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ABSTRACT

Researchers, educators, and science education organizations have accepted the importance of developing informed conceptions of the nature of science (NOS) among students. Despite attempts to improve both students' and teachers' perceptions of the nature of science, research shows that the desired understanding has not been attained. Evaluation of the learners' view of the nature of science is based on standardized and convergent paper-and-pencil instruments. This paper reports on the development of a new instrument, The Views of Nature of Science Questionnaire (VNOS), which provides authentic assessment of students' views of NOS. (Contains 63 references.) (YDS)

Views of Nature of Science Questionnaire (VNOS): Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science

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VIEWS OF NATURE OF SCIENCE QUESTIONNAIRE (VNOS): TOWARD VALID AND MEANINGFUL ASSESSMENT OF LEARNERS' CONCEPTIONS OF NATURE OF SCIENCE

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During the past 85 years, almost all scientists, science educators, and science education organizations have agreed upon the objective of helping students develop informed conceptions of nature of science (NOS) (Abd-El-Khalick, Bell, & Lederman, 1998). Presently, and despite their varying pedagogical or curricular emphases, there is agreement among the major reform efforts in science education (American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council [NRC], 1996) around the goal of enhancing students' conceptions of NOS. However, research has consistently shown that K-12 students, as well as teachers, have not attained desired understandings of NOS (e.g., Abd-El-Khalick & Lederman, 2000a; Duschl, 1990; Lederman, 1992). Several attempts have been, and continue to be, undertaken to enhance students and science teachers' NOS views (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Billeh & Hasan, 1975; Carey & Stauss, 1967, 1968; Carey, Evans, Honda, Jay, & Unger, 1989; Haukoos & Penick, 1983, 1985; Jelinek, 1998; Ogunniyi, 1983; Olstad, 1969; Shapiro, 1996; Scharmann & Harris, 1992; Solomon, Duveen, & Scot, 1994).

Nevertheless, the assessment of learners' views of the scientific endeavor remains an issue in research on NOS (Lederman, Wade, & Bell, 1998). In the greater majority of the aforementioned efforts, standardized and convergent paper-and-pencil instruments have been used to assess learners' NOS views. Several problematic assumptions underlie such instruments and cast doubt on their validity. Moreover, there are several concerns regarding the usefulness of standardized instruments for research related to NOS. The purpose of this paper is to (a) trace the development of a new instrument, the *Views of Nature of Science Questionnaire* (VNOS), which in conjunction with individual interviews, aims to provide authentic and meaningful assessments of learners' NOS views, (b) elucidate the use of the *VNOS* and associated interviews, and the range of NOS aspects that it aims to assess, (c) present evidence regarding the validity of the *VNOS*, and (d) discuss the usefulness of rich descriptive NOS profiles that the *VNOS* provides in research related to the teaching and learning of NOS. However, before discussing the *VNOS*, we will outline the NOS framework that underlies its development, and delineate the problematic nature of standardized and convergent type paper-and-pencil NOS instruments.

NOS

Typically, NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). These characterizations, nevertheless, remain fairly general, and philosophers, historians, and sociologists of science are quick to disagree on a specific definition for NOS. Such disagreement, however, should not be surprising or disconcerting given the multifaceted and complex nature of the scientific enterprise. Moreover, similar to scientific knowledge, conceptions of NOS are tentative and dynamic. These conceptions have changed throughout the development of science and systematic thinking about its nature and workings (Abd-El-Khalick & Lederman, 2000a).

It is our view, however, that many of the disagreements about the specific definition or meaning of NOS that continue to exist among philosophers, historians, sociologists, and science educators are irrelevant to K-12 instruction. The issue of the existence of an objective reality as compared to phenomenal realities is a case in point. Moreover, at one point in time and at a certain level of generality, there is a shared wisdom (even though no complete agreement) about

NOS amongst philosophers, historians, and sociologists of science (Smith, Lederman, Bell, McComas, & Clough, 1997). For instance, presently, it would be very difficult to reject the theory-laden nature of scientific observations and investigations, or to defend a deterministic/absolutist or empiricist conception of NOS. At such a level of generality, some important aspects of NOS are non-controversial. Some of these latter aspects, which we believe are accessible to K-12 students and relevant to their daily lives, were adopted and emphasized for the purpose of developing the *VNOS*. These aspects are that scientific knowledge is: tentative, empirically-based, subjective (theory-laden), partly the product of human inference, imagination, and creativity, and socially and culturally embedded. Three additional important aspects are the distinction between observation and inference, the lack of a universal recipe-like method for doing science, and the functions of, and relationships between scientific theories and laws. It should be noted that these NOS aspects have been emphasized in recent science education reform documents (e.g., AAAS, 1990, 1993; NRC, 1996).

In this regard, it is crucial to note that individuals often conflate NOS with science processes. In agreement with the reform documents (AAAS, 1990, 1993; NRC, 1996), we consider scientific processes to be activities related to the collection and interpretation of data, and the derivation of conclusions. NOS, by comparison, is concerned with the values and epistemological assumptions underlying these activities (Abd-El-Khalick et al., 1998). For example, observing and hypothesizing are scientific processes. Related NOS conceptions include the understandings that observations are constrained by our perceptual apparatus, that the generation of hypotheses necessarily involves imagination and creativity, and that both activities are inherently theory-laden. Although there is overlap and interaction between science processes and NOS, it is nevertheless important to distinguish the two.

Before turning to briefly discuss the aforementioned NOS aspects, it should be emphasized that the generalizations presented in this discussion should be construed in the context of K-12 science education, rather than the context of educating graduate students in philosophy or history of science. Moreover, it should be noted that in the context of K-12 education, each of these NOS aspects could be approached at different levels of depth and omplexity depending on the background and grade level of students.

The Empirical Nature of Scientific Knowledge

Science is, at least partially, based on and/or derived from observations of the natural world, and "sooner or later, the validity of scientific claims is settled by referring to observations of phenomena" (AAAS, 1990, p. 4). However, scientists do not have "direct" access to most natural phenomena. Observations of the natural world are always filtered through our perceptual apparatus and/or intricate instrumentation, interpreted from within elaborate theoretical frameworks, and almost always mediated by a host of assumptions that underlie the functioning of "scientific" instruments.

Observation, Inference, and Theoretical Entities in Science

All students should be able to distinguish between observation and inference. Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. For example, objects released above ground level tend to fall to the ground. By contrast, inferences are statements about phenomena that are not directly accessible to the senses. For example, objects tend to fall to the ground because of "gravity." The notion of gravity is inferential in the sense that it can only be accessed and/or measured through its manifestations or effects. Examples of such effects include the perturbations in predicted planetary orbits due to inter-planetary "attractions," and the bending of light coming from the stars as its rays pass through the sun's "gravitational" field.

An understanding of the crucial distinction between observation and inference is a precursor to making sense of a multitude of inferential and theoretical entities and terms that inhabit the worlds of science. Examples of such entities from the physical sciences include atoms, molecular orbitals, photons, magnetic fields, and gravitational forces. Theoretical entities also abound in the biological sciences, such as the concept of species, which "like the terms 'gene,' 'electron,' 'non-local simultaneity,' and 'element,' is a theoretical term embedded in a significant scientific theory" (Hull, 1998, p. 146).

Scientific Theories and Laws

Scientific theories are well-established, highly substantiated, internally consistent systems of explanations (Suppe, 1977). Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. For example, the kinetic molecular theory serves to explain phenomena related to changes in the physical states of matter, the rates of chemical reactions, and still other phenomena related to heat and its transfer. More importantly, theories play a major role in generating research problems and guiding future investigations.

Scientific theories are often based on a set of assumptions or axioms and often posit the existence of non-observable entities. As such, theories cannot be directly tested. Only indirect evidence can be used to support theories and establish their validity. To test theories (or hypotheses), scientists derive specific testable predictions from those theories (or hypotheses) and check them against tangible data. An agreement between such predictions and empirical evidence serves to increase the level of confidence in the tested theory (or hypothesis).

Closely related to the distinction between observation and inference is the distinction between scientific laws and theories. Generally speaking, scientific laws are statements or descriptions of the relationships among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Scientific theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. The kinetic molecular theory, which explains Boyle's law, is one example. Students often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. Moreover, those students believe that scientific laws have a higher status than scientific theories. Both notions, however, are inappropriate. Theories and laws are different kinds of knowledge and one does not become the other. Theories are as legitimate a product of science as laws. Scientists do not usually formulate theories in the hope that some day they would acquire the status of "law."

The Creative and Imaginative Nature of Scientific Knowledge

Science is empirical. The development of scientific knowledge involves making observations of natural phenomena. Nonetheless, generating scientific knowledge also involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, completely rational, and orderly activity. Science involves the invention of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists. The "leap" from atomic spectral lines to Bohr's model of the atom with its elaborate orbits and energy levels is a case in point. This aspect of science, coupled with its inferential nature, entails that scientific entities, such as atoms and species, are functional theoretical models rather than faithful copies of "reality."

The Subjective and Theory-laden Nature of Scientific Knowledge

Scientific knowledge is subjective or theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge. It is noteworthy that, contrary to common belief, science never starts with neutral observations (Popper, 1992). Observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives.

The Social and Cultural Embeddedness of Scientific Knowledge

Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion. An example may help to illustrate how social and cultural factors impact scientific knowledge. Telling the story of the evolution of humans (*Homo sapiens*) over the course of the past 7 million years is central to the biosocial sciences. Scientists have formulated several elaborate and differing storylines about this evolution. Until recently, the dominant story was centered about "the man-hunter" and his crucial role in the evolution of humans to the form we now know (Lovejoy, 1981). This scenario was consistent with the white-male culture that dominated scientific circles up to the 1960s and early 70s. As the feminist movement grew stronger and women were able to claim recognition in the various scientific disciplines, the story about hominid evolution started to change. One story that is more consistent with a feminist approach is centered about "the female-gatherer" and her central role in the evolution of humans (Hrdy, 1986). It is noteworthy that both story lines are consistent with the available evidence.

Myth of "The Scientific Method"

One of the most widely held misconceptions about science is the existence of "The Scientific Method." The modern origins of this misconception could be traced back to Francis Bacon's *Novum Organum* (1620/1996) in which the inductive method was propounded to guarantee "certain" knowledge. Since the 17th century, inductivism and several other epistemological stances that aimed to achieve the same end (although in these latter stances the criterion of "certainty" was either replaced with notions of "high probability" or abandoned altogether), such as Bayesianism, falsificationism, and hypothetico-deductivism, have been debunked (Gillies, 1993). Nonetheless, some of these stances, especially inductivism and falsificationism, are still widely popularized in science textbooks and even explicitly taught in classrooms. The myth of "The Scientific Method" is regularly manifested in the belief that there is a recipe-like stepwise procedure that all scientists follow when they "do" science. This notion was explicitly debunked by the *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993). There is no single "Scientific Method" that would guarantee the development of infallible knowledge (Bauer, 1994; Lederman, Farber, Abd-El-Khalick, & Bell, 1998; Shapin, 1996). It is true that scientists observe, compare, measure, test, speculate, hypothesize, create ideas and conceptual tools, and construct theories and explanations. However, there is no single sequence of activities (prescribed or otherwise) that will unerringly lead them to functional or valid solutions or answers, let alone "certain" or "true" knowledge.

The Tentative Nature of Scientific Knowledge

Scientific knowledge, though reliable and durable, is never absolute or certain. This knowledge, including "facts," theories, and laws, is subject to change. Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on these claims, and as extant evidence is reinterpreted in the light of new theoretical advances, changes in the cultural and social spheres, or shifts in the directions of established research programs. It should be emphasized that tentativeness in science does not solely arise from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded. There are also compelling logical arguments that lend credence to the notion of tentativeness. Indeed, contrary to common belief, scientific hypotheses, theories, and laws can never be absolutely "proven." This holds irrespective of the amount of empirical evidence gathered in the support of one of these ideas or the other (Popper, 1963, 1988). For example, to be "proven," a certain scientific law should account for every single instance of the phenomenon it purports to describe at all times. It can logically be argued that one such future instance, of which we have no knowledge whatsoever, may behave in a manner contrary to what the law states. As such, the law can never acquire an absolutely "proven" status. This equally holds in the case of hypotheses and theories.

Problematic Nature of Standardized and Convergent Paper-and-Pencil NOS Instruments

During the past 40 years, more than 20 standardized and convergent paper-and-pencil instruments have been developed to assess learners' NOS views (Lederman et al., 1998). Examples of such instruments include *Test on Understanding Science* (Cooley & Klopfer, 1961), *Science Process Inventory* (Welch & Pella, 1967-68), *Nature of Science Scale* (Kimball, 1967-68), *Nature of Science Test* (Billeh & Hasan, 1975), *Conceptions of Scientific Theories Test* (Cotham & Smith, 1981), and *Modified Nature of Scientific Knowledge Scale* (Meichtry, 1992). These instruments comprised forced-choice, such as agree/disagree, Likert-type or multiple-choice items.

Many criticisms have been leveled against the use of standardized instruments to assess learners' NOS views. Two major criticisms were related to these instruments' validity. First, Aikenhead, Ryan, and Desautels (1989) and Lederman and O'Malley (1990) argued that such instruments were all based on a problematic assumption. These instruments *assumed* that respondents perceive and interpret an instrument's items in a manner similar to that of the instrument developers. Lederman and O'Malley argued that ambiguities, which seriously threaten these instruments' validity, result from assuming that respondents understand a certain statement in the same manner that the researchers or instrument developers would, and agree or disagree with that statement for reasons that coincide with those of the researchers or instrument developers. Second, Lederman et al. (1998) noted that standardized instruments usually reflected their developers' views and biases related to NOS. Being of the forced-choice category, these instruments ended up imposing the researchers' or developers' own views on the respondents. Additionally, responses to instrument items were usually designed with various philosophical stances in mind. As such, irrespective of the choices the respondents made, they often ended up being labeled as if they firmly held coherent, consistent philosophic stances such as inductivist, verificationist or hypothetico-deductivist (e.g., Dibbs, 1982; Hodson, 1993). Thus, the views that ended up being ascribed to respondents were more an artifact of the instrument in use than a faithful representation of the respondents' conceptions of NOS.

A third criticism relates to the usefulness of standardized instruments. These instruments were mainly intended to label participants' NOS views as "adequate" or "inadequate"—mostly by assigning those views cumulative numerical values—rather than elucidating and clarifying such views. What is more, researchers and instrument developers never clarified what numerical value on such instruments constituted an "adequate" view of NOS (Lederman, 1986). As such, the use of standardized instruments severely limits the feasibility of drawing meaningful conclusions regarding learners' NOS views and/or assessing the meaningfulness and importance of any gains in understanding NOS achieved by learners as a result of various instructional interventions. Indeed, the use of standardized and convergent NOS assessment instruments is more commensurate with the largely abandoned inputs-outputs behavioristic approach to teaching and learning than with the cognitive constructivist approach that is currently widely endorsed by science educators.

Development of the *VNOS*

VNOS–Form A

In response to the discussed state of affairs, Lederman and O'Malley (1990) developed a seven-item open-ended questionnaire, which they intended to use in conjunction with follow-up individual interviews to assess high school students' views of the tentative NOS. The questionnaire consisted of the following seven items:

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories change, explain why we bother to learn about theories. Defend your answer with examples.

2. What does an atom look like? How do scientists know that an atom looks like what you have described or drawn?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform scientific experiments/investigations when trying to solve problems. Do scientists use their creativity and imagination during these experiments/investigations?

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astrophysicists believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

The use of an open-ended questionnaire was intended to avoid the problems inherent in the use of standardized forced-choice instruments. In contrast to forced-choice items used in convergent style instruments, open-ended items allow respondents to elucidate their own views regarding the target aspects of NOS and the reasons that underlie their views. Moreover, given the concern with the meanings that participants ascribed to the target NOS aspects, and the researchers' interest in elucidating and clarifying participants' NOS views rather than simply labeling or judging them, it was imperative to avoid misinterpreting participants' responses to the questionnaire. As such, individual semi-structured interviews were used to substantiate the validity of the researchers' interpretations of participants' responses as well as establish the face validity of the questionnaire items. The interviews also aimed to generate in-depth profiles of participants' NOS views. During these interviews, participants were provided their questionnaires (pre and post academic year) and asked to read, explain, and justify their responses. By asking respondents to elaborate and/or justify their answers, the researchers were able to assess not only respondents' positions on certain issues related to NOS, but the respondents' reasons for adopting those positions as well.

Lederman and O'Malley (1990) found that inferences drawn regarding participants' NOS views from 3 of the 7 open-ended questionnaire items were not validated during the interviews. Participants were either unable to interpret the intended meaning of these three items or found the items to be vague. These were items 4, 5, and 6 and were eliminated from final analyses. For example, item 5 was intended to assess whether students believed scientists used any creativity or imagination in the interpretation of data, or whether they believed the process to be totally objective. The data indicated that students simply considered the planning of the investigation. That is, students typically believed that scientists needed to be creative to design investigations. In short, students' responses clearly showed that the item did not assess the intended students' beliefs. These results, and others, corroborated the earlier arguments regarding the inadequacies associated with using standardized paper-and-pencil instruments as the sole means to assess learners' NOS views. In this "first attempt," the researchers reported inferences based on participants' responses to the remaining four items (items 1, 2, 3, and 7), whose validity was generally substantiated during individual interviews. But, even with these items, the problem of researchers' misinterpreting students' responses could not have been avoided without interviews. For example, in responses to item 3, students consistently used the word "prove" when distinguishing laws and theories. This led the researchers to conclude that students held absolutist views of scientific knowledge. However, during the interviews, it became clear that students did not use the word "prove" in an absolute sense at all. Indeed, their use of the term was quite consistent with the way scientists use it. So, although the item was valid in its assessment of targeted student views, interpretation of student meaning (without interviews) led to the wrong conclusion by the researchers. These results provided further support for the importance of using follow-up interviews whenever paper-and-pencil NOS assessments are used. The open-ended questionnaire used by Lederman and O'Malley represented an initial attempt to validly assess students' perceptions and was systematically changed based on student responses in an attempt to improve validity. This first questionnaire is considered the first form of the *VNOS* instrument (*VNOS–A*).

VNOS–Form B

Abd-El-Khalick et al. (1998) revised some of the *VNOS–A* items and used this form of the instrument (Form B) to assess preservice secondary science teachers' views of the tentative, empirical, inferential, creative, and subjective NOS, as well as the functions of, and relationships between theories and laws. Initially, the administration of the *VNOS–B* (see Figure 1) was intended to elicit participants' views about some NOS aspects and create a context in which these views could be discussed. This administration was followed with in-depth individual interviews with all participant teachers. During these interviews, participants were provided their questionnaires and asked to read and explain their responses. Participants were asked to clarify the meanings they ascribed to key terms, such as "creativity," "opinion," and "evidence," and provide specific examples to illustrate and contextualize their views. Follow-up and probing questions were also used to clarify vague statements or seeming contradictions in participants' responses. In a sense, the researchers were "learning to read" responses to the *VNOS-B* from the participants' perspectives.

VNOS–Form B

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Figure 1. Views of Nature of Science Questionnaire (Form B)

The *VNOS–B* was used in subsequent studies with preservice secondary science teachers (Bell, Lederman, & Abd-El-Khalick, 2000) and preservice elementary teachers (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Abd-El-Khalick, 2000). In these studies, evidence regarding the validity of the instrument started to emerge. It became apparent that the researchers' interpretations of participants' views based on analyses of the *VNOS–B* responses were mostly congruent with views expressed by those participants during individual interviews. Indeed, the *VNOS–B* was sensitive to recurrent patterns and themes, idiosyncrasies, as well as subtle changes in participants' NOS views. Nonetheless, subtle differences in the specific meanings that participants in each of these studies assigned to a certain NOS aspect were observed. Follow-up interviews remained crucial for valid interpretations of participants' responses to the questionnaire. However, as the researchers became more cognizant of the meanings that participant preservice teachers ascribed to key terms and phrases, and developed more expertise in interpreting participants responses, it was apparent that it was not imperative to interview *all* participants following an administration of the *VNOS–B*. Depending on the sample size, the researchers were now obtaining redundant meanings, categories, and themes (Lincoln & Guba, 1985) from interviews with 15-20% of participants.

Establishing the Construct Validity of the *VNOS–B*

A recent investigation (Bell, 1999) into the decision making of NOS experts and non-experts provided an excellent opportunity to assess the construct validity of the *VNOS–B*. If the instrument had construct validity, then respondents with assessed thorough understandings of NOS should respond much differently than those assessed to possess naïve understandings. A sample of adults was purposively selected to participate in the study. Secondary students were not selected for the principle reason that the nature of the study required one group to have expert understandings of NOS. This criterion ruled out the vast majority of, if not all, adolescents (Aikenhead, 1973, 1987; Bady, 1979; Gilbert, 1991; Lederman & O'Malley, 1990; Mackay, 1971; Rubba & Anderson, 1978; Wilson, 1954). The Expert group comprised nine individuals with doctoral degrees in science education, history of science or philosophy of science. Individuals in these fields may reasonably be expected to have developed NOS understandings consistent with those espoused by current reform efforts. Members of the Novice group were purposively selected to be comparable to those of the Expert group, except for their expected levels of NOS understandings. These nine individuals had comparable educational backgrounds, but their doctoral degrees were in fields, such as American literature, history, and education, in which they were less likely to have contemplated the nature of scientific knowledge.

Each participant completed the *VNOS–B*. The completed questionnaires were first used to generate summaries of each participant's views. Next, the summaries were searched for patterns and/or categories. These categories were then checked against confirmatory or otherwise contradictory evidence in the data and modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data. The categories were then used to construct preliminary profiles of participants' NOS views. After the analysis of the questionnaire responses was completed, participants were individually interviewed to provide them with opportunities to clarify and elaborate on their written responses. They were asked to explain their responses to each item and to respond to requests for clarification or elaboration. The interviews lasted approximately 45 minutes. All interviews were audiotaped and transcribed for analysis. The interview transcripts were first reviewed in order to generate a second set of summaries of each participant's views. Next, these summaries were scrutinized for patterns and/or categories, which were then checked against the data and modified accordingly. Finally, the profiles generated from the separate analyses of the questionnaires and corresponding interviews were compared. When discrepancies between the two profiles were evident, the data were reexamined to determine which profile best reflected the participant's views. Data analyses indicated that the Expert group's responses to the *VNOS–B* reflected current understandings at a rate nearly three times higher than those of the Novice group (see Table 1). The results of this investigation lent strong support to the validity of the

VNOS–B. Following are brief descriptions of Expert and Novice group responses to the *VNOS–B* items for each assessed aspect of NOS.

The Empirical Nature of Scientific Knowledge

All Expert group responses to *VNOS–B* #1 or #4 referred to the empirical NOS. Typical responses included descriptions of scientific knowledge as based on natural phenomena, evidence, data, information, and observation. Several Expert group participants attempted to describe science as a way of knowing by contrasting it with art or religion. These participants tended to focus on science's reliance on empirical data and reason, in contrast to art's focus on aesthetics and religion's reliance on faith and revealed truth. None of the Expert group participants spoke of science using observations or evidence to "prove" its conjectures. Rather, they tended to view empirical evidence as *supportive*, but not able to prove scientific claims in any absolute sense. Additionally, they did not see physical evidence as being the sole determinant in choosing between competing ideas or theories. Rather, they viewed scientific claims as being based on a mix of observational, personal, social, and cultural influences.

The Novice group participants also expressed a belief in an empirical basis for scientific knowledge. Unlike their Expert counterparts, however, many of the Novice group participants indicated that scientific knowledge is based *solely* on the evidence. In their view, the reliance on empirical evidence makes science an objective endeavor. Thus, they emphasized empiricism to the exclusion of the more personal attributes of interpretation, speculation, and opinion. Other Novice group participants spoke of science as a search for objective "truth." Indeed, 6 of the 9 (67%) Novice group participants emphasized the empirical nature of scientific claims to the exclusion of subjective factors, such as human bias and values.

Table 1

Comparison of Expert and Novice Group Responses to the *VNOS-B*

NOS Aspect	Expert group		Novice group	
Empirical Nature of Scientific Knowledge				
Observations used to make scientific claims	9	(100%)	8	(89%)
Science does not rely solely on empirical evidence	9	(100%)	3	(33%)
Supports, rather than *proves*, scientific claims	9	(100%)	3	(33%)
Inference and Theoretical Entities in Science				
Inferential nature of atomic models	9	(100%)	6	(67%)
Nature of Scientific Theories				
Theories change due to new evidence	9	(100%)	7	(78%)
Theories change due to new ways of looking at existing evidence	8	(89%)	4	(44%)
Explanatory power of scientific theories	8	(89%)	1	(11%)
Theories are well-substantiated	9	(100%)	0	(0%)
Theories provide a framework for current knowledge and future investigations	7	(78%)	1	(11%)
Scientific Theories vs. Laws				
Non-hierarchical relationship	9	(100%)	0	(0%)
Laws may change	9	(100%)	1	(11%)
Creativity in Science				
Creativity permeates scientific processes	9	(100%)	4	(44%)
No single scientific method	9	(100%)	0	(0%)
Subjectivity in Science				
Differences in data interpretation	9	(100%)	5	(56%)
Science is necessarily a mixture of objective and subjective components	9	(78%)	2	(22%)
Social and Cultural Influences				
Science as a culture within itself	8	(89%)	0	(0%)
Peer review limits subjectivity	3	(33%)	1	(11%)
Society as an influence on science	2	(22%)	2	(22%)
Overall	169	(89%)	64	(33%)

Inference and Theoretical Entities in Science

In their responses to *VNOS–B* #2, the Expert group participants' demonstrated an understanding of the inferential nature of scientific models. While all were confident that scientists understand much of what atoms are like, none appeared to believe that scientists "know" the structure of the atom in any absolute sense of the term. Rather, they used qualified language to describe scientists' certainty about atomic structure. The Expert group rejected the notion that scientists obtained their understandings of atoms through direct observations and ascribed a role for indirect evidence and/or inference in the construction of atomic models. By comparison, 67% of the Novice group participants held similar views, while the remaining 33% held the naïve view that atomic models have been developed through direct observation.

Nature of Scientific Theories

In response to *VNOS–B* #1, all nine Expert group participants indicated that scientific theories change and almost all ascribed theory change to new data and technologies, as well as to new insights, and social and cultural influences. Several participants described theories as robust, well-supported systems of explanation based on substantial evidence. Their understandings of scientific theories contrasted with the common vernacular sense of the word, in which "theory" is defined as a simple guess or unsubstantiated idea. Eight of the 9 participants cited the explanatory function of scientific theories in their responses to the question concerning the usefulness of learning scientific theories, and most of them (78%) argued that theories provide a framework for current knowledge and/or for future investigations.

In contrast, 7 of the Novice group participants (78%) stated that theories do change and cited a single reason for theory change, the accumulation of new evidence. During the follow-up interviews, 4 of the 7 also cited new ways of looking at existing evidence as a reason for theory change. Unlike the Expert group participants, none of the Novice group members spoke of the well-substantiated nature of theories. Eighty-nine percent of this latter group participants did not seem to appreciate the role that theories play in generating research questions and guiding scientific inquiry.

Distinctions and Relationship Between Scientific Theories and Laws

All of the Expert group participants viewed scientific theories and laws as different kinds of knowledge; thus, the misconception of a hierarchical relationship between theories and laws was nonexistent. These participants viewed theories and laws as being distinct but equally valid forms of scientific knowledge. Only one participant viewed scientific laws as being certain in any absolute sense of the word. For the remaining Expert group members, tentativeness applied to laws just as it does for other forms of scientific knowledge.

Seven of the 9 Novice group participants (78%) explicitly stated the misconception that scientific theories become laws when proven, or when they have "passed" repeated testing. The other two respondents also believed laws were proven true and theories were tentative, either because not enough data are available, or because scientists are unable to design the necessary experiments or apparatus to adequately test theories. None of the Novice group participants contrasted the descriptive role of scientific laws with the explanatory nature of scientific theories, thus differing markedly from the majority of the Expert group respondents who viewed scientific theories as non-observable inferred explanations and scientific laws as descriptions of patterns or relationships among observable phenomena.

The Creative and Imaginative Nature of Scientific Knowledge

Expert group participant responses to *VNOS–B* #4 and #5 reflected the consistent belief that creativity permeates the scientific process, from the earliest conceptions of a research question to the ingenuity required to set up and run an investigation to the ultimate interpretation of the results of the investigation. All group participants viewed creativity in science both in terms of resourcefulness in carrying out experiments and in inventiveness in interpreting data and coming up with inferences and theories. None of the Expert group participants adhered to the rigid view of a single scientific method, but allowed for various approaches to answering various research questions.

By comparison, Novice group responses to these *VNOS–B* items indicated that only four (44%) viewed creativity and imagination as integral to science. Novice group participants' views further contrasted with those of the Expert group in that they all expressed belief in a single scientific method. For these participants, most creativity in science occurs during conjecturing and before the scientific method is employed. After that, the scientific method is used to determine whether the scientist's conjectures were "correct."

<u>The Subjective Nature of Scientific Knowledge</u>

In responding to the astronomical controversy presented in *VNOS–B* #7, Expert group participants focused on differences in interpreting the data due to the scientists' different backgrounds and training. In doing so, they ascribed a role for subjectivity in the construction of scientific knowledge, whereby different interpretations can result from astronomers working within various frameworks, which could vary with the scientists' educational backgrounds, training, philosophical perspectives, theoretical commitments, personal experiences, and beliefs. By comparison, the Novice group participants tended to focus on inadequacies or differences in the data the astronomers were using. Responses like this reflect a more objective view of science. About 56% of the Novice group participants noted that subjectivity is a part of science, especially in regard to interpreting data. However, these participants believed that subjectivity, while a factor of human nature, is to be avoided in science. Only two of the Novice group participants appeared to have informed views of the theory-laden nature of observations, investigations, and data interpretation.

Social and Cultural Influences on Scientific Knowledge

In their responses to *VNOS–B* #4 and #6, the Expert group participants described two types of cultural influences involved in the development of scientific knowledge. The first relates to the culture of science itself and includes such factors as peer review. Eight of the 9 Expert group participants (89%) discussed a culture or community within science that establishes rules of practice and evidence, essentially acting as judge for what is acceptable in science. These rules play a crucial role in limiting subjectivity through the application of peer review and group consensus. The second type relates to the influence of societal factors, such as politics, economics, and religion, on science. Two Expert group participants (22%) noted that the social milieu in which science is conducted influence the kind of science that is done. Such influence is mediated by various factors, including economic and political contexts, funding for science, and gender and racial issues. In comparison, only three Novice group participants (33%) made any reference to social or cultural influences on the development of scientific knowledge.

VNOS Form–C

Abd-El-Khalick (1998) further modified and expanded the *VNOS–B* by adopting item 3, modifying items 1, 2, 5, and 7, and adding five new items. A panel of experts examined these ten items to establish their face and content validity. The panel comprised five university professors: three science educators, a historian of science, and a scientist. The panel had some comments and suggestions for improvement and the ten items were modified accordingly. In addition to assessing respondents' views of the NOS aspects targeted by the *VNOS–B*, the *VNOS–C* (see Figure 2) also aimed to assess views of the social and cultural embeddedness of science and the existence of a universal scientific method. Additionally, Abd-El-Khalick developed an interview protocol to further probe participants' views on relevant NOS issues. These questions were asked during follow-up interviews either as individual questions or sets of interrelated questions. Certain questions or sets of questions were asked following interviewees' explication of their responses to a certain item on the *VNOS–C*. Alternatively, other questions or sets of questions were *only* asked when interviewees expressed certain ideas regarding NOS. Coupled with the *VNOS–C* responses, these interview questions allowed assessing respondents' views of the general aim and structure of scientific experiments, the logic of theory and hypothesis testing, and the validity of observationally-based (as compared to experimentally-based) scientific theories and disciplines.

VNOS–C was administered to college undergraduates and graduates, and preservice secondary science teachers (Abd-El-Khalick, 1998; Abd-El-Khalick & Lederman, 2000b). Many participants noted, often in response to *VNOS–C* #1, that science is characterized by "the" scientific method or other sets of logical and orderly steps. During the follow-up interviews these participants were asked, "Do all scientists use a specific method, in terms of a certain stepwise procedure, when they do science? Can you elaborate?" In their response to *VNOS–C* #2, many participants defined scientific experiments very broadly as "procedures used to answer scientific questions." In the attempt to clarify such responses interviewees were asked, "Are you thinking of an experiment in the sense of manipulating variables or are you thinking of more general procedures? Can you elaborate?"

VNOS–Form C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge **require** experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

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

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

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

(figure continues)

Figure 2. (*continued*)

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 believe that science reflects social and cultural values, explain why. Defend your answer with examples.
   - If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
    - If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Figure 2. Views of Nature of Science Questionnaire (Form C)

Also, mostly in response to the first and second items, many participants noted that scientific knowledge is "proven" knowledge or that scientific experiments aim to "prove" or "disprove" hypotheses or theories. Interviewees were asked, "How would you 'prove' a theory or hypothesis?" A typical response was that scientific claims are "proven" by collecting evidence and/or doing experiments. Interviewees were then asked, "How much evidence or how many experiments does it take to 'prove' a scientific claim?" or "How much evidence and/or how many experiments are 'enough' to prove a scientific claim?"

In response to *VNOS–C* #3, some participants noted that developing scientific knowledge necessarily requires *manipulative* experiments. In an attempt to elucidate how this view relates to the case of "observational" sciences, interviewees were then asked a set of questions. The first question was, "Let's consider a science like astronomy (or anatomy). Can we (or do we) do manipulative experiments in astronomy (or anatomy)?" If interviewees answered in the positive they were asked to explicate their answers and provide examples. This served to further probe interviewees' conceptions of scientific experiments. However, if they answered in the negative, the interviewees were then asked, "But we still consider astronomy (or anatomy) a science. What are your ideas about that?"

Other follow-up questions aimed to assess the depth of participants' understanding of the theory-laden nature of science and the role that scientific theories and theoretical expectations play in guiding scientific research. Two of these questions followed interviewees' explication of their responses to *VNOS–C* #2 on scientific experiments. The questions were, "When scientists perform 'manipulative' experiments they hold certain variables constant and vary others. Do scientists usually have an idea about the outcome of their experiments?" If interviewees agreed, they were then asked, "Some claim that such expectations would bias the results of an experiment. What do you think?" Two other questions followed the fourth item that related to scientific theories. On noting that scientific theories change in their responses to the questionnaire, interviewees were asked, "The history of science is full with examples of scientific theories that have been discarded or greatly changed. The life spans of scientific theories, if you will, vary greatly, but theories seem to change at one point or another. And there is no reason to believe that the scientific theories we have today will not change in the future. Why do we bother learn about these theories? Why do we invest time and energy to grasp these theories?" The other question was, "Which comes first when scientists conduct scientific investigations theory or observation?"

A question that followed interviewees' discussion of *VNOS–C* #5 was "In terms of status and significance as products of science, would you rank scientific theories and laws? And if you choose to rank them, how would you rank them?" Two other questions followed when participants' responses to the sixth item on the structure of the atom were not informative regarding their views of the role of inference and creativity in science. The first question was "Have we ever 'seen' an atom?" If they responded in the negative, interviewees were then asked, "So, where do scientists come up with this elaborate structure of the atom?" Those interviewees who thought that scientists have actually "seen" an atom were asked to elaborate on their answers. Similarly, *VNOS–C* #7 aimed to assess participants' understandings of the role of inference and creativity in science. On noting that scientists were very certain about the notion of species, interviewees were asked, "There are certain species of wolfs and dogs that are known to interbreed and produce fertile offspring. How does this fit into the notion of species, knowing that the aforementioned species are 'different' species and have been given different names?"

To assess whether participants thought of creativity and imagination in scientific investigation more as "resourcefulness" and "skillfulness" or as "invention" of explanations, they were asked, "Creativity and imagination also have the connotation of creating something from the mind. Do you think creativity and imagination play a part in science in that sense as well?" Finally, in response to the item related to the dinosaur extinction controversy, many interviewees thought that the controversy was unjustified given that the evidence supports both hypotheses. In that case, the interviewees were asked, "This is very reasonable. It is very reasonable to say that the data is scarce and that the available evidence supports both hypotheses equally well. However, scientists in the different groups are very adamant about their own position and they publish very pointed papers in this regard. Why is that?"

In addition to undergraduate and graduate college students (Abd-El-Khalick, 1998), the *VNOS–C* was also administered to preservice elementary teachers (Abd-El-Khalick, 2000), and preservice and inservice secondary science teachers (Abd-El-Khalick, 1998; Abd-El-Khalick & Lederman, 2000b; Lederman, Schwartz, Abd-El-Khalick, & Bell, in press; Schwartz & Lederman, in press; Schwartz, Lederman, & Crawford, 2000). Abd-El-Khalick (1998, 2000) established the content validity of the *VNOS–C* by comparing and contrasting participants' NOS profiles that were generated from separate analyses of the questionnaires and corresponding interview-transcripts. In these studies, the questionnaires of interviewed participants were first analyzed to generate a profile of these participants' NOS views. Next, similar analyses were conducted using the same participants' interview transcripts. The independently generated profiles were systematically compared and contrasted. Comparisons indicated that interpretations of participants' NOS views as elucidated in the *VNOS–C* were congruent to those expressed by participants during individual interviews. Finally, it is important to note that all versions of the *VNOS* yield consistent findings in areas of overlap.

Collecting and Analyzing *VNOS* Data: Important Logistical and Conceptual Issues

Administering the *VNOS*

It is preferable to administer the *VNOS* under controlled conditions (e.g., in class under supervision). However, given the open-ended nature of the *VNOS* items, it is important not to set time limits. Our participants typically spent 35–45 minutes to complete the *VNOS–B* and 45-60 minutes to complete the *VNOS–C*. Each *VNOS* item is printed on a single page to provide respondents with ample space to write their answers. Respondents should be encouraged to write as much as they can in response to any one item, make sure to address all sub-sections of an item, and provide supportive or illustrative examples where asked to. The *VNOS* should not be used for summative assessment purposes in any manner since such use might impinge on respondents' answers. Respondents' should be reminded that there are no "right" or "wrong" answers to any item and that the intention is to elicit their views on some issues related to NOS.

Following the administration of the *VNOS*, a reasonable sample of respondents should be individually interviewed. During these interviews, respondents are provided their *VNOS* questionnaires and asked to explain and justify their responses. Follow-up and probing questions could be used to clarify ambiguities, assess meanings that respondents ascribe to key terms and phrases, and explore respondents' lines of thinking. For researchers using the *VNOS* for the first time, we recommend interviewing all or a large majority of respondents. With repeated use, researchers should develop expertise in interpreting *VNOS* responses. Such expertise becomes evident when researchers obtain high degrees of correspondence between their inferences regarding respondents' NOS views as derived from *VNOS* responses and the views elucidated by those respondents during individual interviews. At this point, researchers could interview sub-samples of respondents. As noted earlier, we now find interviewing 15-20% of our respondents sufficient to gauge subtleties of meaning associated with a certain group of respondents or a certain context. Interviewees could be chosen either randomly or purposively depending on the purpose of administering the instrument.

Analyzing Responses to the *VNOS*

The first step in analyzing *VNOS* data is to reaffirm the validity of the questionnaire in the context in which it is used and flesh out the subtleties of meanings that respondents in that context ascribe to key terms and phrases. This step can be achieved by systematically comparing and contrasting profiles of respondents' NOS views that are generated by the separate analyses of interviewees' questionnaires and interview transcripts. If a high degree of congruence between the separately generated profiles is obtained—or once such a high degree is established by modifying the researchers' interpretations of *VNOS* responses to accommodate interview data, all questionnaires data could be analyzed.

When several researchers are involved in analyzing *VNOS* responses, it is crucial to establish inter-rater agreement or reliability. Such agreement could be established by having all researchers independently analyze the same subset of data and then compare and contrast their analyses. Discrepancies could be resolved by further consultation of the data (especially interview data) or consensus. Analyses of all questionnaire and interview data should only proceed after establishing such reliability (see Abd-El-Khalick et al., 1998).

Analysis of responses to *VNOS* items does not assume a restrictive one-to-one correspondence between an item on the questionnaire and a target NOS aspect. To be sure, certain items target one NOS aspect to a larger extent than others. For instance, *VNOS–B* #1 and #5 and *VNOS–C* #4 and #10 largely target respondents' views of the tentative and creative NOS respectively. However, views of the target NOS aspects could be explicated in response to other items on the questionnaires. For instance, understandings of the tentative and creative aspects of NOS could be expressed in response to *VNOS–B* #2 and #3 and *VNOS–C* #1, #5, #6, and #7.

This approach to the analysis has two major advantages. First, it is consistent with our belief that NOS understandings should not be construed in the narrow sense of specific desired responses to cues set by specific questions. Rather, participants could demonstrate their NOS understandings in several contexts. Second, this approach allows to check for meaningful understandings of a NOS aspect versus superficial reiteration of key terms by checking for consistency, or lack thereof, in respondents' answers across *VNOS* items. For example, in response to *VNOS–C* #4, respondents might indicate that they believe that scientific theories could change in the future without providing examples. This might indicate that these respondents endorse a tentative view of NOS. However, if the same respondents explicitly note in response to *VNOS–C* #5 that "theories become laws when they are proven true" or in response to *VNOS–C* #6 and #7 that scientists were certain about atomic structure and the notion of species, then one could hardly infer that they have internalized an understanding of the tentativeness of scientific knowledge. By the same token, if respondents demonstrate understandings of the creative and imaginative NOS in their responses to, say, *VNOS–C* #6, #7, #8 and #10, then it would be safe to infer that they have developed solid understandings of this NOS aspect. To be sure, if respondents explicate informed views of a target NOS aspect in any one item and there were no inconsistencies or other disconfirming evidence in their responses to other *VNOS* items regarding this aspect, then they should be judged to have informed views.

Moreover, it is important to note that "low inference" is desired throughout the analysis. This is not to say that respondents' answers should be taken literally. Indeed, data from follow-up interviews often suggest alternative ways of interpreting responses, which on initial examination seem to strongly suggest certain NOS views. For example, in our studies, many participants often used the terms "prove" and "proof," which could be taken to mean that they harbored an absolutist view of scientific knowledge. However, further probing during the interviews indicated that many of those participants used the term "proof" to refer to "evidence" and not to the more robust meaning of the word "proof," which indicates knowing with certainty. Care should be exercised in order not to load respondents' words and phrases with high-inference meanings or impose on respondents' views consistent structures unless interview data suggest otherwise. Indeed, in many cases we found that respondents' views were fluid, fragmented, and compartmentalized. For instance, some of our participants indicated in their responses to *VNOS–B* #5 that scientists use imagination and creativity in their work. These same participants, however, indicated elsewhere in their questionnaires that scientists use "The Scientific Method." When asked during interviews to address these seemingly contradictory views, it became evident that those participants lacked an overarching consistent framework for their NOS views. This latter finding, it should be noted, was always masked when standardized convergent instruments were used to assess learners' NOS views. Irrespective of whether learners actually did or did not possess a coherent framework for NOS, standardized and convergent instruments, by virtue of their design, gave the impression that those respondents ascribed to consistent philosophical stances.

Most *VNOS* items ask respondents to provide examples to support their views. These examples should be carefully examined and factored in when assessing respondents' NOS views. For instance, some of our participants provided "Murphy's law" and "CH_3 is a methyl group" as examples of scientific laws. Others provided the (historically inaccurate) example of the shift from a "flat to a rounded conception of the shape of the earth" as an example of theory change. Such examples help to contextualize participants' conceptions of key concepts and shed light on some of their naïve (or informed) ideas.

Finally, as a rule of thumb, interview data should be given priority when respondents' views as explicated in the questionnaires are inconsistent with views they expressed during individual interviews. This latter use of interview data, however, assumes "good" interviewing practices, such as observing extended-wait time, avoiding directive cues, testing initial hypotheses about an interviewee's conceptions through non-directive follow-up or probing questions.

Illustrative Examples of Responses to the *VNOS*

Tables 2 and 3 present illustrative examples of responses to the *VNOS–B* and *VNOS–C* items and interview questions respectively. These examples are verbatim quotes selected from *VNOS* responses and interview transcripts of participant undergraduate and graduate college students, and preservice and inservice elementary and secondary science teachers in our various studies. The examples serve to illustrate our respondents' views of several important aspects of NOS, which are presented along continua from more naïve toward more informed views. Needless to say, views of the target NOS aspects are necessarily interrelated and one quote that is used to illustrate naïve (or informed) views of one NOS aspect could as well be used to illustrate naïve (or informed) views of another aspect. The assignment of the quotes is, in that sense, somewhat arbitrary and only intended to make the presentation of respondents' NOS views manageable.

It is important to note that the examples presented in Tables 2 and 3 are shorthand illustrations of the sort of rich and intensive data generated by the use of the *VNOS* and associated interviews. Nonetheless, even with these examples, it is not difficult to discern that the *VNOS* items generate responses that clearly discriminate naïve from informed NOS views and, more importantly, provide insight into respondents' thinking about the target NOS aspects. Additionally, it is not difficult to see how the sort of responses provided by one or several respondents could be used to construct intensive individual or aggregate profiles of NOS views respectively. The kind of data generated by using the various *VNOS* versions clearly surpasses the cumulative numerical data generated by utilizing standardized convergent paper-and-pencil NOS assessment instruments in several respects. First, *VNOS* data explicate what respondents *actually* think in terms of NOS and the reasons underlying their thinking. Respondents' reasoning could be examined further during follow-up interviews. Second, given the non-categorical and rich nature of the *VNOS* responses and their sensitivity to subtle differences in

Table 2

<u>Illustrative Examples of Responses to *VNOS–B* Items</u>

NOS aspect	More naïve views	⇔	More informed views
Empirical NOS	Science is concerned with facts. We use observed facts to prove that the theories are true. (Item #6)	⇔	Scientists collect data to support their interpretation of the world. Artists just show their interpretation of the world. (Item # 6)
Tentative NOS	Theories more develop than change. Scientists keep on adding to our theories so that they become better. (Item #1) If you get the same result over and over and over, then you become sure that your theory is a proven law, a fact. (Item #3)	⇔	Everything in science is subject to change with new evidence and interpretation of that evidence. We are never 100% sure about anything because . . . negative evidence will call a theory or law into question, and possibly cause a modification. (Item #1)
Creative and imaginative NOS	A scientist only uses imagination in collecting data . . . But there is no creativity after data collection because the scientist has to be objective. (Item #5)	⇔	Both science and art are created by humans' minds. Both reach their fullest expression only when the scientist or artist shares his/her creation with other human beings. However, science is based on evidence, whereas art is not. (Item #4)
"The Scientific Method"	Science deals with using an exact method so we can duplicate our results. That way we know we have the right answer. (Item #4)	⇔	There is no one method of doing science. In developing their methods, scientists use imagination and creativity. (Item #5)
Inferential nature of scientific constructs	Scientists can see atoms with high-powered microscopes. They are very certain of the structure of atoms. You have to see something to be sure of it. (Item #2)	⇔	Evidence is indirect and relates to things that we don't see directly. You can't answer . . . whether scientists know what the atom looks like, because it is more of a construct. (Item #2)
Relation between theories and laws	Laws started as theories and eventually became laws after repeated and proven demonstration. (Item #3)	⇔	A scientific law <u>describes</u> something that happens in nature. A theory is an attempt by scientists to <u>explain</u> why nature is the way it is. (Item #3)
Subjective (theory- laden) NOS	Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work. (Item #4)	⇔	Scientists are human. They learn and think differently, just like all people do. They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge. (Item #7)

Table 3

Illustrative Examples of Responses to *VNOS–C* Items and Interview Questions

NOS aspect	More naïve views	⇔	More informed views
Empirical NOS	Science is something that is straightforward and isn't a field of study that allows a lot of opinions, personal bias, or individual views–it is fact based. (Item #1) I believe science is different . . . because it uses concrete facts that have been proven/ are observable/ can be repeated and seen by someone else to get a right or wrong answer. (Item #1)	⇔	Much of the development of scientific knowledge depends on observation . . . [But] I think what we observe is a function of convention. I don't believe that the goal of science is (or should be) the accumulation of observable facts. Rather, I think that . . . science involves abstraction, one step of abstraction after another. (Interview, follow-up on item #1)
"The Scientific Method"	Science has a particular method of going about things, the scientific method. (Item #1) The key to the difference between science and other inquires, is that science follows a rigid set of rules. (Item #1)	⇔	When you are in sixth grade you learn that here is the scientific method and the first thing you do this, and the second thing you do that and so on so forth. That's how we may say we do science, but there is a difference between the way we say we do science and the way that we actually do science. (Interview, follow-up on item #1)
General structure and aim of experiments	An experiment is a sequence of steps performed in order to prove a proposed theory. (Item #2) Experiment is everything that involves the act of collecting data and not necessarily manipulation. (Interview, follow-up on item #2)	⇔	An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same . . . the results . . . will lead the scientist to believe his/her theory has or doesn't have validity. (Item #2) An experiment cannot prove a theory or a hypothesis. It just discredits or adds validity to them. (Item #2)
Role of prior expectations in experiments	You usually have some sort of idea about the outcome. But I think that to have a scientific and valid experiment you should not have any bias or ideas in advance. (Interview, follow-up on item #2)	⇔	In order to organize an experiment you need to know what is going to come out of it or it wouldn't really be a test method. I don't know how you would organize a test . . . if you don't have a general idea about what you are looking for. (Interview, follow-up on item #2)
Validity of observationally-based theories and disciplines	Science would not exist without scientific procedure which is solely based on experiments . . . The development of knowledge can only be attained through precise experiments. (Item #3)	⇔	Experiments are not always crucial . . . [For] example . . . Darwin's theory of evolution . . . cannot be directly tested experimentally. Yet, because of observed data, such as fossils and rock formations, it has become virtually the lynchpin of modern biology. (Item #3)

(table continues)

Table 3. (*continued*)

NOS aspect	More naïve views	⇔	More informed views
Scientific theories			
Nature of	Theories are just that, one person's view or thought on what occurred. (Item #4)	⇔	In the vocabulary of a scientist the word theory is used differently than in the general population. It does not mean someone's idea that can't be proven. It is a concept that has considerable evidence behind it and has endured the attempts to disprove it. (Item #4)
	A theory is an untested idea, or an idea that is undergoing additional tests, Generally it hasn't been proved to the satisfaction of the scientific community. (Item #4)		
Functions of	We learn scientific theories just so that scientists don't start all over from the beginning . . . they just can add to the old ideas. (Item #4)	⇔	Theories set a framework of general explanation upon which specific hypotheses are developed. Theories, even if temporary, also advance the pool of knowledge by stimulating hypotheses and research, which may support the current theory or lead to new theories. (Item #4)
Logic of testing	Many theories can't be completely tested, e.g. the theory of evolution can't be tested unless you create your own world and then live for millions of years. (Item #5)	⇔	Most theories have things we cannot observe. So, we deduce consequences from them that could be tested. This indirect evidence allows us to see if the theory is valid. (Interview, follow-up to item #5)
Difference and relationship between theories and laws	A scientific law is a theory that has been . . . proven again and again over time to be true. (Item #5)	⇔	A scientific law describes quantitative relationships between phenomena such as universal attraction between objects. Scientific theories are made of concepts that are in accordance with common observation or go beyond and propose new explanatory models for the world. (Item #5)
	A scientific law is somewhat set in stone, proven to be true . . . A scientific theory is apt to change and be proven false at any time. (Item #5)		
Tentative NOS	Compared to philosophy and religion . . . science demands definitive answers with right & wrong answers. (Item #1)	⇔	[Science] strives to ask questions and is fueled by the desire to answer such questions and the acceptance that science is not absolute. (Item #1)
	I believe that most of the time they [theories] do *not* change because they are basic theories that will only accept *alterations* [italics in original]. (Item #4)		Theories do change because of new data and because of changing ideas and societies' view of the world changes. (item #4)
	A law has been tested and cannot be changed. (Item #5)		Laws like theories are tentative. (Item #5)

(table continues)

Table 3. (*continued*)

NOS aspect	More naïve views	⇔	More informed views
Creative and imaginative NOS	I don't think scientific investigation is best characterized by creativity or imagination. I think a composer can be creative, a novelist can be imaginative, etc. . . . Scientific investigations are often tedious and repetitive, with the sole purpose of generating new data on the basis of previous data. (Item # 10) You need to sort take away your mind after you collect the data . . . You don't want to be creative when you interpret data. (Interview, follow-up on Item 10)	⇔	Logic plays a large role in the scientific process, but imagination and creativity are essential for the formulation of novel ideas . . . to explain why the results were observed. (Item #10) Scientists use creativity and imagination during their investigations . . . to come up with plausible explanations for the data and possible other questions to pursue answers to. (Item #10)
Inference and theoretical entities	I think scientists are pretty sure about the structure of the atom. The evidence they use is microscopic pictures of the actual atoms. (Item #6)	⇔	Models of the structure of the atom are frequently being updated. Current theories . . . explain observed phenomena with a fairly high degree of certainty, but only indirect evidence can be used to formulate such theories. (Item #6)
	There is . . . scientific certainty [about the concept of species]. While in the early days it was probably a matter of trial-and-error . . . nowadays genetic testing makes it possible to define a species precisely. (Item #7)	⇔	Species is . . . a completely human creation. It is a convenient framework for categorizing things, animals and plants . . . It is a good system but I think the more they learn the more they realize that . . . we cannot draw the line between species or sub-species or sub-populations of a sub-species. (Interview, follow-up to item #7)
Subjective or theory-laden NOS	[Scientists reach different conclusions] because the scientists were not around when the dinosaurs became extinct, so no one witnessed what happened . . . I think the only way to give a satisfactory answer to the extinction of the dinosaurs is to go back in time to witness what happened. (Item #8) This [controversy] might be an instance where, because of lack of real evidence, scientists *did* [italics in original] use their creativity and imagination. (Item #8)	⇔	Both conclusions are possible because they may be different interpretations of the same data. Different scientists may come up with different explanations based on their own education and background or what they feel are inconsistencies in others ideas. (Item #8) Scientists are human and when the geophysicists get together and examine the evidence they are doing it from a certain perspective . . . and tend to emphasize the geophysics data. The paleontologists come along, see the same data and interpret it from their perspective. Scientists, people of a certain ilk, see the world through rose tinted glasses. (Item #8)

(table continues)

Table 3. (*continued*)

NOS aspect	More naïve views	⇔	More informed views
Social and cultural embeddedness of science	Science is about the facts and could not be influenced by cultures and society. Atoms are atoms here in the US and are still atoms in Russia. (Item #9)		Of course culture influence the ideas in science. It was more than a 100 years after Copernicus that his ideas were considered because religious beliefs are the church sort of favored the geocentric model. (Item #9)
	Well, the society can sometimes not fund some scientific research. So, in that sense it influences science. But scientific knowledge is universal and does not change from one place to another. (Interview, follow-up on item #9)		All factors in society and the culture influence the acceptance of scientific ideas . . . Like the theory of evolution was not accepted in France and totally endorsed in Germany for basically national, social, and also cultural elements. (Item #9)

terms of NOS views, the *VNOS* allows for meaningful assessments of changes—no matter how small, in learners' NOS views as a result of various instructional interventions, and an assessment of the interaction between learners' NOS views and the nature of the specific instructional activities undertaken in these interventions from diagnostic and cognitive perspectives. This latter assessment is surely very informative in terms of modifying and enhancing the effectiveness of such interventions.

Conclusion and Implications

Establishing the validity of an instrument is an on-going process. In fact, it is incorrect to speak of validity as ever being "established" in the once-and-for-all sense of the word. Rather, at best, we can only provide evidence of an instrument's efficacy in measuring what it is designed to measure. Due to its open-ended nature, the *VNOS* differs from typical paper-and-pencils instruments. While face and content validity of the various versions of the instrument have been determined repeatedly, its principle source of validity evidence stems from the follow-up interviews. During these interviews, it is possible to directly check respondents' understandings of each item, as well as the researchers' interpretation of these responses. In our various studies, the three forms of the *VNOS* were administered to about 2000 high school students, college undergraduates and graduates, and preservice and inservice elementary and secondary science teachers across four continents. This was coupled with about 500 individual interviews. The results of these studies and follow-up interviews support a high confidence level in the validity of the *VNOS* for a wide variety of respondents. We believe that the *VNOS* items and interview protocol may be applied with confidence when assessing understandings of NOS.

The most significant question to be asked of the present instrument would be: Isn't the *VNOS* just another paper-and-pencil NOS instrument? The response to this question is by no means simple. The *VNOS* is different in underlying assumptions and form from standardized and convergent instruments. It was developed with an interpretive stance in mind, and aims to elucidate learners' NOS views and generate profiles of the meanings they ascribe to various NOS aspects for the purpose of informing the teaching and learning of NOS rather than for labeling learners' views as "adequate" or "inadequate" or sum their NOS understandings into less-than-informative numerical scores. However, even though the open-ended nature of the *VNOS* items do ameliorate some of the concerns associated with the use of standardized convergent paper-and-pencil instruments, the *VNOS* could be easily "abused" if its interpretive stance and qualitative interviewing component were overlooked or undermined. As such, the importance of coupling the use of the *VNOS* with individual in-depth follow-up interviews with all or a reasonable sample of respondents cannot be overemphasized.

Despite these concerns, we decided to "release" the *VNOS* in light of some recent and disconcerting calls within the science education community to develop other forced-choice standardized and convergent NOS instruments (e.g., Good et al., 2000) designed especially for mass administrations to large samples. These calls have ignored the problematic nature of these instruments, recent general trends in education, such as the concern with learners' own conceptions of subject matter, and years of intensive research that has shown the inadequacies of such assessment approaches in informing research on teaching and learning in general, and NOS in particular. Indeed, these calls ignore all that we have learned from research on teaching and learning about NOS over the past 30 years. The present state of this line of research necessitates a focus on individual classroom interventions aimed at enhancing learners' NOS views, rather than on mass assessments aimed to describe or evaluate students' beliefs. Thus, we found it useful to present the *VNOS* for general use with as much qualification as we could with regard to its underlying assumptions and methodological considerations. We hope that the *VNOS* would lead the way toward more valid and meaningful assessment of students' and teachers' NOS views.

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