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RESEARCH REPORT

What Scientists Say: Scientists' views of nature of science and relation to science context

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The purpose of this study is to examine practicing scientists' views of nature of science (NOS) and explore possible relationships between these views and science context. Science educators emphasize teaching NOS through inquiry-based learning experiences throughout science disciplines. Yet aspects of NOS that are agreed upon as relevant to science education have been described in discipline-independent ways. Given the situated nature of learning, we sought to examine how scientists understand recommended aspects of NOS and whether these views vary depending on the science discipline or investigative context of authentic practice. Participants were 24 scientists, representing four broad science disciplines (chemistry, life science, physics, earth/space science) and a variety of approaches (experimental, descriptive, theoretical). Data included questionnaires and interviews. Through intra-group and cross-group comparisons, we examine associations between NOS views, scientific disciplines, and methods of scientific inquiry. Results indicate NOS views are not necessarily related to science context. There appears to be as much variation within groups as across groups. Differences in views seem to be embedded within individual contexts and experiences rather than broader science disciplines. Results support the applicability of advocated NOS aspects across science contexts, and do not support a need to teach different natures of science in the K–12 science arena. We discuss the implications for NOS pedagogy in a variety of contexts.

Introduction

In efforts to promote scientific literacy, science educators and education policy-makers and decision-makers advocate the teaching of science as a human endeavor. This endeavor produces durable (empirically based and internally consistent) yet provisional (tentative) knowledge of the natural world (see, e.g., Duschl, 1990;

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Hodson, 1988). To promote epistemological views of science (nature of science [NOS] and nature of scientific inquiry), reforms recommend scientific inquiry experiences as a context for learning (American Association for the Advancement of Science, 1993; National Research Council 1996, 2000). This approach draws appeal from a situative perspective of learning and knowing (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991).

> Inquiry is a critical component of a science program at all grade levels and in every domain of science, and designers of curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students then will learn science in a way that reflects how science actually works. (National Research Council, 1996, p. 214)

To what extent, however, might variance within scientific contexts influence resultant epistemological views? This study begins to examine "what scientists say." This report is part of a more comprehensive study of scientists' epistemological views of science and their relation to context of scientific practice (Schwartz, 2004). The current paper reports scientists' views of NOS.

Nature of Science

A precise description of NOS is often debated among philosophers of science, historians of science, and science educators (Alters, 1997; Loving, 1997; Matthews, 1994). However, institutions of reform (American Association for the Advancement of Science, 1993; National Research Council, 1996), as well as science education efforts outside the United States (see, e.g., Hodson, 1998; Matthews, 1998; Millar & Osborne, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Ryan & Aikenhead, 1992) present descriptions of NOS that include common generalities and pose little disagreement according to current philosophical perspectives. Chief among these is that scientific knowledge is subject to change. Reasons for the inherent tentativeness of scientific knowledge stems from several other aspects, including: (a) scientific knowledge has basis in *empirical evidence*; (b) collection and interpretation of empirical evidence is influenced by current scientific perspectives (*theory-laden* observations and interpretations) as well as *personal subjectivity* due to scientists' values, knowledge, and prior experiences; (c) scientific knowledge is the product of human *imagination and creativity*; and (d) the direction and products of scientific investigations are influenced by the society and culture in which the science is conducted (*sociocultural embeddedness*). These aspects also reinforce the durability of scientific knowledge. The empirical nature of science, while this aspect underlies the tentativeness of science, also negates an "anything goes" perspective. Scientific knowledge is founded in data that are subject to interpretation (necessarily a theory-laden and socially influenced negotiation) and accepted within the community based on consistency and strength of argument. It cannot be overlooked that there is variability in the strength of the empirical foundation and argument upon which scientific knowledge is based. The knowledge is tentative, yes, yet nonetheless durable because of these other features. We distinguish features more closely related to negotiating meaning from data and justification criteria, as pertaining to the nature of scientific inquiry. These features are explored in the full study (Schwartz, 2004). The intention here is to present our framework and findings related to views of accepted features of the nature of scientific knowledge (NOS).

Distinctions among Science Disciplines

Science disciplines are often compartmentalized based on topics of study such as physics, life science, earth and space science, and chemistry. However, science disciplines differ by more than classification of subject matter. Bechtel (1986) describes three dimensions that define science disciplines: (1) the objects studied, (2) the cognitive activities involved, and (3) the social and institutional organization. Studies of authentic science practices and reasoning provide descriptions of cognitive activities, inquiry methods, and social and institutional organizations of scientific communities, suggesting diversity among disciplines that extend beyond subject matter (e.g., Dunbar, 2001; Knorr-Cetina, 1999; Latour, 1987).

Philosophers of science and scientists recognize distinctions in the nature of science disciplines (e.g., Mayr, 1988, 1997; Ruse, 1998; Spieker, 1972). Discussions explore degrees of tentativeness based on differences in inference and abstractness, such as that between geology and chemistry or physics (Van Bemmelen, 1961), with the former being regarded as more inferential due to the nature of the evidence and limitations of experimentation. Spieker compared specialized areas under the domain of natural science based on number of variables. He arranged fields of natural science in the order: physics–chemistry–geology–botany–zoology, to indicate increasing number of variables, decreasing power of mathematics, and a transition from concentrative fields (physics and chemistry) to more distributive fields. The concentrative fields of physics and chemistry, Spieker argues, have been able to "derive fundamental and universal laws from relatively small and concentrated bodies of data, or so to support generalizations reached through deductive reasoning, this is rarely possible in geology and biology" (1972, p. 75). He states that geology and biology typically require large and diverse amounts of data in order to make generalizations. Mayr (1988, 1997) also distinguishes laws in the physical sciences versus biological science. "The so-called laws of biology are not the universal laws of classical physics but are simply high-level generalizations" (Mayr, 1988, p. 19).

Mayr (1988) described biology as two types of study, distinguished by the type of causation addressed. One line is functional biology and addresses questions of proximate causation. The second is evolutionary biology and addresses questions of ultimate causation.

> The functional biologist is vitally concerned with the operation and interaction of structural elements, from molecules up to organs and whole individuals. His ever-repeated question is "How?" … The evolutionary biologist differs in his method and in the problems in which he is interested. His basic question is "Why?" (Mayr, 1988, p. 25)

Moreover, Mayr sees the questions and methods of the evolutionary biologists as distinct from those encountered in other disciplines of science. "There is nothing in the physical sciences that corresponds to the biology of ultimate causations" (Mayr, 1988, p. 17).

Our purpose is not to delve into a philosophical debate about *the* nature or natures of science or of science disciplines that extend beyond what is advocated for K–12 or even K–16 education. The purpose of these few examples is to acknowledge an awareness of diversity in content, methods, and institutional structures of scientific endeavors that lead to the development of the subject matter included in K–12 science education.

Despite the variance among and within the sciences, recommendations for what a scientifically literate individual should understand about NOS and be able to do and understand about scientific inquiry are typically generalized in a discipline-independent manner (American Association for the Advancement of Science, 1993; Abd-El-Khalick, Bell, & Lederman, 1998; Chinn & Malhotra, 2002; Elby & Hammer, 2001; National Research Council, 1996, 2000; Smith & Scharmann, 1999). That is, the science education literature describes aspects of NOS in a manner specific to the domain of science, but not specific for particular disciplines *within* science. The agreed-upon tenets are assumed applicable across science fields, yet how learners within different contexts understand those tenets may vary. If the disciplines are different, perhaps understandings of NOS, as learned within the disciplines, are also different (Ryder, Leach, & Driver, 1999).

Given the emphasis on relating NOS and scientific inquiry through investigative learning experiences throughout science disciplines, and considering the framework of the situated nature of learning, there is a need to explore potential contextual connections of epistemological views of science within and across science disciplines. The current state of NOS research, with the efficiency and depth of methods, allows us to address questions concerning contextual associations of epistemological views. The present study explored epistemological views of scientists from four science disciplines—life science (LS), earth science (ES), physics (Ph), and chemistry (Ch)—and who employ various approaches to research (e.g., experimental, descriptive, theoretical).

Research Questions

Two primary research questions guided the larger investigation:

1. What are practicing scientists' views of nature of science and scientific inquiry?
2. What are the relationships, if any, among practicing scientists' views of nature of science, views of scientific inquiry, approach to scientific inquiry, and the science discipline in which the scientist participates?

The present report describes results of scientists' views of NOS and potential relationships based on science discipline and research approach. A separate report (manuscript in preparation) examines results related to views of scientific inquiry.

Method

The design is based partly on a phenomological perspective of qualitative research (Bogden & Biklen, 1992; Creswell, 1998), in that perspectives of scientists were sought through open-ended questionnaire and interviews. The aforementioned aspects of NOS served to frame questionnaire and interview items and the initial analysis. Scientists are experts in specific subject matter of their discipline as well as experts in specific skills of scientific inquiry. Science education aims to promote achievement in science subject matter, skills of scientific inquiry, knowledge about scientific inquiry, and knowledge of NOS. Prior studies have suggested impacts of limited subject matter knowledge and inquiry skills, including: (1) the inability to articulate views of NOS due to limited science content knowledge (Abd-El-Khalick, 2001); (2) confusion with NOS and inquiry concepts due to being overwhelmed by an authentic science environment (Schwartz, Lederman, & Crawford, 2004); and (3) limited response due to anxiety or negative attitude toward science (Schwartz, Lederman, & Thompson, 2001). Our focus on experienced scientists enables a descriptive study relating authentic methods of inquiry and corresponding views of NOS while minimizing variance in content expertise or scientific inquiry skills.

The sample was 24 practicing scientists (six female, 18 male) from across the United States and representing four primary science disciplines and a variety of subdisciplines. Table 1 presents individual scientists by discipline and research area. Table 2 summarizes the sample demographic data and discipline groups with respect to number of years since receiving their doctoral degree in science, gender, research approach, and research location.

The selection criteria stem from expert/novice literature and situated cognition literature related to communities of practice (Chi, Glaser, & Rees, 1982; Wenger, 1998). Four selection criteria provided evidence of expertise in science and scientific community membership: (1) earned doctoral degree in science; (2) currently conducting scientific research in an area that can be classified into a broad discipline of physics, life science, chemistry, or earth and space science; and (3) at least two research-based publications in peer reviewed science journals based on current research area within the past 2 years. With an average of 25 years active research experience since earning their doctorate, the participants within this study were clearly experienced within their respective communities. With the exception of one participant (an aquatic ecologist with 22 years post-Ph.D. research experience, currently in a non-academic institution), all held tenured academic positions at universities. All were educated and currently employed within the United States. However, most had international post-doc, sabbatical, or collaboration experiences.

The four primary disciplines chosen for this study align with current content areas relevant to science standards. Classification of participants into a discipline area, research approach, and research location was based on the scientists' written and oral description of their primary research, educational background, and information on C.V. and websites. In addition, all participants were asked to identify themselves within a science discipline. Even though the participants are classified into a broad

Table 1. Scientists' research areas

Scientist	Discipline
	Life science
OEL1	Molecular biology
UEL1	Molecular biology
SEL1	Cell biology
NEFL1	Marine ecology
BEFL1	Forrest ecology
KEDF1	Plant systematics/evolutionary development
MEDF1	Community ecology
PEDF1	Aquatic ecology
SEDF1	Entomology
mDF1	Wildlife ecology
	Earth and space science
GDF2	Fluvial geomorphology
eDF2	Atmospheric science
cDFC2	Atmospheric science
hEDFC2	Astronomy
pEDFC2	Astronomy
	Chemistry
gEL3	Organic chemistry
fEF3	Environmental analytical chemistry
wEL3	Analytical chemistry
bEL3	Mass spectrometry
	Physics
kEL4	Nuclear physics
lTC4	Computational physics
jTC4	High-energy theoretical physics
sTC4	Theoretical planetary physics; astrophysics
pTC4	Relative astrophysics

discipline area, we do not claim to have a sample representative of all scientists within these disciplines. Results are specific to this sample.

Data Collection and Analysis

The VNOS-Sci and the VOSI-Sci are open-ended questionnaires that elicit views of NOS and nature of scientific inquiry (NOSI) (VNOS-Sci is included in the Appendix). The questionnaires were adapted from the instruments of Lederman, Abd-El-Khalick, Bell, & Schwartz (2002) and Schwartz et al. (2001), respectively. Modifications aimed to include the common aspects of NOS and NOSI as well as elicit views and supporting examples from *within the perspective* of the scientist's authentic context of practice. A panel of science educators and scientists examined the

Table 2. Summary of scientists grouped by discipline

Discipline	Total	Life sciences	Earth and space sciences	Chemistry	Physics
Number of participants	24	10	5	4	5
Average years post Ph.D.	25.2 (average) 26 (median) 7.2 (standard deviation)	21.7	28.4	21.3	32.2
Number of males	18	6	4	3	4
Number of females	6	4	1	1	0
Research approach					
Experimental (E)	10	5	0	4	1
Descriptive (O)	5	1	4	0	0
Combination (E/D)	5	4	1	0	0
Theoretical (T)	4	0	0	0	4
Research base					
Laboratory-based	8	4	0	3	1
Field-based	6	4	1	1	0
Laboratory/field	2	2	0	0	0
Field/computer	4	0	4	0	0
Computer/mathematics	4	0	0	0	4

questionnaires for face and content validity. Minor changes were made in wording based on feedback. The panel approved the final versions of the VNOS-Sci and VOSI-Sci. Further validation was established through participant interviews.

Fifty-six potential participants were contacted via email and telephone. Thirty-seven responded favorably; and 34 of these formally committed to participate. These participants were electronically sent the two questionnaires; and requested to provide a current vitae and research description. Twenty-four of the 34 initial volunteers completed the data collection process. Seventeen of the 24 participants returned both completed questionnaires. Two only returned one completed questionnaire (VNOS-Sci), with indications that they preferred to provide their responses to the VOSI-Sci during the interview. In the essence of time, the remaining five preferred to only give their responses through the interview. The most common reason provided for not participating or not completing all data collection was the time commitment.

Semi-structured interviews served to elicit additional information as well as validate scientists' interpretation and responses to questionnaire items (Lederman et al., 2002). Participants were asked to review the questionnaires in preparation for the interview, and all but one of the scientists did so. Twenty-three of the 24 participants were interviewed. Interviews were either in person or via telephone, depending on location of the participant. Information included education and professional history; description of current research projects, research group, and any collaborative efforts; and clarification and requested elaborations based on VNOS-Sci and VOSI-Sci responses. Interviews averaged 2 h each. All were audiotaped and transcribed for analysis.

Consistent with a phenomological tradition of research (Creswell, 1998), the research questions are not based upon *a priori* hypotheses that scientists of particular disciplinary and/or methodological fields will adhere to any predetermined views or differ in particular ways. Consistent with the reform-based framework of the study, data collection and analysis sought scientists' conceptions of the predetermined features of NOS and scientific inquiry deemed important and appropriate for a scientifically literate individual. As such, this framework guided the initial coding of data from questionnaires and interviews (Miles & Huberman, 1994). In addition to the predetermined aspects, responses were sought relative to scientists' ideas about "scientific models" and "experiments" (results not included here). Additional themes emerged and were refined through repeated rounds of analysis. After individual profiles were generated, discipline-based and approach-based comparisons of scientists' conceptions were conducted. Due to sample size, no statistical measures were employed. The results are descriptive.

Results

Presented here are results for scientists' views of NOS. We report results for the total sample and comparisons of NOS views when participants are grouped according to science discipline and research approach. The inclusion of the cross-approach comparison provides additional information to aid the overall exploration as well as offer insights into discipline-based trends. This was especially useful given the fact that four of the five physicists were theoretical researchers. As such, their views, and the views of all in the sample, may be reflective of their research approach as opposed to, or in association with, their discipline area. These results are discussed in terms of suggested patterns within this sample of scientists and should not be generalized beyond this sample.

Research Approaches

Scientists were grouped according to four research approaches. They were "experimental," "descriptive," "experimental/descriptive combination," and "theoretical" (Tables 1 and 2). Participants were classified as "experimental" if their primary practice involves traditional manipulative investigations with controlling variables and assessing cause/effect relationships. Those were classified as "descriptive" if their research is primarily void of direct manipulative features. The five researchers within this group conduct correlational and/or observational studies. The atmospheric scientists in this group emphasized modeling systems (e.g., clouds) through use of computer simulations developed from data they collect in the field as well as from satellite data. Those who work primarily in the realm of mathematical computations and classified themselves as theoretical scientists were classified as such. There were five scientists involved in combined programs of experimental and descriptive investigations. One of the astronomers, for example, indicated she conducts experiments, but not in the traditional direct-manipulative way. She targets the stellar systems she wants to compare based on their composition and characteristics. She considers this work experimental because of her purposeful selection of systems that differ by the one known variable of interest to her. In this way she infers causal factors. Her work also involves description of stellar systems and identifying correlations among system features. Similarly, four of the life scientists participated in combined research. The community ecologist, for example, maintains fields of a host plant (a pitcher plant) that he uses to study ecological relationships among the organisms that live within the pool of water the pitcher plant holds. He not only describes natural relationships, he also manipulates the micro-environments within the host plants (e.g., adding or removing a particular organism) to examine the effects of the introduced changes.

Main Aspects and Emergent Subcodes

There were 14 initial codes used in the analysis of the data. Two additional themes emerged, to make a total of 16 main aspects related to the sample's epistemological views of science (Schwartz, 2004). After repeated rounds of coding and analysis, multiple subcodes emerged within each main aspect to represent the scientists' views. An individual whose view aligned with an emergent subcode received a tally for that code. Subcodes were not mutually exclusive. As such, individuals could have more than one occurrence within the subcodes for a main aspect. Likewise, not all individuals' responses yielded information relative to the main aspects. It is important to note that the subcodes emerged from the qualitative data. That is, these are the ideas generated by the participants. Not being represented within a subcode means the participant did not make a statement aligned with that position which was offered by another participant.

Table 3 presents seven of the 16 main aspects and respective subcodes for each. These categories are the seven NOS aspects targeted on the VNOS-Sci instrument. The VNOS-Sci also elicits ideas about scientific models, but those results are reported elsewhere (Schwartz & Lederman, 2005). Our presentation of the results demonstrate the type of responses within categories and several subcodes of each, our interpretation of responses, and the contextual connections revealed by the participants. The examples are intended to demonstrate the wide range of views within and across disciplines and research approaches, and exemplify how patterns were or were not suggested. Although quotations are used to demonstrate representative views, they also demonstrate the interconnections among the aspects and subcodes. The reader may find the quotes relevant to multiple categories. The open-ended qualitative approach to this exploration enables such coding and identification of connections. A discussion of the results follows each category.

Table 3. Scientists' views of NOS

Aspect		Subcode		Total (n = 24) Total	Total %	Frequency within discipline group LS (10)	ESS (5)	Ph (5)	Ch (4)	Frequency within approach group E (10)	E/D (5)	D (5)	T (4)
Tentativeness	Yes	Affirm change/		11	45.8	0.4	0.4	0.6	0.50	0.3	0.6	0.4	0.75
		Levels of certainty		8	33.3	0.2	0.4	0.6	0.25	0.3	0.2	0.4	0.5
			Complexity	4	16.7	0	0.4	0.2	0.25	0.1	0	0.4	0.25
			Discipline	4	16.7	0.1	0.2	0.2	0.25	0.2	0	0.2	0.25
			Method	2	8.3	0	0.2	0.2	0	0	0	0.2	0.25
	(No)	Approaching certainty		4	16.7	0.3	0	0	0.25	0	0	0.3	0.2
	No	Attain certain knowledge		5	20.8	0.4	0.2	0	0	0.2	0.4	0.2	0
	Other: self-correcting			2	8.3	0.1	0	0.2	0	0	0.2	0	0.25
	Other			1	4.2	0.1	0	0	0	0.2	0	0	0
Empirical	Yes	Empirically grounded		17	70.8	0.8	0.6	0.6	0.75	0.9	0.4	0.8	0.5
		Theoretical yet empirically grounded through confirmation of predictions		2	8.3	0.1	0.2	0	0	0	0.2	0.2	0
	Varies:	Theoretical/mathematical: changing what science is … (String theory)		3	12.5	0	0	0.4	0.25	0.1	0	0	0.5

Table 3. *Continued (1)*

Aspect		Subcode		Total (n = 24) Total	Total %	Frequency within discipline group LS (10)	ESS (5)	Ph (5)	Ch (4)	Frequency within approach group E (10)	E/D (5)	D (5)	T (4)
Subjectivity	Yes	Personal only		9	37.5	0.4	0.4	0.2	0.50	0.4	0.4	0.4	0.25
		Theory-laden (guiding framework)		15	62.5	0.6	0.8	0.6	0.50	0.5	0.8	0.8	0.5
			Positive	8	33.3	0.5	0.2	0.2	0.25	0.3	0.4	0.4	0.25
			Negative	4	16.7	0.1	0.2	0	0.50	0.3	0	0.2	0
		Inconsistent response		3	12.5	0.1	0.2	0	0.25	0.2	0	0.2	0
		Differs with discipline		4	16.7	0.2	0.2	0	0.25	0.1	0.4	0.2	0
		Differs with approach: qualitative > quantitative		5	20.8	00.1	0.2	0	0.75	0.3	0	0.4	0
	No	Not subjective		4	16.7	0.1	0.2	0.4	0	0.1	0	0.2	0.5
			Scientific Method = objectivity (ideal or practice)	2	8.3	0.1	0.2	0	0	0.1	0	0.2	0
Creativity	Yes	Affirmed		16	66.7	0.6	0.8	0.6	0.75	0.7	0.8	0.6	0.5
		Finding patterns/build connections		7	29.2	0.2	0.6	0.2	0.25	0.3	0.4	0.4	0
		Epiphany only examples		3	12.5	0	0.4	0.2	0	0	0.2	0.2	0.25
		Progress		5	20.8	0.3	0	0.2	0.25	0.3	0	0.2	0.25
	No	Data to be clear		3	12.5	0.1	0.2	0.2	0	0.1	0	0.2	0.25

Table 3. *Continued (3)*

Aspect	Subcode			Total (n = 24) Total	Total %	Group frequencies: Frequency within discipline group 10 LS	5 ESS	5 Ph	4 Ch	Frequency within approach group 10 E	5 E/D	5 D	4 T
	Inconsistent responses			1	4.2	0	0	0	0.25	0.1	0	0	0
	Other			1	4.2	0	0	0.2	0	0	0	0	0.25
Socio/cultural	Process/conclusions (how done, reasoning)												
		Internal:	Influence on reasoning through processes, assumptions	4	16.7	0.3	0	0	0.25	0.3	0.2	0	0
		Not s/c influenced: international community, technology		5	20.8	0.3	0	0.4	0	0.2	0.2	0	0.5
		External:	Political and economic pressures	3	12.5	0.1	0	0.2	0.25	0.3	0	0	0

Table 3. *Continued (4)*

			Total (n = 24)		Group frequencies							
					Frequency within discipline group				Frequency within approach group			
			Total	Total %	10	5	5	4	10	5	5	4
Aspect	Subcode				LS	ESS	Ph	Ch	E	E/D	D	T
	Questions/problems studied (What)		1	4.2	0	0	0	0.25	0.1	0	0	0
		Human endeavor	3	12.5	0.1	0	0	0.50	0.2	0.2	0	0
		S/c influenced: political, economic, societal pressures	15	62.5	0.6	0.8	0.4	0.75	0.8	0.6	0.6	0.25
		Not s/c influenced	4	16.7	0	0.2	0.6	0	0	0	0.2	0.75
	Products											
		Universal application/ generalizability	3	12.5	0	0.2	0.4	0	0.1	0	0.2	0.25
		Not universal use	1	4.2	0	0	0	0.25	0.1	0	0	0
	SM: not s/c influenced		2	8.3	0.1	0.2	0	0	0.1	0	0.2	0
	Other		4	16.7	0.1	0.2	0.2	0.25	0.1	0.2	0.2	0.25

Table 3. *Continued (5)*

			Total (n = 24)		Group frequencies							
			Total	Total %	Frequency within discipline group				Frequency within approach group			
					10	5	5	4	10	5	5	4
Aspect	Subcode				LS	ESS	Ph	Ch	E	E/D	D	T
Theory/law	Hierarchical (theories become laws)		13	54.2	0.5	0.6	0.4	0.75	0.4	0.8	0.6	0.5
	Different		8	33.3	0.3	0.6	0.6	0.25	0.4	0.2	0.2	0.5
		Levels of confidence differ: laws > theories; foundations	5	20.8	0.2	0.2	0.2	0.25	0.3	0	0.2	0.25
		Theories more general and complex/laws simple	3	12.5	0.2	0	0.2	0	0.1	0.2	0	0.25
		Theories more likely to change	2	8.3	0	0.2	0.2	0	0.1	0.2	0	0
	No difference		1	4.2	0.4	0	0	0.25	0.1	0	0	0
	Differs with discipline		6	25.0	0.4	0.4	0	0	0.3	0.2	0.4	0
	No laws in field of work		6	25.0	0.4	0.4	0	0	0.2	0.4	0.4	0
Obs/inference	Affirmed role of inference		14	58.3	0.6	20	0.8	0.75	0.6	0.6	0.4	0.75
	Not clear from responses		10	41.7	0.4	80	0.2	0.25	0.4	0.4	0.6	0.25

Scientists' Views of NOS

These scientists' NOS views are complex, yet the results suggest overarching consistencies. There are consistencies at general levels of description and applicability with respect to particular features of NOS. That is, the main categories of NOS are applicable across all the contexts of these scientists, and many of their broad descriptions were similar, as evidenced by the clustering of responses within a few subcodes. Then more subtle complexities emerge within descriptions, those being represented by the multiple subcodes with fewer tallies, as the aspects relate to individual experiences and specific contexts.

Tentativeness. Table 3 presents results of the scientists' views of tentativeness of scientific knowledge. The columns with "yes" and "no" indicate the conviction of the responses toward tentativeness. Those under the "yes" subcode viewed all of scientific knowledge as inherently subject to change. Those under the "no" subcode considered absolute knowledge of reality attainable through scientific endeavors. The other subcode characteristics were more variable, as explained below.

Inherent tentativeness. Eleven of the 24 (45.8%) scientists affirmed that scientific knowledge is inherently tentative. Five of these explicitly made reference to not being able to prove anything absolutely in science, only disprove.

> Usually an experiment only disproves something, a theory. So physicists tend to have an open mind. You postulate a theory. You do all the experiments you can think of. You predict new things and then you measure that. Then you say, ok, those experiments have proved that the experiment is valid. You haven't proved that it is right. It can always be wrong and superceded by another theory. But an experiment can prove that a theory is wrong. It can't prove it is right. … If it agrees, it just means it isn't wrong. [lTC4, interview]

Another view related to conventions of the scientific community:

> I think a lot of scientists take themselves too seriously. It is really hard to get scientists to stop thinking "statistics prove," because they don't. … Scientists fight over things … If people think about it there are all these reminders that people have thought about in the past that we don't know what we are measuring in all cases, or we have changed what we are measuring. We may be accepting the simplest answer, the most pragmatic possibility, but that doesn't mean it is always the right one. There are just conventions that we have all agreed to use more or less. That doesn't mean they are right. [SEDF1, interview]

Responses provided evidence that views of different aspects were connected. For example, a few participants related the perspective of inherent tentativeness to their view of scientific theories and laws. Their understanding of laws as confirmed absolutes were reconciled with their being unattainable within science, because all knowledge is subject to change:

Scientist: There have been several points in the history of science, interestingly, where scientists absolutely believed that was it. There was nothing more to be discovered. And so anything that was ruled at that time would be laws. We now know that there is hardly anything we know that probably there isn't something else that eventually what we know now will be a special case of a broader overarching theory or concept of nature. So I don't find a lot of distinction between these two things.

Researcher: So do you think reaching this law status is unachievable in the strictest sense?

Scientist: I believe so. The evidence of the past is that very few things that we might consider laws now might survive as such … We can't really know that things are irrefutable or engraved in granite and came down to Moses like the Ten Commandments. Things just don't work that way. [bEL3, interview]

Approaching certainty or attaining certainty. Some scientists suggested that science attains certain knowledge (five scientists) (that being absolute knowledge of the reality separate from the observer) or that science progresses nearer and nearer to certain knowledge (four scientists). Those who suggested certain knowledge is attainable implied achievements of pure discovery, where interpretation is unnecessary. These views suggest there may be little to no negotiating meaning from data.

> Scientists do not develop laws. They discover them! [KEDF1, VNOS]

An atmospheric scientist responded, when asked about the certainty of the model of the atom, "Certain. It's the way nature is" [cDFC2, VNOS]. This view of certainty is in contrast to one of the theoretical physicists who stated in reference to scientists understanding of the atom, "As certain as we can be" [pTC4].

Four scientists indicated that science progresses asymptotically toward better approximations of the truth. The aquatic ecologist commented on approaching certainty through the self-corrective nature of science in his VNOS response:

> Scientific knowledge changes as better approximations of nature are realized while religious knowledge is dependent on established (or accepted) elements … All scientific knowledge is subject to question, doubt and criticism (a further distinction from religion) … Nonetheless, someone will eventually challenge an accepted scientific finding and take a fresh look at it. … That is the self-corrective nature of science. Does science lead to universal truths? It leads to close approximations of universal truths. [PEDF1, VNOS]

Levels of certainty. Eight participants (33.3%) indicated scientific knowledge can vary in terms of certainty. That is, some types of knowledge are more certain than others.

> I think there are levels of certainty. I think that there are certain principles or insights that have very high levels of certainty attached to them. [example of Albert Einstein and his insight into the theory of relativity] … It is very similar in this case to religion. To have a mystical experience that is absolutely true and it is absolutely unquestionably true. The question is what to do with it. Do you hold it within? Do you become a

> teacher? I am trying to get at this idea that there are certain insights that have a very high level of certainty. They cannot be questioned or challenged. They don't come about necessarily because you do a set of experiments and the experiments then … you say, "ah hah" They come about because of some more subterranean mechanism. Some of the best science does. Maybe the best science comes about this way. [GDF2, interview]

There were only four scientists who indicated there were differences in the certainty of knowledge that was attributed to differences in complexity of the system involved (16.7%, four participants) and/or associated with the discipline (16.7%). These features are not mutually exclusive. Regarding certainty of the model of the atom, a theoretical physicist said:

> Very certain, in the sense that we have a theory that does a spectacular job explaining an extraordinary diverse set of observations and experiments. The mental picture we use of electrons orbiting and so on is perhaps less certain but it does not matter! There is a profound difference between a description that works and literal belief in the picture—you don't need the latter in order to have a spectacular success of the former. [sTC4, VNOS]

> Researcher: Do you think there are some areas of science that may be more certain than others?
>
> Scientist: There are some areas of physics especially; I think chemistry which is close to physics these days, where the level of certainty becomes very high because the system that you are studying is very simple. So when a chemist, a physical chemist, says they have a very complete understanding of what happens when two hydrogen molecules collide or when two simple molecules collide and a reaction takes place. I believe that because that is a repeatable experiment and it is also an experiment that can be matched with a computational machinery that comes from quantum mechanics … That doesn't mean it is absolutely true. That means there is a very high level of confidence … In that kind of science, a lot of physics, not all of physics, but a lot of physics is in that category. A lot of chemistry. In that kind of science there is a very high level of certainty. In other areas, for example climate change or … can we decide whether we can predict Earthquakes or do we know when the Earth's magnetic field is going to reverse next … In those kinds of areas there is a low level of certainty and in some cases even the question is wrong, meaning that the correct question might be *can* we predict, not when … So the question has to be removed somewhat to a level where you say, well, this is the kind of complex system where you cannot even make a prediction, so you will never have perfect knowledge. Weather is also in that category. [sTC4, interview]

In discussing his use of models and a specific example of resistance to model change within his community, a chemist also indicated complexity of systems as a reason for levels of certainty of the knowledge produced.

> The idea is you start off with systems that are very simple and very well controlled and you rely on the fundamentals. Then there are good models and everyone will more or less agree on the results. Then you make systems increasingly more complicated and there is less and less agreement on what you are doing and less and less agreement on the results. It is a continuum. Some things are certain. Some things are not. Most things

> are sort of in the middle. In particular things that people care about are in the grey zone. [wEL3, interview]

Group comparisons. Table 3 presents the frequency of responses among discipline groups. While statistical tests are not appropriate, we can describe interesting tendencies. The life science (LS) group leans more toward absolutist views in comparison with the sample as a whole. Four of the five total appearing in the "attain certain knowledge" subcode were LS. When comparing just group percentages, 40% of the LS fell within the "attain certain knowledge" subcode, as compared with 21% of the total group. In contrast, none of the physicists or chemists appeared in this subcode. Three of the four in the "approaching certainty" subcode were LS. No difference was evidence among scientists who "affirmed change." That is, even though the LS showed more tendency toward a view of "attain certain knowledge," they were, nonetheless, as typical as the total sample with regard to describing scientific knowledge as inherently tentative. Three of the five physicists, and two of the four chemists, fell within the "affirm change" category. The other two physicists indicated different levels of certainty determined by complexity of the system under investigation. These results show the LS were split in their views of tentativeness, demonstrating a range from absolutist views to views of inherent tentativeness with fairly equal frequency. In comparison, the physicists and chemists tended to make statements more demonstrative of "affirm change."

When comparing by approach (Table 3), four of the five in the "attain certain knowledge" and all four in the "approaching certainty" were either E or E/D. Thus, the LS who engaged in experimental or mixed E/D programs were more likely than the other groups to view scientific knowledge as absolute truth or progressing toward knowledge of that reality. The theoreticians were lower than the total group with respect to "attain certain knowledge" (0% versus 21%), and higher than the total group with respect to "affirm change" (75% versus 21%).

Discussion: Views of the tentative NOS. Only 46% of the sample demonstrated views that all scientific knowledge is *inherently* tentative. These, combined with the six additional participants who reported quite sophisticated examples of different levels of certainty, comprise 17 of the 24 scientists in the sample. The notion of differences in certainty due to complexity of the system under study had not been depicted in previous NOS studies with scientists, teachers, or students. The remaining seven scientists indicated the knowledge either progressively approaches certainty or reaches certainty. That some of the participants demonstrated somewhat more absolutist views of scientific knowledge is consistent with other reports (e.g., Glasson & Bentley, 2000), while inconsistent with predictions that scientists hold views of open-minded realism (Harding & Hare, 2000). Many of the scientists in the current study reported using "what works" with the understanding that "what works" might change or might not be an exact representation of the real phenomenon. In this way, they demonstrated what Harding and Hare considered open-mindedness. However, with the exception of those participants who explicitly mentioned science *as* knowledge of reality or approaching knowledge of reality, these scientists were seemingly comfortable with empirically supported relativist positions, seeing knowledge as "what works" as opposed to "small scale truths" (Harding & Hare, 2000). They were consistent and did not mix meanings in their responses. Overall, the participants in this study primarily affirmed that scientific knowledge is subject to change, recognized there are areas of science that are more certain than others, yet some viewed science as progressing toward knowledge of external reality. Of the five who stated scientists reach that knowledge, four were life scientists; none were physicists or chemists.

Why might these life scientists, as opposed to the physicists or chemists, lean toward more absolutist positions? These results are contrary to what one might expect given the "hard science–soft science" continuum (or demarcation in some cases) that has been used to describe these science disciplines (e.g., Spieker, 1972; Van Bemmelen, 1961). In fact, some of the scientists in this study used these descriptors, referring to the physical sciences as "hard" and the natural sciences as "soft." These descriptors indicate the type of data relevant to the field, as well as the number and controllability of variables (Knorr-Cetina, 1999; Mayr, 1997; Spieker, 1972). With seemingly more variables and less control of the system, one might expect those in the life sciences and earth and space sciences to consider the tentativeness of scientific knowledge as compared with the physicists and chemists. Likewise, one might expect those engaging in non-experimental research be more likely to consider tentativeness in comparison with the experimentalists. The results of this study do not support these conjectures. The fact that one of the atmospheric scientists fell to the absolutist side of the range of tentativeness clearly goes against expectations based on the "hard science/soft science" rationale.

Combining the results of the chemists and physicists for review of this category, the life scientists still have a greater tendency toward absolutist views. These results might be explained by virtue of a difference based on discipline; these results might be a feature of the small sample size; moreover, these results might be a feature of this particular sample. Four of the physicists in this sample were theoretical researchers and may not hold views typical of physicists *in general*. Indeed, the theoretical approach may affect a more tentative view because of the lack of direct empirical basis. In contrast, the life scientists explore living systems through empirical means. In any event, the views voiced by this group, and all the groups, should be reviewed in light of the sample characteristics.

Empirical. Empirically grounded. Seventeen of the scientists (70.8%) indicated scientific knowledge requires an empirical basis. Yet, what constitutes empiracy may differ by science discipline:

> Evidence for a chemical synthesis is far different from evidence for the evolutionary development of a biological feature; however, both areas demand the development of

> sequence of logical connections between the observable phenomena and the predictions of the hypothesis. [gEL3, VOSI]

A life scientist related the empirical NOS to scientific method and certainty of knowledge.

> As a scientist, I would say that we use the scientific method to explore and understand the natural world … from the data we collect we attempt to develop a picture of that world … a picture that is as accurate as possible. Art, on the other hand, is sometimes accurate, but need not be so. [NEFL1, VNOS]

This statement suggests that, because science demands observations (data), the knowledge produced is more accurate than that produced void of observations, such as art. Not surprisingly, this participant also fell within the "approach certainty" category of tentativeness.

Views of an empirical basis for scientific knowledge emerged in through comparisons of science and religion or philosophy:

> [Religion] is very much based on faith. Science hopefully has less faith involved and the idea is that it is more empirical and less bias … Religion and philosophy are purely mental constructs. There is no data needed or wanted. Don't confuse me with the facts, you know … creation versus evolution. [fEF3, interview]

> The general practice of religion seems rooted more in faith and belief and some sort of super natural which is beyond the realm of science. It can't be observed. It can't be manipulated or tested. In that sense the practice of religion cannot be scientific. [UEL1, interview]

Varies: theoretical/mathematical valid basis. Three of the 24 (12.5%) indicated valid scientific knowledge can be acquired through purely theoretical or mathematical means. This position was related to views of mathematics or reliance on mathematics to do science.

> [Comparing science and art] There are certainly elements of taste. There are elements of subjectivity. There are elements of fashion. There are those elements in physics too, especially recently with cutting edge theoretical physics … [In science] if something that is mathematically inconsistent or if something is inconsistent with a great wealth of data that is known about the physical world, you just don't give it any further consideration. It is wrong. So that really is the difference. It is difficult to really pin down the way good science and art are different, except of course, the mathematical content could be brought in, the restrictive structures of mathematical consistency. You can say there is bad science, but I don't think you could say there is bad art. [pTC4, interview]

String theory was provided as an example of a non-empirical science, blending mathematics and science:

> Scientist: One of the things that characterizes physics is this enormous reliance on the definitiveness of mathematics. The clearest distinction I can make is that in mathematics, in mathematical research, there is no external motivation. You are fascinated by the mathematics in and of itself.
>
> Researcher: You use mathematics in your work. Is there ever a blend?

Scientist: Oh yes, and sometimes it is not clear what you are doing. String theory is the best example … .[string theory] is much more mathematics at present than it is physics. They hardly ever talk about, they never talk about data. They are looking for mathematical consistency in patterns of symmetry of the theory … In the cutting edge of modern theoretical physics, it is getting more and more difficult to get data. You can't do the experiment. … One is that the data will be very difficult or in principle impossible to get, after all if some conditions only existed at the beginning of the universe, you just can't duplicate that. Secondly the mathematics is so difficult that it may be extraordinarily difficult or maybe impossible to use mathematical restrictions, mathematical considerations themselves to nail down sufficiently the field of possibilities … Right now theoretical physics is in a strange state. String theory is like nothing else seen before … They may have it right, but how will we ever know. [pTC4, interview]

Discussion: Views of the empirical NOS. The full study explored views of "empirical," "observation/inference," "models," "experiment," "anomaly," "data/evidence," "justification," "reproducibility," and "prediction." These aspects relate in some way to the role of empirical data in the development of scientific knowledge. Among the participants, there was overwhelming agreement in the importance of empirical data in the development and justification of scientific knowledge. These results are consistent with reports of others (Bell, 2000; Glasson & Bentley, 2000; Osborne et al., 2003).

The theoretical physicists had a greater tendency than any other group or the whole sample to state that valid knowledge could be developed through mathematical and theoretical means, without extraneous empirical support. This result is consistent with their research approach and reported conventions of their research community. In their view, developments in technology and mathematical theory have extended the boundaries of what is considered science, citing String theory as revolutionary in pushing those boundaries. These ideas, although valid from these scientists' perspectives, are probable beyond the level of practical consideration for the typical K–12 classroom, at least for near future. These are extremely sophisticated ideas that have not been reported elsewhere in studies involving K–12 science teachers or students (e.g., Khishfe & Abd-El-Khalick, 2002; Abd-El-Khalick & Lederman, 2000), and not included among scientists' suggestions for K–12 science topics (Osborne et al., 2003).

Subjectivity. Theory-laden. Fifteen of the 24 (62.5%) indicated a view of subjectivity that went beyond personal differences (e.g., reading the instrument differently). These scientists suggested their theoretical framework, or that of other scientists, guides their questioning, their investigations, and their data interpretation. This position is in line with the study's NOS framework.

> Without models, observation would amount to cataloging data. [Models] motivate the questions asked of the data, and thereby determine what data are going to be taken. [pTC4, VNOS]

> I don't think there is any purely observational program … We don't just say "let's point the telescope there and see what we find" but we have some basic idea of what we are trying to find out about that is guided by more theoretical knowledge of what is going on. [pEDFC2, interview]

> Researcher: What makes people weigh evidence differently?
> Scientist: Basically training and experience. It is your particular bias. Biases in science are typically best represented by how you weigh the evidence. For example, if you are a sedimentologist, you are very used to looking at the sedimentary record. You will believe evidence that is sedimientological over that which, for example, might be a computer simulation of the climate. On the other hand, if you are a computer modeler or a climatic modeler and spend a lot of time modeling the climate, you really believe this model … you might think the sedimentological data is not that important. [GDF2, interview]

Scientists saw both positive and negative implications based on guiding frameworks. Positive features related to progress in science. For example, expectations and assumptions help scientists recognize anomalies:

> Researcher: You talked about the purpose of a model … You said simplification allows the user to focus on particular factors of interest, while of course, ignoring or holding other factors constant. My question is how do you decide what to focus on and what to ignore?
> Scientist: There is the human bias. You focus on things that interest you. You focus on things you thought were going to be interesting or have some intuition or some prior information to know which parts of the system you can ignore.
> Researcher: Do you ever think you ignore something and come back later and say, "shoot, I shouldn't have ignored that."
> Scientist: Absolutely! All the time … Usually it is because the system starts to exhibit behaviors that you can't understand anymore. That, you know, by making those types of assumptions, you say, "oh, if I tweak it this way, it should do that." You tweak it that way and it doesn't do that at all, you realize that it is sometimes because of assumptions you have made in part of the model you use to make those predictions. [MEDF1, interview]

Negative implications related to funding sources and problems associated with identifying and addressing alternatives:

> [in talking about a coral reef debate]. [Another group of scientists] believe strongly that their process is the more important one. I sometimes wonder if it is a function of our system today in that people have their areas of research and scientists get funding … Grouping of people into different camps may be due to the fact that they have to make the case to receive funding for their research. If you get locked into thinking only one way, you can sometimes be blinded to other possibilities. [NEFL1, interview]

> [theories] define the world and probably restrict some of our thinking. For example, an observation that doesn't fit our collective model might be ignored, rather than being seen as the key to a new set of experiments to redefine our world view (for example, insects as regulators). [SEDF1, VNOS]

Qualitative methods are more subjective than quantitative methods. Five of the 24 stated qualitative methods are more subjective than quantitative methods, and made reference to statistics as a means to reduce subjectivity.

> Scientist: We are all human so I don't think you can remove completely subjectivity or social and cultural values from science … There is a fine line there between collecting the data, interpreting the data, and in my area … risk assessment. … .Find measures that communicate risk but do not communicate bias. It's a hard one.
>
> Researcher: Do you think there are some types of science that are more subjective than others?
>
> Scientist: I will bring my bias to the table. Some … forestry practices, for example, have the appearances of being supported by data, yet it doesn't seem to match … Without numbers, there is more bias. [fEF3, interview]

Science is not subjective. Four suggested science is not subjective at all.

> Science and serious art are both searches for truth. … Successful art need not be objective, quantitative, or reproducible. [eDF2, VNOS]

A theoretical physicist described how theoretical perspectives may lead to different explanations, yet with sufficient data, the controversy would be resolved. When asked why there could be different explanations for dinosaur extinction, he responded:

> They are essentially not using the same data. Because I suppose either group cannot explain all the data … . One has to go into the other's territory and look. … Part of the problem is that you tend to look under the light when you lose your keys … because that is where it is brightest. So you tend to look for the explanations for things where you are most comfortable looking, rather than where the keys actually are. My impression there is that the fields are a little different and therefore the outlooks are different and they are not weighting all the data in the same way. [jTC4, interview]

Although initially this statement sounds supportive of accepting theory-laden observations, this participant then went on to say "The truth will be revealed with enough data." Therefore, although there may different foci with different groups, given time and data, the one answer will be evident. Two participants indicated that the "Scientific Method" should maintain objectivity in science. Both of these included a caveat that this was an ideal situation, and not always attainable.

> I think a lot of science … the essence of the scientific method is that you shouldn't care. It is very transcendental. No ego. Very few people in science, including myself, are able to do that. And so that is one of the things that defines how you weigh evidence … It fits with something more interesting. Your advisor likes it that way. Someone you don't like in science likes the other story. [GFD2, interview]

> This approach [scientific method] is supposed to provide objective unbiased answers. In my mind the conduct of science isn't as objective as many people would say. *Sometimes* there is room for interpretation and clearly scientists come from different backgrounds and experiences and therefore have different perspectives. [NEFL1, VNOS]

Discussion: Views of the subjective NOS. A majority of the scientists acknowledged the influence of current scientific theory and paradigm in directing scientific research. They recognized theory-laden observations and investigations from within their research contexts and provided examples. We consider this view more sophisticated in comparison with only recognizing personal subjectivity, such as variances in taking measurements. Few beginning teachers who participated in a science research internship were able to achieve this deeper level of understanding (Schwartz et al, 2004). Perhaps the extended authentic experience, and moreover, true membership within the community (Lave & Wenger, 1991) provides opportunity to not only (1) develop expertise in the theoretical framework driving the research, but also to (2) contribute to that framework through original research, and (3) develop practical utility of that framework for acquiring funding necessary to maintain that research. The 15 scientists who demonstrated this view provided evidence of an almost common-sense notion of theory-ladenness. One of the responses relative to use of scientific models is case in point: "Every scientist uses models, and if they say they don't, they fail to understand what they are doing." In other words, use of theory to drive one's work may be implicit or explicit. The framework is there whether the scientist recognizes it or not. As these results suggest, not all of the scientists recognize it. The fact that 15 of the 24 scientists in this study did explicitly describe this feature of subjectivity is interesting because of the contrast to other reports (e.g., Glasson & Bentley, 2000), and, as mentioned, perhaps a function of their prominence and longevity within the scientific community, in addition to the reflective prompting of the questionnaire/interview methodology.

There are a couple of interesting features of the group comparisons. Eighty percent (four scientists) of the earth and space scientists (ESS) held views of theory-laden NOS. This is greater than the 62.5% of the total group. Within the subcode of "differs with approach," three of the four chemists indicated qualitative methods as more subjective than quantitative methods. That is, three of the five of the total within this subcode group were chemists. These results are consistent with their view of the importance of statistical analysis. None of the physicists voiced this view.

For the present study, four stated that their work and that of other scientists is objective, and two of these mentioned the use of the Scientific Method as a mechanism for eliminating subjectivity. These types of views are more consistent with naïve notions of subjectivity, commonly voiced by learners before explicit NOS instruction (e.g., Abd-El-Khalick & Lederman, 2000).

Creativity. *Affirming creativity.* Sixteen (66.7%) of the total sample claimed scientific knowledge was partly a creation of the mind, as opposed to being strictly revealed through empirical data.

> Noteworthy scientists and artists bring to bear superior imaginative and creative resources that leave the rest of us standing in awe. Whereas science often leads to new science, new understanding, applications that change lives, etc., good art simply leaves us standing in awe. [cDFC2, VNOS]

Several indicated creativity was involved specifically in data interpretation:

> [creativity] is what distinguishes genius from pedantic activities in science … the one [phase] that has probably the most imagination is interpreting the data. [bEL3, interview]

> You just look at the data and, you know, … interpretation … there is a lot of art … in the interpretation there is a lot of creativity in how you choose to interpret the data, as well as in how you choose to design the experiment in the first place. [SEDF1, interview]

Finding patterns and connections. Only seven (29.2%) related patterns and connections as created products:

> You get deluged with a bunch of facts, you have to sit back, you don't worry about laws, theories, or principles, or anything. You day dream. You say, well … as I go through I sometimes find two different papers in the messy office and say, "wait a minute. There is an interesting connection." That is largely what you do as a scientist … . So that is what the real divergence is between how you *do science* versus what being in the *profession of science* is. Doing science is playing. It is a lot of fun. The profession of it is convincing other people that you've really done something, that it is not an artifact … . *It is a difference in creativity versus marketing and establishing something as a fact.* [OEL1, interview; emphasis added]

Progress/success. Five participants connected creativity to progress or success as a scientist:

> Not all scientists use creativity and imagination in their investigations, but it is my assessment that the best scientists do. Science only progresses if it moves beyond what is already known; a creative person is needed to perform novel research and to look at things in a fresh light. [mDF1, VNOS]

There was evidence of connecting views of subjectivity and creativity. A participant uses a story about his young son's creation of a train from puzzle pieces to describe how science progresses:

> I view it in like building a puzzle. It is hugely complex and you don't have a picture of what the overall thing is by looking at individual pieces. You push them together and you build different things. … [tells story of his son linking puzzle pieces together and calling it a choo-choo train] … So when you've got a lot of different pieces, you put them together, you build a theory. You build your own choo-choo train and you are pretty enthusiastic about it and your grants get funded. There is a lot of momentum behind this train. The idea that you have to take the pieces apart and look at them, and maybe rearrange them a bit to make them look a little different is very hard to do. You have so much involved intellectually and financially in getting this train moving in the first place. You've to hope it's not a blind track you are running into in a train wreck where all the pieces are going to fall off when you take it apart. But if you can take off one piece and bring it around to another and get a different view of the puzzle. That is perfectly fine. I think that is the way science evolves … . In biology in particular we've got to be particularly careful in being willing to take the pieces apart and put them back together in different directions. [OEL1, interview]

No creativity in making meaning from data. There were only three participants to suggest that knowledge generation from data does not involve creativity. Typical among these responses were that creativity is involved in the initial stages, such as design, but not in interpretation.

> You can be a creative data analyst, searching for patterns in things. I don't think that is necessarily science … You are not scientific if you let beliefs interfere with the assessment of data. [eDF2, interview]

> … the act of creativity is focused on the design of the device to take the data. [pTC4, VNOS]

Discussion: Views of the creative NOS. In comparison with the total scientists, the ESS more frequently indicated the role of creativity in all phases of investigation (four of the five ESS), and in finding patterns and building connections in particular (60% of the ESS, compared with 29.2% for the group). In general, the ESS affirmed a role of creativity in finding patterns and building connections slightly more so than the other discipline groups. However, the overall frequency of this subcode is low. When comparing based on approach, there is slight tendency for those scientists involved in E/D or D methods to indicate this view (four of the seven). None of the theoreticians fell within the subgroup of "finding patterns/build connections."

Overall, the majority affirmed a role of creativity as well as inference. According to Ziman (1995), pattern recognition is linked to subjectivity and is a mainstay of all scientific practice.

> … the bodily senses are the only link between the human mind and the world he or she inhabits. Visual perception, by its intersubjective consensibility, is an essential element in the creation and validation of scientific knowledge, and pattern matching provides a standard of consensuality which is never completely superseded by more "objective" devices such as mechanical instrumentation. (Ziman, 1995, pp. 55–56)

For the given data-set, there were no consistent responses beyond affirmation of inference, and just a few that expanded on the role of creativity. Thus, even though the results suggest most of these scientists consider scientific knowledge to partially be the product of creativity and inference, few could actually explicate the use of creativity in making meaning of data.

The scientists tended to emphasize empirical data and supporting conclusions with that data to justify claims to themselves and their peers. Creativity was seen as a part of the process of science in general, but not necessarily as a part of developing solid claims specifically. There was a division between doing and justifying. The extent to which these scientists all saw this division is not determined from the current data. However, the comment from one of the molecular biologists on the distinction between *doing science* and *being in the profession of science*, in terms of having fun and being creative versus writing up the work to the acceptance of your peers, demonstrates this division. Perhaps some of the participants did not recognize the role of creativity in making meaning of data due to the muddy lines between doing science and being in the profession of science. In their study of scientists' views of science and science writing, Yore, Hand, and Florence (2004) report that scientists see writing as a means to clarify and build knowledge, but this process is, or should be, void of creativity and subjectivity. Yore et al. state:

> the researchers interviewed did not freely mention the creative human and social components of constructing knowledge claims in science and technology. It appeared as if these academics believed that they needed to constantly stress the objective science traditions of observations, measurements, accepted procedures, and canonical knowledge, and to avoid mentioning the subjective human dimension of making sense of these data in science and technology. (2004, p. 363)

Socio/cultural influence. There were three main clusters of subcodes under "socio/cultural influence." One focuses on the questions that are asked, or *what* science is conducted. Another focuses on reasoning processes, or *how* science is conducted. The third focuses on the products of science.

Political, economic, societal pressures on what questions are probed. In general there were few occurrences within this main aspect other than the view that society and culture influence *what* science gets done because of political/economic/societal pressures affecting funding. Fifteen of the 24 scientists (62.5%) voiced this view. The following quotes are representative. They also demonstrate a blending of views with other subcodes.

> … at least in the environmental area you are heaping all of these human factors on top of the scientific answer and then people try to support whatever it is they want to do for whatever reasons with the scientific argument. [wEL3, interview]

> How they get you in the end is in the budget. They just don't put the research money in. There is a political effort out now to stop certain areas of research, like gene cloning … [cDFC2, interview]

> Science reflects social values … what science receives funding. However, once a problem is identified, proper use of the scientific method should lead to unbiased results. Nevertheless interpretation of these results may under some circumstances reflect personal biases e.g. gender and racial bias that colored interpretations of brain sizes. [NEFL1, VNOS]

The influence of funding agencies may force scientists to alter their own agendas, and therefore the direction of research:

> You try to match your research idea with the funding agency. Sometimes you put a spin on it, or rationale that will convince the funding agency you want to work on a problem here that has implications to these problems the agency has interest in. … It is stakeholder-driven research. Just doing research for research sake is gone … You have to be flexible with what you are willing to research. Be more dynamic and responsive or else you are not going to make it. [fEF3, interview]

Sociocultural influences on the processes of science (how science is conducted). Only four participants stated that methods of scientific investigation and reasoning processes are influenced by the society and culture in which the science is practiced.

> I think it [science] is absolutely performed within a cultural context. Scientists are human beings. Humans are part of their culture and scientists will certainly operate, we can pull examples up through history on how people's ideas are embedded in the culture they live in. There is no way around that. We can try as individuals to pull ourselves out and be objective, but there is no way. European science is very different from US science … Chinese science is even more different than US science. … [BELF1, interview]

A molecular biologist discussed his views of the international science community and differences he has seen in how science is conducted.

> Americans are extremely competitive and hardworking and driven, pushing at the latest technology. They follow trends and fashions. In fact if you don't follow the latest trends you get penalized in your grant reviews because you are doing something that is old and everybody knows it. In the European system it takes forever to get established and the probability of succeeding is … once you are there you've got great freedom. You can work on things that interest you to a great extent but you don't have to be competitive and right at the cutting edge. I really like South American scientists because they can't afford to buy a box of reagents. They think about their experiments a lot more. My friends there are a lot more philosophical … You have to sit and listen and suddenly the brilliance comes through … they have sat back and gotten at the bigger picture. [OEL1, interview]

The following excerpt demonstrates a chemist's view that sociocultural influences vary depending on the type of science. Within this one dialogue, we find connections between views of subjectivity, reproducibility, and sociocultural embeddedness. Ideas of what constitutes valid science come forth.

> Natural sciences tend to be universal … This would include mathematics, physics, and chemistry. What we know about the world, or let's say the questions we pose and what we choose to explore about nature in the natural sciences, though, are usually determined by cultural and political forces … . I am often quoted by my students, I believe there are only two things that enable science. That is either a desire to gain economic advantage or a desire to gain political advantage. If you look at the history of science, these are the forces that drive science. The third component … is intellectual curiosity … . Biological sciences tend to be both [universal and culturally embedded]. Investigations in biology usually are very very cultural and driven by society … Cloning, the issues of stem cell research because we can only get them from embryos. These are tied into very very divisive issues … . Often times investigations in previous times were extraordinarily controversial … around the time of Darwin. The whole idea that humans evolved from monkeys, uh-uh. Even today is still not universally accepted. So these are very much involved with culture and society … . The natural sciences people don't get so excited about … . The social sciences, just by the nature, it is reflected in the name 'social sciences' of course, are social and cultural … The questions asked, and thus the approaches to scientific inquiry can definitely reflect social and cultural issues, but the outcomes must be universal if they are to qualify as science. This is why often natural scientists, like myself, will say the social sciences aren't really sciences. Sometimes we … just the process of investigation interferes with the thing you are observing in such a way that one has to question the validity of the observation. So you can often times get a room full of psychologists and they will disagree about how a person is behaving. They may not, I don't know. But it gets difficult for them to meet this standard of repeatability … When you get into the social sciences, it is really hard for us to

> become totally objective. We can't escape our biases. That isn't meant to demean those sciences … So a scientist in this country would pursue one of these investigations very differently than say someone even in Europe, which is very close to our society. But somebody in India or Sri-Lanka or Africa or Asia, may look at this totally differently. And the kinds of questions that occur to you or me to ask may never occur to them to ask … In chemistry, we can take this thing and this thing and put them together and say, "oh, it turned blue." Well, I don't have to be Asian or European or African to see that it turned blue, assuming I am not colorblind. So I can ask the question, why did that turn blue? That is not … a cultural issue is not going to come into play. [bEL3, interview]

With regard to her own research, an astronomer felt there was no impact from society because the discipline does not directly effect society. However, she sees sociocultural impacts within other cultures and sciences:

> I think that science itself is universal, but because science is a human activity that has impact on the lives of people. It is affected by cultural values and beliefs. Because astronomy has little direct impact on our lives, the work of astronomers isn't much affected by cultural values (except in terms of access to technology to carry out our work …) … Scientists whose work is reflective of cultural values (e.g. African scientists who maintain the AIDS is not a sexually transmitted disease, or paleontologists who maintain that the fossil record shows the world was created in 4000 BC because of their religious beliefs) are generally marginalized because their work ignores a large body of evidence. [pEDFC2, VNOS]

No effect of society or culture on what science is done. Four scientists indicated that science is universal, or at least, ideally universal. They stressed that regardless of current beliefs, with sufficient information, the products of science would be the same regardless of the investigator.

> Science should ultimately develop a universally applicable framework, which provides a broad and deep explanation of the world around us … . Ultimately, the truth, rather than our opinions, will prevail. [jTC4, VNOS]

Effect of an international community on minimizing sociocultural influences. A unique perspective emerged in reference to the effect of international collaborations and technology on minimizing cultural differences. The global culture is seen overriding individual cultures.

> I work with so many different people from so many different places that I am lead to believe that science is universal. [jTC4, interview]

Discussion: Views of sociocultural influences. A majority of the scientists highlighted the importance of funding and the influence of political and societal pressures on the direction and continuation of scientific research. The influence was directed toward *what* questions get asked more so than on the reasoning processes involved with *how* the science is conducted. In this way, scientific knowledge was seen as a socially and culturally embedded product, but the sociocultural influences were primarily external to the scientist. The scientists reported tailoring their research programs toward the agendas of funding agencies. Political and societal institutions establish standards and direct research through funding decisions, and are a recognized feature of scientific–social dynamics (Knorr-Cetina, 1999; Ziman, 1995). However, this influential feature is typically overlooked in the context of science education. Through contacts with scientists in practice, students and teachers have learned about the pressures of acquiring funding, and recognition of such requirements may also lead to recognizing the theory-laden NOS (Ryder et al., 1999; Schwartz et al., 2004). As several of these scientists stated, the grant-writing process itself mandates work be framed within current theory and directed toward worthy goals that fit the visions of current scientific progress. However, this vision may or may not fit exactly with the preferred direction of the scientist, as in the case of the astronomer who changed her research focus from older planetary systems to younger systems to satisfy the interests of NASA:

> I look at what is going on in the field and I put the emphasis in the grant proposal in a direction that I think will be more fundable than necessarily in a direction that might be easier for me to carry out a research program. I put in a proposal for NASA funding this last summer … to detect planets around young stars and look at the evolution of planetary systems. It is a whole lot easier to do that project if we look at clusters that are 100 million years old or older because those stars are more stable and it is easier to make the measurements we need to make. The question that is more likely to get funded is what is happening in stars that are 20 and 30 million years old. So I had to revise my thinking in order to see how I would carry out this observational program to really target that age group. [pEDFC2, interview]

Interestingly, four of the five scientists in the ESS group fell within the category of "political, economic, societal pressures on the questions asked (what science is done)." This group then had little representation within other subcodes of this main category. The theoretical physicists were under-represented within this category (one of four in the T group; one of the 15 total). The remaining three theoretical physicists fell within "not socioculturally influenced" with respect to what science is conducted. They represented three of the four total within this subcode. Compared with the other groups of scientists, those scientists engaging in a theoretical research had more tendency to consider science void of sociocultural influences. Whether trends are related to discipline, research approach, individual situations, or combinations of factors is undeterminable.

An interesting feature of a few of the scientists' views of socio/cultural influences, or lack thereof, is the role of the international community in minimizing differences across cultures. They specifically reported their involvement with international groups through conference attendance, collaborations, and advances in technology lead to a global scientific society. The extent to which this global perspective is shared by less established scientists or by scientists from other cultures would be interesting to pursue. Despite the low frequency of statements indicating a global community, there were still few scientists who identified an internal feature of culturally based differences in *how* science is conducted. The more sophisticated view that scientific reasoning and the processes of developing and accepting scientific knowledge is influenced by the culture and society within which the science is practiced was only voiced by a few of these scientists. This result is not surprising, given again the international status of the scientific community and the high occurrence of external influences. Moreover, this more sophisticated perspective of sociocultural embeddedness seems to be generally difficult for individuals to develop, even through explicit instruction (e.g., Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001).

Scientific theory and scientific law. *Hierarchical relationship: Theories turn into laws with sufficient time and/or repeated testing.* Thirteen (54.2%) of the participants held a hierarchical view of the relationship between scientific theories and laws. They stated that theories hold lower status in terms of certainty than laws, but through repeated use or testing, theories can become laws that represent more certain knowledge.

> A theory is when we're pretty sure about something but not so sure that we aren't leaving room for a little doubt; there is no doubt in a law. [mDF1, VNOS]

> There are several degrees of certainty in science. The first level is an hypothesis that can be tested as a way of understanding the cause of observed phenomena. If the hypothesis continues to be supported by various studies, it eventually reaches the status of a theory. Continued support of the theory eventually elevates it to the status of law. Of course, at any time, a study producing data inconsistent with even a law can require that it be modified or replaced, but the likelihood of this decreases from hypothesis to theory to law. [SEDF1, VNOS]

During the interview we discussed how they thought a theory may make the transition into law.

> Scientist: $E = mc^2$ was initially a hypothesis. Now it is a theory of relativity. Sometime it will be the law of relativity. It wasn't initially the theory of gravity. It was a hypothesis. That is a law now. Everything has continued to support that. At some point, I don't know if there is a rule for when things become a law. I think it is sort of by convention maybe somebody starts calling it a law and people just agree.
> Researcher: Do you all just vote or what?
> Scientist: I've never gotten to [laughs]. That may be something. There are conferences of zoologists for instance who establish rules for scientific nomenclature and things like that. There may be some body of physicists that meet to decide that this theory has become … reached the status of a law, get some agreement on that. Biologists fight among each other too much. The physicists work together … [SEDF1, interview]

Another participant was asked for an example of a change in status.

> Scientist: A law, I consider to be something that is at least at the time and space in which it is generated, it is an invariant statement about nature and how it works … For a law is in a sense a very very established theory. That is what I would say. I recognize a law in one generation may turn out to be a theory … may lose that status in another. But that is a rare phenomenon.
> Researcher: Do you have an example of that happening?
> Scientist: Well, for example, I mean, the way that Newtonian mechanics was a sense found to be only a special case on Einstein's theory of relativity …

that was sort of … well they didn't lose their status of laws, but they somewhat, well they lost some of their status as the … the broadest overarching statement you could say about … .they were subsumed by something that came after. … [tries again to find an example … unsuccessfully]

Researcher: Are there cases where theories have become laws?

Scientist: Oh Yeah … I think … uh … uh … uh … uh … [long pause] … …

Researcher: First of all, what would make that happen?

Scientist: uh … I think if the theory is found to be substantiated by multiple lines of evidence, repeated by multiple people over a sufficient length of time.

Researcher: What makes it sufficient?

Scientist: Well, that it … it is all a level of agreement. It is all in the agreement … it is all in your view … what we agree on changes. We agreed that the Earth is the center of the universe and then at some point somebody came up with a theory that said it is not. There were enough other observations that could be fit in that new theory that were not explained by that other theory … Plate tectonics is another one, it is a funny one because it has been a theory for a long time … There is something there, you know, with how the continents align, but there was no mechanism; no one could figure out how it happens. So is plate tectonics a theory? I think it is more than a theory. It is a principle. Now whether it is a law in the same way that force equals m a is a law, I am not sure. There is a certain complexity, but are the continents moving? Yes they are moving. You cannot explain the forms of the world without that. It doesn't make sense. Something which has that quality to it, I call a law. I move it out of the realm of theory … [gELF2, interview]

His examples and attempts to find examples are consistent with his view of difference in power of explanation based on certainty. His views about certainty and status are consistent. As ambiguity decreases, certainty increases, as such, status increases. He views laws as having higher status compared with theories. However, he could not solidify an example of change in status in either direction. This discrepancy was dismissed as simply not making sense. In his view, the status change *should* happen and at some point *would* happen. This view suggests there is a point at which the "community" agrees to make the switch. Several other participants expressed similar views. Yet they themselves have not been involved in making any decisions about status changes and they were not successful in providing concrete examples. Yet they maintain the community must decide because such a process fits with their conception of law and theory. Some scientists suggested calling certain theories "laws" in light of their centrality to the field and acceptance through repeated confirmations.

> I would classify 'atomic theory' as a law, in that it is as well confirmed and as central to the field. [gEL3, VNOS]

Others did not see that laws apply, again due to their view of laws as infallible. Here we see consistency between views of laws and views of the tentative NOS. They saw a hierarchical relationship, but laws as truly unlikely because scientific knowledge is inherently tentative. Many of the statements were critical of conventions of labeling theories and laws and showed preference for calling everything a theory that had an evidentiary basis.

> But a law really is a theory. It is just a theory that people have been using for so long that people have stopped calling it a theory. Again I don't believe in certainty at all in science. I don't believe certainty exists. I believe we approach certainty as a limit, but we don't get there. I guess you could use a law for something known, like gravity. It exists. Gravitational theory, we refer to gravitational theory, but it is a law. It is as close to a law as one could get. You drop a ball and it falls to the ground, and we know why. We know those masses attract. In my own science, we very very rarely actually deal with things on that level with certainty, so it doesn't come up much. [BEF1, interview]

In discussing whether laws change, one scientist responded, "Yes, obviously, because a law is nothing more than a theory dressed in fancier clothes."

Theories and laws are different types of knowledge, but not hierarchical. Eight of the 24 saw theories and laws not as hierarchical, but as different in terms of generality and complexity.

> A law is a well established phenomenon that can usually be described with a few words or single equation. An example would be the laws of conservation of energy or matter. Theories are more general and more complex statements of a set of principles and predictions about some natural phenomena. For example, a well established theory is evolution by natural selection. This can be described briefly but the theory is very wide and deep encompassing many topics and many diverse lines of evidence. [eDF2, VNOS]

In the following exchange, a physicist describes theories as having solid evidentiary basis. This view was accepted among most of the participants. He then describes theories and laws with respect to levels of complexity. The connection of this participant's views to his field of physics is clear, but then he generalizes beyond physics to the broader domain of science.

> Scientist: Theory we mean something exact, something complete, something we think is the final answer. So for particle physics there is a theory now known as quantum chromo dynamics. It is a field theory … . To solve that problem requires exchange of 16 different particles simultaneously. So it requires hundreds of equations to be solved simultaneously, and they are integral equations … But in theory one has a complete mathematical description.
>
> … The theory is the Bible; the law is the Ten Commandments. You know, you'd say there often are a few basic laws which express a lot of what is in the theory, basic principles you might call a law. And if you look at it more abstractly, many of what we call the laws of nature are conservation laws, at least in physics. They are a direct consequence of symmetry in the world. … Theories don't have to be simple. Laws tend to be simple. Like the Ten Commandments. Those are the basic laws …
>
> Researcher: Do you think laws can change?
>
> Scientist: A physicist always has an open mind. If there is a law, it means, this is what experiment has showed us it holds. Then what typically happens it only holds in the realm of validity where the measurements have been made. It might be that the measurements, if they are made at the atomic or subatomic level that the law no longer holds. So you don't say the law doesn't hold, or is no good, you say it doesn't apply in this realm … [lTC4, interview]

Differs by discipline. A few of the scientists (six participants) mentioned differences in specific science disciplines to explain how laws may or may not be appropriate.

> Researcher: Do biological sciences have laws like the examples you have given for physics or chemistry?
>
> Scientist: Yeah, in fact I think there are more laws, at least from the way I look at it, than biologists believe, and they just haven't learned how to use the information that is available from chemistry and apply it to biology … [OEL1, interview]

> Most theories and laws involve physics and chemistry, both of which I know little about. In biology, when you involve the element of life (neurological function and complex gene sets) there are always surprises and no laws, therefore only theories. [mDF2, VNOS]

No laws in own field of research. Six participants specifically stated that laws do *not* apply to their particular field of research. Most of these related to the idea of laws representing "certainty" and that within complex systems, certainty was not attainable.

> We have no laws in atmospheric sciences. Things are too nebulous to really speak of laws. Everything is almost a law, approximate. We certainly use the second law of thermodynamics. That is one of our backbones. The other one is conservation of energy. The other one is conservation of momentum. These are laws. So we use them [cDFC2, VNOS]

> Very interesting questions. In my field, there is no such thing as scientific law. Law somehow implies infallibility, which is impossible given the bizarre way that science works … nothing is a certainty in science, making "laws" unrealistic. [MEDF1, interview]

Discussion: Views of scientific theories and laws. Participants demonstrated well-articulated and fairly consistent views of scientific theories, but some wavered in describing scientific laws. Over one-half reported hierarchical views that theories develop into laws with repeated testing and/or after sufficient time. Differences within and between groups appear similar, with the slight exception of those scientists engaged in both experimental and descriptive research. This group tended to cluster slightly more within the hierarchical subcode than the other approach groups (four of the five E/D participants). Nonetheless, there are no clear patterns in responses that suggest one particular group of scientists hold a different view from another group.

Unlike typical hierarchical view of theory and law, most of the participants maintained laws as tentative knowledge claims. Prior research has described a typical hierarchical perspective involving laws as theories that have been proven true through repeated testing (Lederman et al., 2002). None of these scientists used or suggested "proven true" to describe the transition from theories to laws. They tended to use the idea of a consistently established theory, historical use of terminology, and even the suggestion of a community vote to mark the use of the word "law" in a hierarchical transition. In this sense their hierarchical view was not typical of teachers' and students' naïve views (Abd-El-Khalick & Lederman, 2000; Lederman et al., 2002).

In this regard, the scientists' views of theory and law were consistent with their views of the tentative NOS. Recognizing differences in the application of laws based on discipline is consistent with considering different levels of certainty in knowledge claims. Some reported laws to be more certain than theories, and this certainty depends on the discipline under study, especially as related to the complexity of the system within the discipline. In this view, those fields that are seemingly less complex, with variables that are more controllable and predictable, are more likely to have established laws, and, thus, have more certainty attached to them. With increasing complexity comes decreased certainty, and thus decreased development of laws. Although somewhat inconsistent with the accepted classifications of scientific theories and laws, the argument is logical.

Mayr (1997) described laws in biological sciences as distinct from laws in the physical sciences. Some of these scientists held similar views that laws differ with scientific disciplines, and even that there are no laws in their field. Despite only six scientists falling into these two subcodes, there may be discipline-based distinctions in expressed views. The life scientists and ESS not only saw differences based on discipline, but they also claim there are no laws in their field of research. In contrast, the physicists and chemists saw laws similarly across all the sciences. What is intriguing about these results is that there are no notable patterns between how laws are defined and the applicability of laws within disciplines. How views of theory/law may relate to use of theories and laws within different disciplines and investigative approaches should be explored further.

Observation and inference. Only 14 of the 24 scientists affirmed a role of inference in science. This low total may be a function of the instrument, as the responses from the other 10 scientists did not provide a clear indication relative to this aspect. Statements indicative of "affirming inference" tended to be subtle and contextualized within remarks related to other topics.

> The facts of science go beyond just experimental data. The facts of science involve interpretation of experimental data … A fact of science is that energy is conserved. A lot of information goes into that. [kEL4, interview]

> The conclusion can often be very abstract or subtle … I think what is very hard for people not in the field [of particle physics] to appreciate is how indirect the measurements are. So they are not direct measurements like you make with a ruler. There is much inference. There are many steps. So you say you are measuring something that has nothing to do with a ruler or devices. It almost always has to do with counting events. [lTC4, interview]

Discussion: Views of observation/inference. Except for lacking representatives from the ESS group and abundance of representatives from the physics group in the "affirm inference" subcode, there are no other clusters or trends based on discipline or approach. Overall, this sample acknowledges a central role of empirical observation and requirement of inference. These results are consistent with their views of the empirical NOS and creativity. The context-laden responses are an indication of sophisticated understanding and application of observation and inference in their practice.

Discussion and Conclusions

Are Variations in Scientists' NOS Views Related to Authentic Science Context?

Scientists' NOS views have been described, compared and contrasted. The results show that these participants' NOS views are complex and multi-faceted. The results demonstrate connections between *individual* authentic scientific contexts and these scientists' views of NOS. However, their views are not necessarily consistent with any particular philosophical position, nor do any patterns emerge to suggest a predictable relationship between NOS views and science discipline. It is important to note that the purpose of the present study is not to align these scientists with any particular philosophical stance (e.g., relativist, absolutist, etc.). The variations described here provide evidence that these scientists do not all hold to the same view of "the" NOS. What "the" NOS *is*, is not the point of the study.

On a broad level, we find consistencies in description and applicability with respect to particular features of NOS. That is, the main categories of NOS apply across all the contexts of these scientists, and many of their broad descriptions were similar. What these results indicate is that, on the level of broad generality, NOS views do not seem to differ according to science disciplines or investigative approaches. The more subtle complexities emerge within the details, those being represented by the multiple subcodes with only a few occurrences therein. Some of the variation may be related to contextual issues of discipline and/or research approach, yet no *overarching* pattern emerges that serves to explain all the tendencies observed. Variations in these scientists' views are more idiosyncratic, emerging at levels of specificity that are tied to *individual* contexts and experiences, as opposed to broader discipline levels. These differences are interesting in their own right and worth exploring further; however, they are probably beyond practical application to K–12 science.

For the finer scale differences we do observe, we cannot pose explanations or identify trends based on discipline or approach only. For example, the chemists and the life scientists clustered similarly with the experimentalists and the E/D combination scientists for some of the categories. All the chemists and one-half of the life scientists were also experimentalists, and four of the other five life scientists were E/D scientists. As such, when these groups clustered together, the common factors are both disciplinary and investigative approach. Most notably distinct, however, were the theoretical physicists. They had a greater tendency to cluster differently from other groups. That these four scientists stood apart from the rest suggests something about their experience, be it knowledge, research experience, scientific community, or something else, perhaps being related to their different perspectives. This group, having somewhat different perspectives in comparison with the other discipline and approach groups, suggests situational features similar among these scientists may inform views of some aspects of NOS. This claim should not be overstated, however. Clearly, the views expressed by these participants are contextualized within their authentic practice. However, the extent to which the relationships are predictable based on discipline or an investigative context is equivocal from these results.

Why is there not a Consistent Pattern?

The fact that there are typically 50% or fewer participants represented within the subcodes suggests the level of description may be too specific to identify a pattern. That is, beyond the general affirmation and broad descriptions of categories as they apply within the scientist's research, the participants provided details very specific to their contexts. In doing so, detailed profiles and descriptions of participants' contexts were generated. Many subcodes emerged, and there is low overall frequency within many of the subcodes. The emergent subcodes enlighten the finer detail of these participants' views of NOS. It is at this level of specificity that most context-based variances in views were identified. Given the low overall frequency, these trends appear idiosyncratic in nature. It is likely that broader representation of the subcodes would dissolve these subtle differences. The results support the notion that the agreed-upon aspects of NOS are applicable *across* science contexts and consistent with the guiding framework for what is appropriate for K–12 science curricula (Osborne et al., 2003; Smith & Scharmann, 1999; Smith, Lederman, Bell, McComas, & Clough, 1997). Moreover, these results do not support a need to address different positions of NOS depending on the science discipline being studied (Alters, 1997).

Scientists' epistemological views of science: informed or naïve? Prior studies often put results in terms of "adequacy" of views as they compare with the desired, contemporary perspectives. This position is considered the "informed" view. As is evident in the subcode frequencies for the total sample and as discussed above, the scientists in this study did not necessarily hold informed *or* naïve conceptions. They were neither all here nor all there—but everywhere. Compared with other studies involving scientists, these scientists demonstrated somewhat more informed conceptions than has previously been reported (Bell, 2000; Glasson & Bentley, 2000; Kimball, 1967–68; Pomeroy, 1993). With respect to views of the tentative NOS, the results here are more similar to those reported by Yore et al. (2004) where the scientists' views were described as "evaluativist." Nonetheless, engaging in authentic scientific inquiry as a successful member of the scientific community is not *necessarily* sufficient in and of itself to ensure informed conceptions of NOS, or conceptions the same as others within the scientific community. Those who engage in authentic scientific inquiry may or may not develop NOS views aligned with positions for scientific literacy. Those views may be bound to the context of the individual scientists, and, as has been shown in this study, individual contexts vary considerably across and within disciplines. These results also provide further evidence that success within the scientific community does not depend on views of NOS (Elby & Hammer, 2001).

Consistency and interdependence among aspects of NOS. These scientists were consistent in their NOS views. For example, those who viewed science as inherently tentative did not report that scientific laws are definitive unchanging facts. They either reported laws were also susceptible to change or laws were not applicable to science because science is inherently tentative. In general, there were few inconsistencies or inappropriate examples. Moreover, the quotations and discussions show that many of the participants were able to demonstrate interconnections among aspects of NOS. These scientists as a group were considerably more definitive and sophisticated by means of demonstrating connections, providing examples, and showing conviction in their perspectives, than teachers or preservice teachers from prior studies (Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Pomeroy, 1993; Schwartz & Lederman, 2002). A recent study of research chemists and chemistry graduate students support the suggestion that sophistication and consistency in responses correspond to level of research expertise (Samarapungavan, Westby, & Bodner, 2006). We suggest future study to explore NOS views held by scientists at various levels of their careers. When and under what circumstances are definitive and consistent views evident?

Implications for science education: The adequacy of the generalized treatment of NOS. The relationships that emerged in this study were primarily idiosyncratic and specific to the few scientists within subgroups. The level of specificity, the examples provided, and the extent of the participants' reflection on their years of practice yielded descriptions of sophisticated epistemological views. The practical application of the expressed detail to the classroom is questionable. At the broad levels of generality, the subcodes with the highest frequency, the scientists demonstrate overall consistency. The results lend support to the growing consensus on aspects of NOS that are relevant within authentic science settings (Osborne et al., 2003; Smith & Scharmann, 1999; Smith et al., 1997). This and the impracticality of introducing all the finer perspectives of authentic science practice into school-based science lead to the conclusion that the generalized treatment of NOS across science disciplines is appropriate for K–12 science. With the numerous distinctions and nuances associated with authentic science practices, there is a danger of losing the "forest through the trees" if those nuances are the focus of science instruction rather than the broader, overarching commonalities among the contexts. A focus on differences may muddle the broader concepts. Instructional objectives for NOS are probably more attainable and relevant to the goals of scientific literacy when kept at levels of generality shown here to apply across science disciplines and approaches. It is important to be mindful that the target of scientific literacy is the general citizenry. All individuals are consumers of science, all types of science.

Redefining "generalized" to embrace connections across diverse contexts. We recommend that K–12 science should target the development of generalized NOS views, where the "generalized" classification includes: (1) understanding of the core categories of NOS, as described in reform documents and broadly in this study; (2) understanding connections among NOS aspects and science experiences; and (3) recognizing that aspects may manifest themselves in a variety of ways, that is "variability by context." This redefined level of generality presents a comprehensive picture of NOS that is inclusive of authentic science practices. The trends and, moreover, the variability within and among the groupings have implications for teaching about NOS. Basically, a one-size-fits-all approach to scientific *inquiry* is not representative of authentic science practice and probably not appropriate for advancing consistent and desired epistemological views of science, even through explicit/reflective means. Even though the generalized NOS aspects are appropriate across disciplines, opportunities to learn how NOS can connect across disciplines may be overlooked. A variety of contexts may be required, along with explicit instruction, in order to more fully encompass the essence of authentic scientific inquiry and NOS as represented among the sciences.

Our message to teacher education and professional development is one of raising awareness. Programs should consider the inquiry experiences and associated explicit NOS instruction provided to their students. How representative are these experiences of authentic science? Are additional experiences and explicit instruction needed to address an inclusive view of NOS as advocated for scientific literacy? If one discipline or one approach is utilized to teach about NOS, the resultant view may not represent science as a complete domain due to unexpressed connections across contexts. Even though NOS aspects apply, the teachers and learners may not see connections. Learners may not easily transfer NOS conceptions from one science context to another. Further, newly developed views are not necessarily robust (Akerson, Morrison, & McDuffie, 2006). Multiple learning experiences targeting a consistent NOS message may help establish and reinforce connections between NOS and science contexts (Abd-El-Khalick, 2001; Akerson et al., 2006; Lederman et al., 2001). We recommend further study to explore the impact of single versus multiple inquiry experiences on epistemological views of science.

These results are limited by these participants, their contexts, and the researchers' interpretations. Contextually based influences need further exploration to establish the generalizabilty of these results among scientists in these disciplines and others, as well as the application within classroom-based science. To better understand the finer nuances of context and epistemological views, we recommend inquiries into deeper situational features that may elucidate associations among experiences, of theoretical physicists for example, and NOS views.

Implications of methodology: The importance of facilitating reflection. Reflection on experiences with science, either in the classroom or authentic setting, has been identified as a critical element necessary for formalizing views of NOS (Schwartz & Crawford, 2004). However, as several participants reported, scientists do not typically reflect on their practice (Glasson & Bentley, 2000), and this has been posited as a reason for holding more traditional, absolutist, objective views of science (Kimball, 1967–68; Pomeroy, 1993). Furthermore, a study of preservice teachers in a science research internship suggested those individuals most closely aligned within the science community had the most difficulty responding to philosophically-focused questions (Author et al., 2004). For the present study it was necessary to facilitate the participants' reflection through the questionnaires and interview prompts. Given the individualized nature of data collection, these participants were encouraged to reflect on their work in a philosophical sense that was challenging and novel to most. Probing follow-up questions often resulted in further details and reflections. Some stated they had continued to think about the issues after filling out the questionnaires, or gave thought between their initial reading and filling them out or giving the interview. The two-part approach may have helped these scientists become reflective and voice views previously unconsidered. Finally, given that there were 25 years average research experience per participant, these scientists were experienced. Perhaps that longevity was a luxury or a comfort that was key to transition-ability, a requirement for reflection (Schwartz et al., 2004). Without the reflection, the details and level of sophistication voiced here, such as the connections among categories, may not have emerged. It is also possible that the act of reflection is a treatment itself. Where many of these scientists had not previously reflected upon and formalized their views, the opportunity to do so, through the guidance of the questionnaires and interview, may have influenced the views they eventually reported. Future study of scientists and science learners at various stages of education and career may help us better understand features of transition-ability and identity as they relate to NOS views.

The reflective responses contribute to our understanding of general and subtle connections between NOS categories and authentic science examples. Many of these subtle connections described in this study have not been identified in prior studies. This study contributes to overall understanding of scientific practices and scientific perspectives. The research examples and perspectives from contemporary practices place scientific inquiry in real time and real places, being conducted by real people. The variability *within and among* science disciplines is evident, exemplifying scientific inquiry and the communities of science as dynamic and diverse. The examples, quotations, and results from this study may be useful for teachers and teacher educators to portray NOS with examples from contemporary science.

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Appendix. Views of Nature of Science Questionnaire, Scientist version

VNOS-Sci

Name:_________________________________
Date: _________________________________
Science research area/discipline: _______________

Instructions

❑ Please answer each of the following questions. Include relevant examples whenever possible. You can use the back of a page if you need more space.
❑ **There are no "right" or "wrong" answers to the following questions. I am only interested in your opinion on a number of issues about science.**

These questions aim to elicit your views concerning science as it is practiced within your own research area. Please consider this authentic context in your responses.

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2. How are science and art similar? How are they different?
3. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus.
   (a) How certain are scientists about the structure of the atom?
   (b) What specific evidence, or types of evidence, **do you think** scientists used to determine what an atom looks like?
4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with examples from your own research, if appropriate. If not appropriate, explain why and provide examples from another area of science.
5. (a) After scientists have developed a scientific theory, does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change:
     - Explain why theories change.
     - Explain why we bother to learn scientific theories. Defend your answer with examples.

   (b) After scientists have developed a scientific law, does the law ever change?
   - If you believe that scientific laws do not change, explain why. Defend your answer with examples.
   - If you believe that scientific laws do change:
     - Explain why laws change.

- Explain why we bother to learn scientific laws. Defend your answer with examples.

6. (a) What is a scientific model?
   (b) What is the purpose of a scientific model?
   (c) Describe a scientific model from your own area of research, if appropriate. If you do not use scientific models, describe a scientific model from another area of research. Describe why your example is a scientific model.
7. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
   - If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why and how scientists use imagination and creativity. Provide examples from your own work.
   - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples from your own work.
8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two have enjoyed wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and **use the same set of data** to derive their conclusions?
9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

- If you consider science to be reflective of social and cultural values, explain why and how. Defend your answer with examples from your own work.
- If you consider science to be universal, explain why and how. Defend your answer with examples from your own work.
- If you view some science as universal and some as reflective of social and cultural values, explain why and how. Defend your answer with examples from your own work.