

Exploring contextually-based views of NOS and scientific inquiry:

What scientists say

[tentativeness, creativity, scientific method, and justification]

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Paper presented as part of the related paper set, "Setting an empirically supported and synergistic agenda for research on nature of science," National Association for Research in Science Teaching, San Francisco, CA. April 3, 2006.

To promote epistemological views of science (nature of science and nature of scientific inquiry), reforms recommend scientific inquiry experiences as a context for learning (AAAS, 1993; NRC 1996; 2000). This approach draws appeal from a situative perspective of learning and knowing (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Yet potential influence of the learning context on epistemological views has not been examined. This study begins to address this question in terms of variance in science discipline and methods of inquiry within authentic science practices. The present report is derived from a comprehensive look at scientists' epistemological views of science (Schwartz, 2004). Here we discuss just a few of the features found in the larger study, with the additional purpose of discussing the methodology of eliciting views from the perspective of the scientist's context.

Nature of Science [NOS]

Reform documents (AAAS, 1990, 1993; NRC, 1996) and international science education efforts (see, for example, Hodson, 1998; Matthews, 1998; Millar & Osborne, 1998; Osborne et al., 2003; Ryan & Aikenhead, 1992) present descriptions of NOS that include common generalities. These general tenets 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 which 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.

Nature of Scientific Inquiry

The NRC (2000), AAAS (1993), the National Academy of Sciences (2002), science educators (e.g. Chinn & Malhotra 2002; Harwood, Reiff, & Phillipson, 2002; Hodson, 1998; Minstrell & van Zee, 2000), and researchers who have explored scientists in practice (e.g. Dunbar, 2001; Knorr-Cetina, 1999; Latour & Woolgar, 1979) offer descriptions of scientific inquiry, beyond basic investigative skills, that share commonalties. These commonalties are utilized here as a basis for agreed upon aspects of the nature of scientific inquiry deemed relevant and important for science education. The general aspects of nature of scientific inquiry include: a) multiple methods of scientific investigations, b) multiple purposes of scientific investigations, c) the form and role of argumentation in the development and acceptance of new knowledge, d) recognition and handling of anomalous data, e) sources, roles of, and distinctions between data and evidence, and f) community of practice. The relevance of "community of practice" to science education is within processes of peer review and communication that are associated with negotiating meaning within a social setting.

Why the distinction between NOS and NOSI?

For our purposes we distinguish between NOS and NOSI, yet recognize this distinction as incomplete, with areas of overlap. NOS aspects are those that pertain most to the product of inquiry, the scientific knowledge. NOSI aspects are those that pertain most to the processes of inquiry, the “how” the knowledge is generated and accepted. The NSES also offer some distinction between the nature of the product and the process. The content standards regarding “understanding about scientific inquiry” guided the generation of our NOSI aspects (e.g. The inquiry content standards present the objective that students should understand there are “multiple methods” to scientific investigations.). We recognize the interdependency of NOS and NOSI.

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 & Woolgar, 1979). The education community, philosophers of science, and scientists recognize distinctions in the nature of science disciplines and practices, including conventions of evidence and justification of claims (e.g. Ault, 1998; Mayr, 1988; 1997; Ruse, 1998; Spieker, 1972). We 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-16 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 (AAAS, 1993; Abd-El-Khalick, Lederman, & Bell, 1998; Chinn & Malhotra, 2002; Elby & Hammer, 2001; NRC, 1996, 2000). That is, the science education literature describes aspects of NOS and scientific inquiry in a manner specific to the domain of science, but not specific for particular disciplines *within* science. The agreed upon tenets are understandably applicable across science fields, yet how learners within different contexts understand those tenets may vary. If the disciplines are different, perhaps understandings of NOS and NOSI are also different. Recent work has provided insights into contextually-based epistemic views of chemistry students and chemists (Samarapungavan et al., 2006). Their work suggests discipline-specific aspects of science that the general NOS descriptions may overlook.

Given the emphasis on relating NOS and scientific inquiry through inquiry-based 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 qualitative methods, allows us to address questions concerning contextual-based variance in epistemological views. We explored (1) scientists’ views of NOS and NOSI and 2) potential contextual connections between views of NOS/NOSI and scientific discipline (Schwartz, 2004). Participants were 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 summarizes main findings of the larger study and discusses methodological issues in eliciting views from scientists from the perspective of their research context.

METHOD

Perspectives of scientists were sought through a two step process of open-ended questionnaires and interviews. The aforementioned aspects of NOS and NOSI served to frame questionnaire and interview items and the initial analysis. The sample was 24 practicing scientists (6 female, 18 male) from across the United States and representing four primary science disciplines and a variety of subdisciplines (Table 1). 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 PhD 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, information on C.V. and websites. In addition, all participants were asked to identify themselves within a science discipline.

Data Collection and Analysis

The VNOS-Sci and the VOSI-Sci are open-ended questionnaires that elicit views of NOS and NOSI (Appendix A). The questionnaires were adapted from the instruments of Lederman et al. (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 questionnaires for face and content validity. Further validation was established through participant interviews.

Thirty-four initial participants were electronically sent the two questionnaires; and requested to send back current vitae and research description. Twenty-four completed the data collection process. Seventeen of the 24 final 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. The remaining five preferred to give their responses through the interview only. The most common reason 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. Many indicated having thought about the questions in the interim between filling out the questionnaires and the interview. 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 hours each. All were audiotaped and transcribed for analysis.

Consistent with the reform-based framework of the study, data collection and analysis sought scientists' conceptions of the predetermined features of NOS and NOSI deemed important and appropriate for a scientifically literate individual. As such, these predetermined aspects of NOS and NOSI guided the instrument design and 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." Additional themes associated with the scientists' epistemological views emerged through analysis. After individual profiles were generated, similarities and differences were sought based on the context of the scientists. Due to sample size, no statistical measures were employed. The results are descriptive.

RESULTS

Here we summarized a portion of the findings from the comprehensive study. Full results can be found in Schwartz (2004), Schwartz & Lederman (2004), and Schwartz & Lederman (in preparation). Described are results for the total sample and comparisons of NOS/NOSI 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 4 of the 5 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.

Main Aspects and Emergent Subcodes

There were 14 initial NOS and NOSI start 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 offered forth by the participants through questionnaire and interview responses. Not being represented within a subcode means the participant did not make a statement aligned with that position which was offered by another participant. The final 16 categories were:

- | | | |
|------------------|-------------------------|-------------------|
| ■ Tentativeness | ■ Observation/inference | ■ Justification |
| ■ Empirical | ■ Models | ■ Reproducibility |
| ■ Subjectivity | ■ Purpose | ■ Data/evidence |
| ■ Creativity | ■ Experiment | ■ Prediction |
| ■ Socio/cultural | ■ Methods | |
| ■ Theory/law | ■ Anomaly | |

Scientists' Epistemological Views of Science

Table 2 lists results for 10 of these 16 categories. The first seven main categories are the targeted NOS aspects. The eighth is “models” and is included here as models are both products of investigations as well as tools used in investigative practices to develop additional knowledge. A separate paper dedicated to scientists' views of models is forthcoming (Schwartz & Lederman, 2005). Results for “methods” and “justification” are included as examples of categories more relevant to NOSI. Table 2 also presents results when scientists are grouped by discipline and by approach. The current discussion summarizes a few features of these results (tentativeness, creativity, scientific method, and justification), with full description of all aspects available in the aforementioned documents.

These participants' epistemological views of science 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. The results for categories of NOSI are similar in consistencies across disciplines, with a couple of exceptions (justification and prediction) (Schwartz, 2004).

We have chosen to discuss results for four of the categories in order to demonstrate the type of responses gathered, our interpretation of responses, and the contextual connections revealed by the participants. These examples also demonstrate the wide range of views within and across disciplines and research approaches, and exemplify how patterns were and were not suggested. For each of the four categories, we describe some of the subcodes and provide representative quotations. A discussion of the results follows each category.

Tentativeness

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 superseded 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. [ITC4, int]

In relating his ideas about “disproving” in science, one of the molecular biologists revealed that his views had changed since becoming a scientist:

S: [in explaining hypothesis] The concept of hypothesis is actually very important because you can never prove yourself right. You can only prove yourself wrong. ...But you collect data and you can have an idea and make a prediction as to what it might be and that is what your hypothesis is, and you test that. If it doesn't work, you know something is wrong with your hypothesis. ...My view has changed a lot from when I started out. I couldn't believe in Kuhnsian paradigm shifts.

R: When you first started?

S: Yeah. Well ‘of course there is truth in knowledge’, you know. Everybody knows what is right and wrong and it's absolutely true.

R: As a graduate student you held these views?

S: No, more as an undergrad. [OEL1, int]

Others related their view 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:

S: 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.

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

S: 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, int]

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...And of course, just the uncertainty. We've got all these uncertainty laws...ocam's razor, Heisenberg's uncertainty. 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, int]

Approaching certainty or attaining certainty. Some scientists held views that science attains certain knowledge (5 scientists) (that being absolute knowledge of the reality separate from the observer) or that science progresses nearer and nearer to certain knowledge (4 scientists). Those who suggested scientists can attain certain knowledge, they often implied achievements of pure discovery. These views suggest potential for little to no negotiation of meaning from data.

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

If you mean valid in the sense of true, I don't think that is knowable, *at least not immediately*. You get more and more certain with passing time. [SEL1, int]

This latter participant also indicted patterns in nature are “there to be discovered.” 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, int]

There were only four scientists who indicated there were differences in the certainty of the knowledge that was attributed to differences in complexity of the system involved (16.7%, 4 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]

R: Do you think there are some areas of science that may be more certain than others?

S: 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, int]

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, int]

Discussion of tentativeness

Only 46% of the sample demonstrated views that 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 involved 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 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 this 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 (2000) considered open-mindedness. However, except for the nine 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 have the greater tendency toward absolutist views? These results are contrary to what one might expect given the “hard science – soft science” continuum (or demarcation in some cases) that is often 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, 2000; Mayr, 1997; Spieker, 1962). With seemingly more variables and less control of the system, one might expect those in the life sciences and Earth and space sciences to hold more relativist views of scientific knowledge as compared to the physicists and chemists. Likewise, one might expect those engaging in nonexperimental research to hold relativist views in comparison to the experimentalists. The results of this study do not support these conjectures. The fact that one of the atmospheric scientists demonstrated more absolutist views 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.

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. The following are typical responses when participants compared art and science.

Both are creative; both have a mixture of individuality and community; both are conducted within the mind of the individual. The difference lies in repeatability. [PEDF1, vnos]

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, int]

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, int]

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

[Science involves] putting things together in ways not previously connected. [GDF2, int]

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, int] [emphasis added]

No role in making meaning. 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.

S: Creativity periods are in the beginning, when we had these great observations of El Nino but the models couldn't explain it. Then we got to the point where we could explain the historical record, did a great job on that, then a new one came and it didn't do a good job. We realized there were different regimes in the ocean....So the most creative work has happened when those periods where everybody just doesn't understand.

R: How about data analysis?

S: Uh...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, int]

I do not work directly with data, so cannot give examples of that type. Others working in my field do take data, and the act of creativity is focused on the design of the device to take the data. [pTC4, vnos]

Connections with other aspects. 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, int]

Discussion of Creativity

A majority of the participants affirmed a role of creativity, and some made connections between creativity, inference, and subjectivity. 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, p. 55-56)

For the given data set, most of these scientists consider scientific knowledge to partially be the product of creativity and inference, yet 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. One of the questions on the VOSI-Sci (Schwartz, 2004) asked the scientists to compare “data” with “evidence.” The nature of the discussions about data and evidence and means of justifying one’s claims was very different from the nature of the discussion about science and art, even though both topics could introduce ideas of creativity in making meaning of data. 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, a 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.

Methods

The multiple subcodes for this aspect suggest the scientists voiced a diversity of views related to methods of scientific investigations. Six participants said there was a single Scientific Method that all scientists use *or should use*. Sixteen participants said scientific investigations could follow multiple methods. The frequencies within the subcodes of “all hypothesis-driven” and “not all hypothesis driven” were similar for the total sample (29.2% and 33.3%, respectively). A third feature within this theme lies within the subcode of “hierarchy.” Nine participants indicated that claims made through experimental methods were more valid than claims made through non-experimental methods. The following excerpt from an interview with an atmospheric scientist illustrates this view:

R: Do you consider some types of science to be more valid than other types?

S: Yeah, I think so. I tell you what in climate change we have a run into a difficult problem. Early on back in the 70s, it was perceived as a physics problem. Fill the atmosphere with these gases and we have these consequences. Which is a physical problem. No question about that. The research funding, and there’s where it hurts, initially that is where the funding went. We have gone for many years now with essentially constant level funding. But now that funding is going into ecology this...ecology that. What happens to this worm in that environment? We have to save the ecosystem of this and the ecosystem of that. The trouble with this is I see these ecosystem studies as ill-posed and open-ended. *Really*

open-ended. Largely simply descriptive with little real predictive capability. And because there are so many different parameters that affect the results, scientists are left to observations so they can't really constrain their study very well. So we didn't really learn anything. So what we are left with is a bunch of descriptive work. When...how the devil are we going to be able to say anything if we don't get the physics in the problem right? So you see the budgets diffuse out to a large number of researchers in various fields and part of that is simply political also. They outnumber use 10 to 1. Congressman A or Congressman B looks at his district and says we need more ecosystem research because he's got 10 people doing that type of work for every physical scientist doing that type of work. It is very clear why the budgets have gone that way. So the result is we still are left with a basic problem. We still haven't solved a physics problem. All this eco-research is going to be meaningless. They will be prepared for something...but we have no idea what for. So there is that type of frustrations.

My feeling is that anytime you have a science that relies so heavily on the eloquent speakers and what not, which I think most of ecology does because people are very good at telling stories, I get suspicious because where is the hard evidence and how does the evidence come together to really make their story? People are really good at making arguments...when you have such open-ended systems how do you really explain what is going on and is that the only answer, what are you finding? That is the first questions that comes to mind is whether this has really gotten us anywhere or not. [explains that one counter example kills the whole point] [cDFC2, int]

This excerpt demonstrates connections among several aspects that relate to this participant's view of experimental methods being more valid than descriptive, such as prediction, socio/cultural issues in terms of funding, and justification. Not all the scientists presented such a view. Some gave equal importance to investigative methods. In response to the VOSI-Sci question #5, structure/function correlation, one scientist said:

That is where being scientific is hugely important. These types of studies [teeth/food source example] are important. It might not get down to the cause of why the difference is there or why the homeobox that caused these teeth to have these shapes. There is a difference in shape. Can you explain how...have a reasonable hypothesis of why it might be that way.

Do I consider it to be an experiment? Not so much. It is an observation. He has not actually done a manipulation to see..generate a hypothesis and manipulate the system to see if this does vary. You can still publish this. You can still address the information. Uh...but it is not actually testing a mechanism. It happens all the time in medicine. [OEL1, int]

This response also provides an example of a scientific investigation that produces justifiable claims that does not have an up-front hypothesis. Another response representative of equal status among investigative methods is seen in the following:

R: if you cannot do manipulations, is it still scientific?

S: yes

R: and are your conclusions equally valid?

S: sure, you can't manipulate gravity, for instance. You can only measure it. But you can make predictions about what the strength of gravity should be in different places and then go measure them to see if the predictions are validated. [SEDF1]

Three participants stated that descriptive sciences were immature sciences that have not yet produced enough understanding to become experimental. Geology and ecology were provided as examples of such immature or “early phase” sciences.

Geology is still in the descriptive phase: this type of mineral is found here; that type is found there...

I think science varies in degrees of intellectual development and varying degrees of honoring of this scientific method. I think there are a number of disciplines, for example, that are very very much tied up with description. That tends to be early in the development of a scientific field where people just don't know a lot. You've got to assemble the basic stuff from which you make the more causal connections.

R: Can you give an example?

S: I think a lot of ecology. You are working with cryptic organismsWe won't understand it. What is the role of predation? What is the relative importance of predation? A lot of what you have to do in that case...it is hard to keep track of all the population. There are big broad areas; they live in the ocean; they live in the wilderness. My job is easier. I work with rivers and water. The laws that I work with are primarily physical laws, laws of force and gravity, density, temperature. Biological systems are much more complex. In order to understand biological systems, before you get to the point of saying, "I think that the salmon are declining because of x and y" you have to understand a lot about the basic building blocks of this fish. That involves a lot of observation. Whereas science ultimately wants to be headed in that direction, it is not there yet by nature of dealing with nature. ...Is it still science? Yes, they are all science. I think they are all to varying degrees scientific. I think sciences that are most mature are those that have integrated experimentation. Physics, chemists, biologists on the molecular level, use experimentation as the primary driver of how to understand things. [GFD2, int]

Discussion of Methods

The fact that some of the scientists stated views of a single scientific method was alarming at first. However, when they clarified their view, only a couple held the traditional view of scientific method as an experimental approach. Thus, the importance of clarifying terminology through the interview process is highlighted with this example. These other scientists were using the term of “scientific method” in a broad way to describe what scientists do, in general, involving asking questions and collecting information and hypothesis testing. Nonetheless, this view may still be narrow with respect to *all* methods of scientific inquiry because of the criterion of *a priori* hypotheses. What is disturbing is that *any* of the scientists hold convictions toward a single Scientific Method in the traditional sense that scientists only engage in a strict step-wise practice of hypothesis-testing and experimentation. According to these narrow views, several participants in this study do not do credible science.

The scientists who said there are multiple methods, and that not all scientific investigations require hypothesis testing, provided examples from their own contexts. Given that these are successful scientists, their multiple methods are examples of scientific research, regardless of the presence of formal hypothesis testing or controlled experimentation. These results further portray authentic scientific inquiry as comprising dynamic, creative, and multiple processes involved in the development of scientific knowledge (e.g. AAAS, 1996; Lehrer, Schauble, & Petrosino, 2001; Knorr-Cetina, 1999; NRC, 2000; Osborne et al., 2003; Simon, 2001; Ziman, 2000). A single method or even a general method requiring hypothesis testing is inconsistent with many of these scientists’ views and reports of their authentic practice.

About the same number of scientists considered hypotheses to be a requirement as considered hypotheses to be dependent upon the approach (29% versus 33%). As with the findings for “experiment” (not included here), the role of hypothesis testing was given opposite priority by

the Earth and space scientists and the chemists. In this category, the chemists and the life scientists favored hypothesis testing, and the physicists and the Earth and space scientists were contrary to the requirement of hypothesis testing.

The results based on group comparisons are difficult to interpret in any strict sense because they are supported by the individual's research context. That suggests the research context for these experienced scientists relates to their perceptions of valid scientific methods. Some are more open than others to methods of investigation and justification outside of their area of expertise. Thirty-seven percent recognized differences in disciplines and considered there to be differences in validity of methods. However, 60% of the E/D combination approach group thought experimental methods are more valid than descriptive approaches. Perhaps their experiences with multiple investigative methods help to clarify distinctions between those methods.

Justification

The VOSI-Sci items #5 and #6, and VNOS-Sci #8 elicited scientists' views of justification of scientific claims. During the interview, participants were prompted to describe what they consider to be requirements within their field, and science in general, to justify claims. Most prominent features included views of reproducibility (internal and external), validity of different investigative approaches and disciplines, peer review, and a need to address alternatives.

Reproducibility. Internal reproducibility (11 participants) deals with replicas within an investigation and measures of statistical analysis. In response to VOSI #5, a participant responded,

Do I consider this persons investigation [VOSI #5] to be scientific? The answer really comes down to how does he present his data and how does he present his conclusions. Are the results there that he can reproduce? [OEL3, int]

The three most recent 'must do' items for wildlifers in the last several years have been power analysis (statistics), AIC analysis (statistics), variable density sampling (a small mammal capture design). Scientists, if anyone, should know that "one size doesn't fit all," but they appear to be a "fashion conscious" group (to my personal dismay). [mDF1, vnos]

Often times I am sitting here reviewing a manuscript that an editor has sent me to review. You will look and there will be some experiment the author has conducted and they will draw conclusions from the outcome of this single experiment. Many times I or another reviewer will raise the question of "this is only one observation." There is no evidence in your work that you even repeated the experiment yourself to give some statistical measure of its reliability. That you can do internally within your own laboratory. Always we like to see multiple observations of the same thing. That gives an indication of the variation within our own experiment. That enables us to establish reliability. If that variation is small compared to the magnitude of the observation, then we are confident that this is probably a

good result. We say it is statistically significant. But if the variation is large, compared to the magnitude of the result, we will have very little confidence in the result. [bEL3, int]

External reproducibility (3 participants) deals with the notion of multiple researchers conducting similar investigations and getting the same results. This was considered separate from “consistency” (3 participants) which was more in reference to theoretical framework and/or current paradigm within the community. Again it should be noted that participants were not restricted to only one subcode, but single quotes were often applicable within multiple subcodes as well as main categories.

A new scientific claim in astronomy is the existence of a new form of energy called ‘dark energy’ which in fact comprises most of the total mass-energy of the universe. The acceptance of this claim has required investigation by several different teams of astronomers using different techniques. The claim must also be consistent with all existing data. [pEDFC2, vosi, 6]

[In reference to VOSI #6, justification of natural selection] Based on just these observations no. That conclusion would need a broader context of data on other physical characteristics and environmental variables. After all, even polar bears like to eat carrots. [pEDFC2, vosi]

Experiment over description. Consistent with the findings for “Methods,” is the subcode of “experiments over description (10 participants). VOSI item #6 sought respondents’ ideas about justifying a causal claim (natural selection) from a correlation investigation. The following response demonstrates this scientist considers controlled experiments to be more valid approach than a correlational study. He rationalizes his position with claims of predictive function.

I mean, you would have to set up real experiments, I think..or, yeah,..controlled situations in which you have controlled source of variability in the population and you have relatively limited sources of food and then... Otherwise you just have a correlation... You have to be able to do something with your conclusion, otherwise it is not justified. [eDF2, int]

The following responses suggest the added complexity of relying on qualitative, rather than direct experimental and quantitative evidence, makes causal claims problematic.

Likelihood of being wrong is much higher than in something like physics where you are colliding elementary particles together. The reason is that you are looking at something that is really rather complicated and the scientist in this instance is looking at one aspect of a full

range of measurements or observations that might be relevant to the question. A chemist might come along, we actually have people who do that type of thing, and do isotopic measurements... We are dealing with an area of science which is complicated and some are more quantitative than others. And this particular example you are talking about, from my perspective, is someone less quantitative and therefore, as a nonexpert looking at this...I am not an expert looking at this...I would find it interesting and worthy of publication, but I would retain substantial skepticism. In the end it would come down to how the results were presented, not whether the results were presented. [sTC4, int]

[In reference to VNOS #8, the dinosaur extinction controversy] The data are incomplete. Also paleontology is an observational science, which makes experiments impossible. The scientists have to work with what they see in the rocks, and make educated guesses about what caused the patterns that they see. If they could do an experiment (revive the dinosaurs and try dropping a meteorite on them) it might remove some of the ambiguity, although maybe not. [KEDF1, vnos]

Some scientists drew examples from other areas of research to suggest experimental results were more justifiable than non-experimental. Interestingly, the following quotes are from participants who engage in descriptive research or a combination of experimental and descriptive research.

Solid, defendable conclusion in science come from repeatable cause/effect phenomena. Because we don't have dinosaurs nor can we experiment with meteorites and volcanoes, all we have to examine is the effect. In the real world, multiple things can cause the same effect. ...It is always difficult to infer cause/effect after the fact (which is why experimental research is far superior to observational research, if it can be done). [mDF1, vnos]

If you can do a clear cut experiment and test a hypothesis, you should go ahead and do so... You set it up first by presenting a hypothesis either from a model or from previous literature or whatever. So once you set up a hypothesis correctly, that is all the justification you need for the experiment. Ok, because that model should kind of state 'here's what I am testing' and if that is what you are testing when the experiment must be designed that is what you are manipulating and it is going to make it very clear that everything else is going to be controlled or explained. [MEDF1, int]

The entomologist studies the effects of clearcuts and forest conditions on invertebrate populations. He saw differences in confidence of claims between investigations he is able to do involving direct manipulations of forest plots versus natural plots.

If you establish plots where the storm went then you are accepting the fact that certain trees blow down because of where they are, so that whatever differences you see could possibly be attributable to local soil conditions or where in the draining it is, whether it is on a ridge or in a valley is going to affect whether it blows down...you know certain things like that.

Where if you go into an area and randomly pick plots that are going to be subject to different treatments, then you have a lot more confidence that it is the treatment that is responsible for whatever the change you see. [SEDF1, int]

Differs with discipline/context. The largest subcode included 14 (58.3%) of the scientists who indicated that means of justification varies by context, both within and across disciplines. Some of the scientists had difficulty answering questions about justification in other fields. As one physicist said, “It is not simple to answer. [Justification] is laden with context. It varies enormously from field to field. Context and comparison is important.” Others were better able to articulate differences based on context:

If I make a claim about a river today, there has to be physics. If I make a claim about a river yesterday or last century or last millennium, it will have a different kind of evidence. But it has to be consistent with what other people know. [GFD2, int]

Generally, we want a true manipulative experiment. However, consider scientists that use genetic similarity to determine evolutionary trees. They cannot go back in time to make observations or conduct experiments. They can test their methods, but not their conclusions – in many cases, this is all that is possible to make a scientific claim. [MEDF1, vosi]

Well, to a physicist, what can be done by experimentation is as close as you can get to the word of God. I mean, you literally can say “the word of God,” meaning this is what nature is. This is the real nature that we like to explore. So you don’t try to replace experiment...as a physicist. As a computational scientist, people in like drug research, they often will use the computer to develop a drug rather than nature because it is faster. And they develop the codes to the point where it agrees with nature perfectly. The same is true for bomb builders, the simulation of nuclear reactors, nuclear piles...it is all done computationally. But as far as a physicist...you don’t beat experiment. That is the ultimate test. What you do have, though, is, anytime you do something on the computer, it is an approximation for the mathematics because you are approximating numbers, which can be intimately precise, which are only stored to a certain length. And so then you ask the question, are your results believable? Are they truly a solution or are they just approximate solution that has errors? So this now comes close, similar to experiment. Yes, you’ve done a measurement, but unless you know how big your uncertainties are, you don’t how reliable that measurement is. [ITC4]

The entomologist included a description of differences among scientists’ perceptions of justified science. The difference lies with the level of certainty and quantification that is possible in different types of science:

A lot of ecologists are accused of having physics envy because physicists don't deal with variation. I've been to.. the climate change workshops... A lot of the attendees were meteorologists, physical climatologists, oceanographers, people like that. They are not dealing with variation. I mean they know if you've got a certain temperature in seawater, this is how much carbon dioxide it will hold. They can measure the fluxes in and out of seawater very precisely. If there is any variation it is due to experimental error. Basically instrument error or something you can control. In ecology, you can get variation from so many different sources, including just the fact that if you do the experiment twice with the same population, you've got different genetics the second time, you've got different experiences if you have long lived organisms. The organisms themselves change in how they respond based on experience. There is just no way...most of our....for example, one of the conclusions from these climate change workshops was the physical climatologists and the folks who study carbon flux were looking for 1.2 gtons of missing carbon in their model. They weren't looking for 1.2 plus or minus anything.... There are just incredible levels of variation in ecology because you can't hold all the conditions constant. If you do, the results are meaningless...Ecology is sometimes viewed as a loose science by people in physics and chemistry. They are just not used to dealing with variation. Where ecologists, I mean, variation....part of our job is trying to figure out what the source of all the different variation are. But is hard sometimes talking back and forth and understanding that, yeah terrestrial forests probably are a source of missing carbon but we probably aren't going to find 1.2 gtons and be that precise. That is not very satisfying for them...But I think it is important for scientists to talk to each other for just that reason. So you can start sharing these perspectives and understand that, yeah how you do research and what you get out of it isn't the same in all the fields. [SEDF1, int]

Peer review. The role of peer review in establishing and maintaining justification standards was expressed by nine participants.

The ultimate test is whether the conclusions serve to change the way others think about the world. I suspect that many conclusions are never check[ed], because it may not make much difference to others whether they are right or wrong. If the results are significant, they will be checked by others, and then the reputation of the scientist hangs in the balance, depending upon whether the project has been carefully done. [jTC4, vosi]

It is hard to fit into one sentence. What makes it valid is enough of your peers saying it is valid. They are basing their opinion on their experiences of what is good and what is not. [SEL1, int]

Address alternatives. Five participants included a need to address alternatives in the process of justification. Without acknowledging and discrediting possible alternative explanations for the data, the conclusions remain suspect.

I think it is incumbent upon scientists when they come up with somethingto be serious about distinguishing it from prevailing theories. And to talk about the critical test that will ultimately distinguish the validity of the two theories. I think that is what distinguishes a lot of good science from bad science. Maybe I'm looking at it from too much of the perspective of an experimentalist, but ultimately I think it has to come down to things that can be measured in the laboratory. That's what science is about. [kEL4, int]

[Justification requires] a conclusive experiment. An experiment in which every other possibility has been eliminated by controls. That would be a conclusive study. If the hypothesis was reasonable, didn't violate any physical laws. The tests were reasonable, all well controlled, all consistent without any anomalies, then that would be acceptable as strong evidence for a particular model. [UEL1, int]

Discussion of Justification

These scientists recognized that the justification and acceptance of scientific knowledge depends on the context in which the knowledge is developed and the community that determines acceptability of the claims. These results suggest that negotiation of meaning is indeed a social activity (e.g. Lave & Wenger, 1991); and a particular scientific/social community has standards that are established *from within* and may not apply across the board of the scientific domain (Knorr-Cetina, 1999; Samarapungavan et al., 2006; Ziman, 2000). Recognizing that there are differences in standards for justifying claims, even though specific differences were not necessarily articulated by all of the participants, is evidence of awareness of science as a domain beyond the individual research context.

The group comparisons for both justification and reproducibility revealed considerably more differences than what was typically found within other categories. An interesting finding from this category was the different focus on use of statistics from the discipline and approach groups. The life scientists, chemists, experimentalists, and E/D groups emphasize statistics for justification, whereas the other groups were well below the total sample percentage. In fact none of the Earth and space scientists or the physicists claimed statistical analysis was important for justifying knowledge claims in their field. The focus of the Earth and space scientists was more on external reproducibility, that being other researchers conducting similar investigations and finding similar results. The physicists discussed the role of predictions and testing in knowledge justification, but with the caveat that this approach depended on the context of the investigation.

The majority of the life scientists and E/D groups' description of use of experiment over descriptive methods to justify claims may be indicative of the standards of their community. The fact that the E/D scientists voiced this view is not surprising given they engage in both practices. This is similar to their claim of validity of methods. Nonetheless, they still emphasized the use of statistics, in contrast to those strictly in the descriptive sciences.

DISCUSSION

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

The larger investigation identified 16 core categories of these scientists' epistemological views of science that are applicable across the science disciplines and contexts involved in this study. On the level of broad generality, epistemological views do not seem to differ across disciplines or approaches. However, there are variations in how these scientists described the

categories, and these variations are represented within the more minor subcodes. Some of the variation can be related to contextual issues of discipline and/or research approach, yet no *overarching* pattern emerges that serves to explain all the tendencies observed. It appears that views vary within groups as between groups. With a few exceptions, variations in these scientists' views are more idiosyncratic, emerging at levels of specificity that are tied to individual contexts and experiences.

Distinctions cannot be made between trends based on discipline and approach. 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 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 routinely stood apart from the rest suggests something about their experience, be it knowledge, research experience, scientific community, or something else, has influenced their perspectives of NOS and NOSI. This group having consistently different perspectives in comparison to the other discipline and approach groups is evidence for discipline/approach-based epistemological views of science, within this sample of scientists.

In total, these results provide evidence for contextually-based epistemological views of science, yet the influential context may be at the individual level as opposed to the discipline level. 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 isn't there 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. It is at this level of specificity that most context-based variances in views were identified. However, given the low overall frequency, these trends are idiosyncratic in nature. It is likely that broader representation of the subcodes would dissolve these subtle differences. Broad representations of inquiry, for example, were found to apply to a range of scientific contexts in the investigation by Reiff et al. (2002). In that study, deeper contextual details were not sought. Thus, for the present study, there are generally no differences between disciplines or investigative approaches with respect to broad perspectives of NOS. The results suggest the general aspects NOS and inquiry are applicable across science contexts and consistent with the guiding framework for what is appropriate for K-12 science curricula.

Scientists' Epistemological Views of Science: Informed or Naïve?

A primary aim of this study was to describe practicing scientists' epistemological views of science. Those views have been described, compared and contrasted. Prior studies put results in terms of "adequacy" of views as they compare to the desired, contemporary perspectives. This position is considered to be the "informed" view. As is evident in the subcode frequencies for the total sample and as discussed above, the results show that these scientists did not necessarily hold *informed* conceptions of all NOS and NOSI categories. Overall, however, these results suggest

these scientists, as a group, demonstrated somewhat more informed conceptions than has previously been reported (Bell, 2000; Glasson & Bentley, 2000; Kimball, 1967-68; Pomerory, 1993; Sumarapungavan et al., 2006). *Yet*, the methodology of this study generated a great deal more description of epistemological views than these studies. 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 and NOSI, or conceptions the same as others within the scientific community. Those who engage in authentic scientific inquiry may or may not develop epistemological views of science 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 demonstrate success of the scientist does not depend on epistemological views of science (Elby & Hammer, 2001).

The results of the present study do show that *many* of these scientists were able to explicate sophisticated views of some of the identified NOS categories, as evidence by their reflective responses. It is the detail and sophisticated explanation that is informative for understanding general and subtle connections between these categories and authentic science examples. With the exception of Sumarapungavan and colleagues (2006) and their study with chemists, many of these subtle, albeit primarily idiosyncratic, connections 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. The examples, quotations, and results from this study may be useful for teachers and teacher educators to portray perspectives and examples from contemporary science.

Consistency and Interdependence among aspects of NOS and NOSI

The results demonstrate that, in general, these scientists held consistent views across the examined categories of NOS. 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 in responses 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.

Implications for Science Education: The Adequacy of the Generalized Treatment of NOS

The epistemic views explored in this study were contextualized on the level of the individual more so than on the level of discipline or approach. 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 consistency. The results lend support to the growing consensus on aspects of NOS that are relevant within authentic science settings (Osborne, et al., 2003). This, and the impracticality of introducing all the finer perspectives of authentic science practice into school-based science, support the conclusion that the generalized treatment of NOS across science disciplines is appropriate for the K-12 context. 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. That is not to say there aren’t important context-based issues

that can and should be addressed to promote an inclusive image of scientific practices. Instructional objectives for NOS are likely more practically attainable and relevant to the goals of scientific literacy when kept at levels of generality shown here to apply across science disciplines and approaches. Yet, as discussed below context *is* important.

The Importance of Variety

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 not likely appropriate for advancing consistent and desired epistemological views of science, even through explicit/reflective means. Even though the NOS and inquiry aspects are appropriate across disciplines, as we have shown, understandings of these aspects may vary based on *specific* experiences (“variability by context”). A variety of conventions, not just methods, may need to be the focus of explicit instruction and experiences in order to more fully encompass the essence of authentic scientific inquiry and NOS as represented among the sciences.

Further study

Contextually-based differences need further exploration to establish the generalizability of these results among scientists, as well as the application within classroom-based science. Teacher education and professional development should consider the inquiry experiences and associated explicit instruction provided to their students. How representative are these experiences of the conventions of authentic science? Are additional experiences and explicit instruction needed to address an inclusive view of NOS as advocated for scientific literacy? Are particular contexts more conducive to learning NOS and inquiry than others? Is there a developmental effect that should be considered when planning learning contexts for NOS? If one discipline or one approach is utilized to teach about NOS, the resultant view may not represent science as a complete domain. Consider, for example, learning about justification of claims only through the perspective of an experimentalist. Such an experience may limit one’s understanding of scientific method and justified claims. Further study is needed to explore the impact of single versus multiple experiences on epistemological views of science. Finally, this study was done with very experienced scientists who not only are a part of their scientific community but have set the rules of their communities through their careers. Do views change as one is apprenticed and then becomes a part of the scientific establishment? Comments within this study and another (Sumarapungavan et al., 2006) suggest they do. We ask how and why, and if understanding these changes might inform classroom science in target areas to help students advance.

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, 2005). 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 their typically holding more traditional, absolutist, objective views of science (Kimball, 1967-68; Pomeroy, 1993). Furthermore, a prior 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 (Schwartz 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 to become reflective and voice their views where previously they had not considered such issues. Finally, given that there were 25 average years research experience per participant, these scientists were experienced. Perhaps that longevity was a luxury or a comfort that was key to transition-ability (Schwartz et al., 2004) needed for reflection. 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.

References

- Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). NOS and instructional practice: Making the unnatural natural. *Science Education*, 82, 417-436.
- Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22(7), 665-701
- American Association for the Advancement of Science. (1990). *The Liberal Art of Science: Agenda for Action*. Washington D. C.: AAAS Publication.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: A Project 2061 report*. New York: Oxford University Press.
- Akerson, V., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: A yearlong case study of a fourth-grade teacher, *Journal of Research in Science Teaching*, 40(10), 1025-1049
- Ault, C. (1998). Criteria of excellence for geological inquiry: The necessity of ambiguity, *Journal of Research in Science Teaching*, 35(2), 189-212.
- Bechtel, W. (1986). *The nature of scientific integration*. In Bechtel, W. (Ed.) *Integrating Scientific Disciplines*, Martinus Nijhoff Publishers, Dordrecht, The Netherlands.
- Bell, R. L. (2000). *Understandings of the nature of science and decision making on science and technology based issues*. Unpublished doctoral dissertation, Oregon State University, Oregon.
- Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18, 32-42.
- Chi, M., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed), *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, NJ: Erlbaum.
- Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, 86, 175-219.
- Dunbar, K. (2001). What scientific thinking reveals about the nature of cognition. In K. Crowley, C. Shunn, & T. Okada (Eds.), *Designing for science: Implications from everyday classroom and professional settings*. Mahwah, NJ: Lawrence Erlbaum Associations, Inc.
- Duschl, R. A. (1990). *Restructuring science education*. New York: Teachers College Press.
- Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, 85(5), 554-567.
- Glasson, G., & Bentley, M. (2000). Epistemological undercurrents in scientists' reporting of research to teachers. *Journal of Research in Science Teaching*, 84(4), 469-485.
- Harding, P., & Hare, W. (2000). Portraying science accurately in classrooms: Emphasizing open-mindedness rather than relativism. *Journal of Research in Science Teaching*, 37(3), 225-236.
- Hodson, D. (1998). *Teaching and Learning Science: Towards a Personalized Approach*. Philadelphia, PA: Open University Press.
- Justi, R., & Gilbert, J. (2003). Teachers' views on the nature of models. *International Journal of Science Education*, 25(11), 1369-1386.
- Khishfe, R., & Abd-El-Khalick, F. (2002). The influence of explicit reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, 39(7), 551-578.
- Kimball, M.E. (1967-68). Understanding NOS: A comparison of scientists and science teachers. *Journal of Research in Science Teaching*, 2(1), 110-120.
- Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge: Harvard University Press.
- Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.) Chicago: University of Chicago Press.
- Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of Nature of Science Questionnaire (VNOS): Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science. *Journal of Research in Science Teaching*, 39(6), 497-521.
- Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., & Bell, R. L. (2001). Preservice Teachers' Understanding and Teaching of the Nature of Science: An Intervention Study. *The Canadian Journal of Science, Mathematics, and Technology Education*, 1(2), 135-160.
- Lederman, N. G., Schwartz, R. S., Lederman, J., Matthews, L., & Khishfe, R. (2002, April). *Project ICAN: A teacher enhancement project to promote teachers' and students' knowledge of scientific inquiry and nature of science*. Symposium presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.
- Loving, C. (1997). From the summit of truth to its slippery slopes: Science education's journey through positivist-postmodern territory. *American Educational Research Journal*, 34(3), 421-452.
- Mtthews, M. (1994). *Science teaching: The role of history and philosophy of science*. New York: Routledge.

- Matthews, M. R. (1998). The nature of science and science teaching. In B.F. Fraser, & K. G. Tobin (Eds.), *International Handbook of Science Education*, Great Britain: Kluwer Academic Publishers, (981-999).
- Mayr, E. (1988). *Toward a new philosophy of Biology: Observations of an evolutionist*. Cambridge, MA: Harvard University Press.
- Mayr, E. (1997). *This is biology: The science of the living world*. Cambridge, MA: Harvard University Press.
- Millar, R., & Osborne, J. (Eds.) (1998). *Beyond 2000: Science education for the future*. London: Kings College.
- Minstrell, J., & van Zee, E. H., (Eds.), (2000). *Inquiring into inquiry learning and teaching in science*. American Association for the Advancement of Science, Washington, DC.
- National Academy of Sciences, (2002). Guiding principles for scientific inquiry. In *Scientific research in education*. www.nap.edu/openbook/03090829/html
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academic Press.
- National Research Council. (2000). *Inquiry and the National science education standards*. Washington, DC: National Academic Press.
- Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What ideas-about-science should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, 40(7), 692-720.
- Pomeroy, D. (1993). Implications of teachers' beliefs about NOS: Comparison of the beliefs of scientists, secondary science teachers, and elementary teachers. *Science Education*, 77(3), 261-278.
- Reiff, R., Harwood, W., & Phillipson, T. (2002). Scientists' conceptions of scientific inquiry: Voices from the front. Submitted manuscript.
- Ruse, M. (Ed.) (1998). *Philosophy of biology*. New York: Prometheus Books.
- Ryan, A.G., & Aikenhead, G. S. (1992). Students' preconceptions about the epistemology of science. *Science Education*, 76(6), 559-580.
- Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching*, 36(2), 201-220.
- Samarapungavan, A. (1992). Children's judgments in theory choice tasks: Scientific rationality in childhood. *Cognition*, 45, 1-32.
- Samarapungavan, A., & Bodner, G. (in press). Contextual epistemic development in science: A comparison of chemistry students and research chemists, *Science Education*.
- Schwartz, R. S. (2004). Epistemological views in authentic science practice: A cross-discipline comparison of scientists' views of nature of science and scientific inquiry. Unpublished doctoral dissertation. Oregon State University, Corvallis, OR.
- Schwartz, R. S., & Crawford, B. A. (2005). Authentic scientific inquiry as a context for teaching nature of science: Identifying critical elements for success. In Flick, L., & Lederman, N. (Eds.). *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning, and Teacher Education*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Schwartz, R. S., & Lederman, N. G. (2002). "It's the nature of the beast": The influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching*, 39(3), 205-236.
- Schwartz, R. S., Lederman, N. G., & Crawford, B. (2004). Developing views about nature of science in authentic contexts: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88(4) 610 – 645.
- Schwartz, R. S., Lederman, N. G., & Thompson, R. (2001, March). *Grade nine students' views of nature of science and scientific inquiry: The effects of an inquiry-enthusiast's approach to teaching science as inquiry*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.
- Spieker, E. M. (1972). The nature of geology and its place among the natural sciences. In Moulton, B. (Ed.) *Readings in earth sciences*. New York: Van Nostrand Reinhold Company.
- Van Bemmelen, R. W. (1961). The scientific character of geology, *Journal of Geology*, 69, 453-463.
- Van Driel, J. H., & Verloop, N. (1999). Teachers' knowledge of models and modeling in science. *International Journal of Science Education*, 21, 1141-1153.
- Westerlund, J., Schwartz, R. S., Lederman, N. G., & Koke, J. (2001, March). *Teachers learning about nature of science in authentic science contexts: Models of inquiry and reflection*. Symposium presented at the annual meeting of the National association for Research in Science Teaching, March 25-28, St. Louis, MO.
- Ziman, J. (1995). *Reliable knowledge: An exploration of the grounds for belief in science*. New York: Cambridge University Press.

Table 1. Summary of scientists grouped by discipline

Discipline	Total	Life Sciences	Earth & Space Sciences	Chemistry	Physics
# of Participants	24	10	5	4	5
Average # Years post PhD	25.2 (avg) 26 (median) 7.2 (st. dev)	21.7	28.4	21.3	32.2
#male	18	6	4	3	4
#female	6	4	1	1	0
Research Approach					
Experimental	10	5	0	4	1
Descriptive	5	1	4	0	0
Combination E/D	5	4	1	0	0
Theoretical	4	0	0	0	4
Research base					
Laboratory-based	8	4	0	3	1
Field-based	6	4	1	1	0
Lab/Field	2	2	0	0	0
Field/computer	4	0	4	0	0
Computer/mathematics	4	0	0	0	4

Table 2. Scientists' Views of NOS and Inquiry

			Total	Group frequencies								
				Frequency within discipline group				Frequency within approach group				
			24	10	5	5	4	10	5	5	4	
Aspect		Subcode	total	total %	LS	ESS	Ph	Ch	E	E/D	D	T
tentativeness	yes	affirm change/ levels of certainty	11	45.8	.4	.4	.6	.50	.3	.6	.4	.75
		complexity	4	16.7	0	.4	.2	.25	.1	0	.4	.25
		discipline	4	16.7	.1	.2	.2	.25	.2	0	.2	.25
		method	2	8.3	0	.2	.2	0	0	0	.2	.25
	(no)	approaching certainty	4	16.7	.3	0	0	.25	0	0	.3	.2
	no	attain certain knowledge	5	20.8	.4	.2	0	0	.2	.4	.2	0
		other: self correcting	2	8.3	.1	0	.2	0	0	.2	0	.25
empirical	yes	empirically grounded	17	70.8	.8	.6	.6	.75	.9	.4	.8	.5
		theoretical yet empirically grounded through confirmation of predictions	2	8.3	.1	.2	0	0	0	.2	.2	0
	varies:	theoretical/mathematical: changing what science is....(string theory)	3	12.5	0	0	.4	.25	.1	0	0	.5

Contextually-based views of NOS 30

subjectivity	yes	personal only	9	37.5	.4	.4	.2	.50	.4	.4	.4	.25
		theory -laden (guiding framework)	15	62.5	.6	.8	.6	.50	.5	.8	.8	.5
		positive	8	33.3	.5	.2	.2	.25	.3	.4	.4	.25
		negative	4	16.7	.1	.2	0	.50	.3	0	.2	0
		inconsistent response	3	12.5	.1	.2	0	.25	.2	0	.2	0
		differs with discipline	4	16.7	.2	.2	0	.25	.1	.4	.2	0
		differs with approach: qualitative > quantitative	5	20.8	.1	.2	0	.75	.3	0	.4	0
	No	not subjective	4	16.7	.1	.2	.4	0	.1	0	.2	.5
		Scientific Method = objectivity (ideal or practice)	2	8.3	.1	.2	0	0	.1	0	.2	0
creativity	yes	affirmed	16	66.7	.6	.8	.6	.75	.7	.8	.6	.5
		finding patterns/build connections	7	29.2	.2	.6	.2	.25	.3	.4	.4	0
		epiphany only examples	3	12.5	0	.4	.2	0	0	.2	.2	.25
		progress	5	20.8	.3	0	.2	.25	.3	0	.2	.25
	no	data to be clear	3	12.5	.1	.2	.2	0	.1	0	.2	.25
Socio/cultural		process/conclusions (how done, reasoning)										
		internal: influence on reasoning through processes, assumptions	4	16.7	.3	0	0	.25	.3	.2	0	0
		not s/c influenced: international community, technology	5	20.8	.3	0	.4	0	.2	.2	0	.5
		external: political and economic pressures	3	12.5	.1	0	.2	.25	.3	0	0	0
		Questions/problems studied (What)	1	4.2	0	0	0	.25	.1	0	0	0
		human endeavor	3	12.5	.1	0	0	.50	.2	.2	0	0

Contextually-based views of NOS 31

	s/c influenced: political, economic, societal pressures	15	62.5	.6	.8	.4	.75	.8	.6	.6	.25
	not s/c influenced	4	16.7	0	.2	.6	0	0	0	.2	.75
	products										
	universal application/generalizability	3	12.5	0	.2	.4	0	.1	0	.2	.25
	not universal use	1	4.2	0	0	0	.25	.1	0	0	0
	SM: not s/c influenced	2	8.3	.1	.2	0	0	.1	0	.2	0
	other	4	16.7	.1	.2	.2	.25	.1	.2	.2	.25
Theory/law	hierarchical (theories become laws)	13	54.2	.5	.6	.4	.75	.4	.8	.6	.5
	different	8	33.3	.3	.6	.6	.25	.4	.2	.2	.5
	levels of confidence differ: laws > theories; foundations	5	20.8	.2	.2	.2	.25	.3	0	.2	.25
	theories more general & complex/laws simple	3	12.5	.2	0	.2	0	.1	.2	0	.25
	theories more likely to change	2	8.3	0	.2	.2	0	.1	.2	0	0
	no difference	1	4.2	.4	0	0	.25	.1	0	0	0
	differs with discipline	6	25.0	.4	.4	0	0	.3	.2	.4	0
	no laws in field of work	6	25.0	.4	.4	0	0	.2	.4	.4	0
Obs/inference	affirmed role of inference	14	58.3	.6	.8	.8	.75	.6	.6	.4	.75
	not clear from responses	10	41.7	.4	.8	.2	.25	.4	.4	.6	.25

Models	explain or organize obs/predict/test	17	70.8	.7	1.0	.4	.75	.6	1.0	.8	.5
	understanding of system/complexity made simple/abstract										
	made visual	9	37.5	.3	.2	.8	.25	.3	.4	.2	.75
	mathematics	6	25.0	.1	.4	.4	.25	.2	.2	.4	.25
	physical system	3	12.5	0	.4	.2	0	.1	0	.4	0

Aspect	Subcode	Total #	total %	LS	ESS	Ph	Ch	E	E/D	D	T
Methods	Single Scientific Method	6	25.0	.4	.2	0	.25	.3	.4	.2	0
	Multiple methods ...	16	66.7	.5	.6	.8	.75	.6	.6	.6	1.0
	all hypothesis driven	7	29.2	.5	0	0	.5	.5	.4	0	0
	not all hypothesis driven	8	33.3	.2	.4	.4	.5	.4	.2	.4	.25
	reductionist	2	8.3	0	0	0	.5	.2	0	0	0
	expt, descriptive	11	45.8	.7	.4	0	.5	.7	.4	.4	0
	expt, observational, theoretical	7	29.2	.1	.4	.8	0	.1	.4	.2	.75
	methods influenced by complexity of systems	5	20.8	.2	.2	0	.5	.3	.4	0	0
	Hierarchy:										
	Validity/confidence of claims influenced by methods: expt > descriptive	9	37.5	.5	.4	.2	.25	.3	.6	.4	.25
	Maturity of the science: Expt more mature than desc	3	12.5	0	.4	0	.25	.1	.2	.2	0
	Theoretical sciences: pushing the limits of science/mathematics	4	16.7	0	.2	.6	0	.1	0	.2	.5
	Discipline differences: complexity of systems, ability to repeat	9	37.5	.4	.4	.4	.25	.4	.4	.4	.25

Aspect	Subcode	Total #	total %	LS %	ESS %	Ph %	Ch %	E %	E/D %	D %	T %
Justification	reproducibility										
	internal: statistics	11	45.8	.7	0	0	.75	.6	60	20	0
	external: multiple researchers/same results	3	12.5	0	.4	0	.25	.1	0	.1	0
	consistency with others	3	12.5	0	.4	0	.25	.1	0	.4	0
	experiments over description	10	41.7	.7	.2	.4	0	.4	.8	.2	.25
	peer review	9	37.5	.3	.2	.4	.5	.4	.4	.2	.5
	address alternatives	5	20.8	.3	0	.2	.25	.4	.2	0	0
	predictions/tests	8	33.3	.2	.2	.8	.25	.3	.2	.2	.75
	model/ predict/test	2	8.3	0	.4	0	0	0	.2	.2	0
	scientific method/hypothesis test	3	12.5	.2	0	0	0	.1	.4	0	0
	differs with discipline/context	14	58.3	.6	.4	.8	.5	.4	.8	.4	1.0

Appendix

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:
 - (a) Explain why theories change?
 - (b) Explain why we bother to learn scientific theories. Defend your answer with examples.
 - (c) 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:
 - (a) Explain why laws change?
 - (b) 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.

Appendix B
VOSI-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 of scientific inquiry as it is practiced within your own research area. Please consider this authentic context in your responses.

1. What scientists choose to study and how they learn about the natural world may be influenced by a variety of factors. How do scientists decide what and how to investigate? Describe all the factors you think influence the work of scientists. Be as specific as possible.
2. (a) How would you define “scientific inquiry” as it is conducted in your field of research? Give an example from your work that represents your view.
(b) Do you think your approach to scientific inquiry is representative of all scientific research, some fields of research, or specific only to your field? Explain with examples.
3. (a) What do you think the purpose(s) of scientific inquiry is? Describe how your work represents this purpose?
(b) Do you think all scientific inquiry has the same purpose? Why or why not?
4. (a) Write a definition of a scientific experiment?
A scientific experiment is.....
(b) Give an example from something you have done or heard about in science that illustrates your definition of a scientific experiment. Explain why your example is an experiment.
(c) Do you think that the generation of all scientific knowledge requires the use of experiments? If so, explain why. If not, explain why not.
5. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that here is a relationship between teeth structure and food source in the animals.
(a) Do you consider this person’s investigation to be scientific? Please explain why or why not.
(b) Do you consider this person's investigation to be an experiment? Please explain why or why not.
(c) Compare the *investigative approach* used in the tooth example with the types of investigations you conduct in your own research. How are they similar? How are they different?

6. The person in the investigation (#5) identified a correlation between tooth shape and food source.
 - (a) Do you think this person is also justified in concluding that natural selection shapes the teeth to fit specific food resources? Please explain why or why not.
 - (b) What type of information is critical for scientists in **your** field of research to justify and accept a scientific claim?
 - (c) Do you think all fields of science hold the **same** conventions as you stated in (b) for justifying and accepting scientific claims? Explain.

7.
 - (a) What does the word “data” mean in science? Provide an example from your own work.
 - (b) Is “data” the same or different from “evidence” ? Explain and provide an example from your own work.
 - (c) Compare how you identify and use of evidence in your research to that in other types of science. Do you think all scientists identify and use evidence in the same manner? Why or why not?

8. Scientists sometimes encounter inconsistent findings (anomalous information). Consider such a case in your own research to answer the following questions:
 - (a) How are anomalies identified? (i.e. What is considered “inconsistent” in your field of research?) Provide an example.
 - (b) What does the scientist do when an anomaly is identified?
 - (c) Do you think **all** scientists identify and handle anomalous information this same way? Why or why not?