sure you write answers for each part.

- This is not a test and will not be graded. There are no "right" or "wrong" answers to the following questions. I am only interested in your ideas relating to the following questions.

1. What is science?

2. How is science different from other subjects you have studied?

3. Scientists produce scientific knowledge. Some of this knowledge is found in science books. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. a. How do scientists know that dinosaurs really existed?

   b. How certain are scientists about the way dinosaurs looked?

   c. Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

a. Do you think weather persons are certain (sure) about these weather patterns?

b. Why or why not?

6. What do you think a scientific model is?

7. Scientists try to find answers to their questions by doing investigations/experiments. Do you think that scientists use their imagination and creativity when they do these investigations/experiments?

Circle one → YES NO

a. If **NO**, explain why?

b. If **YES**, in what part(s) of their investigation (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

Appendix B. Codes Identified in the Data

<u>Tentative Informed</u>

Code = Old “incorrect” knowledge isn’t bad, but the best they had to work with

Code = New knowledge is added AND old knowledge is corrected with new technology and data collected

Code = Knowledge becomes less tentative with accumulation of more data

Code = Scientific knowledge isn’t 100% sure, but that’s o.k.

Code = Scientific knowledge is subject to change

Code = Won’t Use Proof Anymore

<u>Tentative Transitional</u>

Code = Clarifies use of word “proof”

Code = “May” correct old knowledge

Code = Knowledge will change with new technology, but doesn’t explain how or why

<u>Tentative Naïve</u>

Code = Overly tentative in context of weather

Code = Overly confident with physical models

Code = Some knowledge is absolute

Code = Proof (unclarified)

Code = Only change in science textbooks is how it is presented

Code = Terminology, Classification, etc. changes Code = Scientific knowledge is just so complex it will have to change Code = New scientific knowledge will be added
<u>Empirical Informed</u> Code = Must have some basis in empirical evidence Code = Some scientific knowledge lacks “hard data” but is based on empirical evidence Code = Natural science doesn’t study supernatural; needs some empirical <u>Empirical Transitional</u> Code = Lacks confidence in answer Code = Some current scientific knowledge once lacked empirical evidence (pre-science?) Code = Leans toward needing empirical evidence, but lacks conviction Code = While stating no empirical evidence is needed, references empirical evidence Code = Science uses empirical evidence, but doesn’t explain how <u>Empirical Naïve</u> Code = MUST have empirical (no inferencing) Code = Some scientific knowledge you just have to believe (without empirical) Code = Hypotheses require no empirical evidence Code = No empirical evidence is needed Code = Can’t identify what is empirical evidence

Code = Empirical means it’s absolutely right Code = Unsure of need for empirical evidence
Subjective Informed Code = Educational background can influence interpretation Code = Theory laden (using theories to interpret data) Code = Subjectivity can fuel discovery Subjective Transitional Code = Personal opinions cause subjectivity Code = Different backgrounds cause subjectivity Code = Incorporates new knowledge into old knowledge (but not quite to theory laden) Code = Subjectivity isn’t ‘BAD’ but we need to be aware of it Subjective Naïve Code = Subjectivity is “just a human thing” Code = Subjectivity is bad for science Code = Doesn’t seem to understand “subjective Code = Conflates subjective with tentative Code = Conflates Subjectivity with interest, creativity, inference Code = Science is Objective

Creative Informed

Code = Scientists create new knowledge

Code = Creativity to explain occurrences

Creative Transitional

Code = May be creative in conclusions/analyzing (but can’t articulate how)

Code = Creative in all aspects of science (but can’t articulate how)

Code = Maybe creative in developing new theory

Code = Creativity fuels discovery (but can’t articulate how)

Code = Creativity means open to new ideas

Code = Creativity in context of medicine (but not general science)

Code = Inner nudge/intuition

Code = Conflates creativity and subjectivity but realizes it’s import

Code = Creativity is in learning new stuff (no reference to creating it)

Code = Creative in finding solutions

Creative Naïve

Code = Creativity only in set-up

Code = Creativity in developing new questions

Code = Creativity equals Curiosity

Code = Science is very logical

Code = Creativity NOT in analysis Code = Creativity opposes empirical evidence
<u>Socially and Culturally Embedded Informed</u> Code = Social and cultural values direct science <u>Socially and Culturally Embedded Transitional</u> Code = Social and cultural values can limit science Code = Social and cultural values can have some effect (but can’t articulate) Code = Conflates personal interest with social and cultural values <u>Socially and Culturally Embedded Naïve</u> Code = Conflates social and cultural with subjective and conditional Code = Some cultures have better scientists Code = Culture of science rewards good scientists and punishes bad scientists Code = Social and cultural values SHOULDN’T influence science
<u>Observations and Inferences Informed</u> Code = Using current knowledge and theory to make inferences (predict) Code = Using current knowledge and theory to make inferences (retrodict) Code = Confidence in inferences increases with more data Code = Use current knowledge to make inferences Code = Describes observations and inferences

Observations and Inferences Transitional Code = Lacks confidence in inferences; needs hard data Code = Describes use of past/present evidence, but doesn't explain Code = More confident in context of weather Code = Less confident in context of weather Code = Describes use of theory but lacks confidence Code = Mediocre description of observations and inferences Observations and Inferences Naïve Code = Science is organization of knowledge (no reference to inferences) Code = Confidence in new technology (but can't justify why) Code = MUST be testable to be science (naïve on theories/inferences) Code = Can't describe observations and inferences Code = MUST have hard data or it's just speculation Code = No idea how inferences are made
Theories and Laws Informed Code = Theories are explanatory Code = Laws are descriptive Theories and Laws Transitional Code = Describes theories and laws o.k., but lacks confidence

Code = Recognizes Theories and Laws are different

Code = Will “try” to use the new definitions

Code = Lacks confidence in new understanding

Code = Described theory as “how” and Law as “what” but still held the hierarchical view

<u>Theories and Laws Naïve</u>

Code = “just a theory”

Code = Conflates hypothesis, theory, and law

Code = Theory is tentative; Law is not

Code = Hierarchical View

Code = Use laws to make theories

Code = Conflates theory and law

Code = Unsure on hypothesis, theory and law

Code = Describes theories and laws poorly

Appendix C. Data Summary Sheet (All Participants Pre- to Post-)

Participant	Tentative Pre	Tentative Post	Empirical Pre	Empirical Post	Subjective Pre	Subjective Post	Creative Pre	Creative Post	Soc. & Cult. Pre	Soc. & Cult. Post	Obs. & Inf. Pre	Obs. & Inf. Post	Theory & Law Pre	Theory & Law Post
Angela	5	5	3	4	2	2	1	3	3	3	4	4	1	3
Brenda	4	4	3	3	5	4	2	3	3	3	4	4	1	2
Christina	4	5	1	1	1	2	1	3	1	1	2	3	1	1
Dana	4	4	3	5	2	2	2	5	3	3	4	4	2	2
Elise	3	4	2	3	3	4	2	3	2	2	4	4	1	3
Flora	1	5	3	5	2	2	1	3	4	4	4	4	1	4
Gina	4	3	1	1	1	1	2	2	1	1	3	3	1	2
Hannah	4	5	1	5	5	5	5	5	5	5	4	4	1	3
Irene	2	4	3	4	1	1	5	5	5	5	3	3	1	3
Jeri	4	4	5	5	2	2	1	3	3	3	3	3	1	1
Keren	5	5	4	5	3	3	3	4	1	4	3	4	1	1

Totals	Tentative Pre	Tentative Post	Empirical Pre	Empirical Post	Subjective Pre	Subjective Post	Creative Pre	Creative Post	Soc. & Cult. Pre	Soc. & Cult. Post	Obs. & Inf. Pre	Obs. & Inf. Post	Theory & Law Pre	Theory & Law Post
Informed	2	5	1	5	2	1	2	3	2	2	0	0	0	0
Tran/Inf	6	5	1	2	0	2	0	1	1	2	6	7	0	1
Transitional	1	1	5	2	2	1	1	6	4	4	4	4	0	4
Trans/Naiv	1	0	1	0	4	5	4	1	1	1	1	0	2	3
Naive	1	0	3	2	3	2	4	0	3	2	0	0	10	3

Appendix D. Supplemental VNOS-D Interview Questions

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

1. To what degree do you believe that scientific knowledge is tentative? _______

Please explain your answer.

Please explain your answer.

****

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

2. To what degree do you believe that scientific knowledge must be, at least partly, based upon empirical (observable/measurable) evidence? ________

Please explain your answer

Please explain your answer.

****

3. What is a scientific law? Can you give an example?

****

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

4. To what degree do you believe that scientific knowledge is subjective? _______

Please explain your answer

Please explain your answer.

****

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

5. To what degree do you believe that scientific knowledge is objective? _______

Please explain your answer

Please explain your answer.

****

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

6. To what degree do you believe that social and cultural values influence the advancement of science and/or the processes of science? _______

Please explain your answer.

****

7. What is a scientific hypothesis? Can you give an example?

****

For the following question, please answer with a value from 1 to 10 with 1 indicating very little agreement and 10 indicating very much agreement.

8. To what degree do you believe creativity plays a role in the process of science? ____

Please explain your answer

Please explain your answer

****

9. Please describe the role of observations and inferences in the advancement of scientific knowledge.

****

10.   What is a scientific theory? Can you give an example?

****

11. We have discussed scientific laws, hypotheses, and theories. Are there any relationships between scientific laws, hypotheses, and theories?

If so, explain.

CHECKS LAB

Record the data and then make an inference.

	Data	Inference (story)
First set of checks		
Second set of checks		
Third set of checks		

Appendix F. Paired Statements Activity

PAIRED STATEMENTS ACTIVITY

Directions

1. With your partner(s), read each pair of statements below.

2. For each pair of statements, identify one statement that is MORE reflective of science and one that is LESS reflective of science.

3. Justification: Explain how you made your decision **for each pair**. What is/are the main characteristic(s)/criteria that distinguish(es) the two members of each pair?

1.A. If you break a mirror, you will have seven years of bad luck.

1.B. If hair color is inherited, then identical twins should have the same hair color.

2.A. Humans have a soul.

2.B. The rate of acceleration of all falling objects on earth is constant.

3.A. The rate of acceleration of an object due to the influence of the earth's gravity is 9.8 meters per second per second.

3.B. If you dream of tea, someone will die. This actually happened to me once.

4.A. Scientists in the 18th century believed that acquired traits (like musical performance ability) were inherited. Research data later showed this to be largely false.

4.B. Some people believe that the earth is flat because it looks flat to them. They are not willing to consider other data such as pictures of the earth taken from space.

5.A. If HIV causes AIDS, then every person with AIDS should have the virus in their body.

5.B. Humans today are the reincarnations of people in the past.

6.A. Astrology is the prediction of the future from the stars. Astrology has not led to new hypotheses and other areas of study.

6.B. Genetics is a fertile new science that has led to many new hypotheses and new area of study.

7.A. Some people believe that placing magnets on parts of the body that hurt will cure the problem. They are unwilling to consider the possibility that they could be wrong.

7.B. Experiments in psychology are often replicated because psychologists recognize that the conclusions of earlier experiments could be wrong.

8.A. In 1989, researchers reported that they had been able to perform cold fusion – a process widely thought by others to be impossible. Many people did not believe the researchers until they saw the data themselves.

8.B. A parapsychologist “reads the mind” of another person. The audience is awed by the parapsychologist’s skill.

9.A. If the Koran says it is so, it is so.

9.B. Many scientists do not believe that Vitamin C will prevent the common cold even though Linus Pauling, the Nobel laureate who discovered the structure of Vitamin C, claimed it will.

10.A. I believe that God loves me.

10.B. The average IQ in the freshman class is over 100.

Appendix G. NOS Checklist

NOS CHECKLIST

- Please make a brief description of where you see the characteristics listed in the table below. You may fill in other characteristics you observe (that are not listed) in the blank rows on the back.

Characteristic Observed	Description
Creative/Imaginative	
Distinguishes Laws from Theories	
Distinguishes Observation from Inference	
Empirical (Evidence-based)	

Self-Correcting (repeatability, peer review)	
Subjective	
Social and Cultural (guides research & sets paradigms)	
Tentative (Dynamic, Changing)	
Other Aspects	

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ABSTRACT

THE EFFECT OF A PROFESSIONAL DEVELOPMENT INTERVENTION ON INSERVICE SCIENCE TEACHERS' CONCEPTIONS OF NATURE OF SCIENCE

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This research focuses on inservice science teachers conceptions of nature of science (NOS) before and after a two-week intensive summer professional development program that included explicit NOS instruction. It combines this explicit approach to NOS instruction with reflective, dialogue about the interventions used throughout the professional development. It addresses the seven commonly-held tenets of NOS that are deemed significant to K-12 science teachers. Finally, it borrows qualitative methodologies for analyzing the Views of Nature of Science Questionnaire and associated interviews to gain a richer understanding of the teachers' NOS understanding before and after the interventions. By using this approach to data analysis, this research better describes the ways in which teachers' conceptions of NOS aspects align with and/or deviate from the desired understanding put forth in the professional development. This description of their understanding avoids reducing the participants' diverse and complex conceptions of these tenets into simple "informed" or "naïve" categories. It is through this more detailed analysis of the participants' data that this research examines inservice science teachers' conceptions' of nature of science before and after engaging in an explicit, long-term, professional development intervention.