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

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Abstract: Helping students develop informed views of nature of science (NOS) has been and continues to be a central goal for kindergarten through Grade 12 (K–12) science education. Since the early 1960s, major efforts have been undertaken to enhance K–12 students and science teachers' NOS views. However, the crucial component of assessing learners' NOS views remains an issue in research on NOS. This article aims to (a) trace the development of a new open-ended instrument, the Views of Nature of Science Questionnaire (VNOS), which in conjunction with individual interviews aims to provide meaningful assessments of learners' NOS views; (b) outline the NOS framework that underlies the development of the VNOS; (c) present evidence regarding the validity of the VNOS; (d) elucidate the use of the VNOS and associated interviews, and the range of NOS aspects that it aims to assess; and (e) discuss the usefulness of rich descriptive NOS profiles that the VNOS provides in research related to teaching and learning about NOS. The VNOS comes in response to some calls within the science education community to go back to developing standardized forced-choice paper and pencil NOS assessment instruments designed for mass administrations to large samples. We believe that these calls ignore much of what was 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

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than on mass assessments aimed at describing or evaluating students' beliefs. J Res Sci Teach 39: 497–521, 2002

During the past 85 years, almost all scientists, science educators, and science education organizations have agreed on the objective of helping students develop informed conceptions of nature of science (NOS) (Abd-El-Khalick, Bell, & Lederman, 1998; Duschl, 1990; Meichtry, 1993). 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) about the goal of enhancing students' conceptions of NOS. However, research has consistently shown that kindergarten through Grade 12 (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; Ryan & Aikenhead, 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, 1968; Haukoos & Penick, 1983; Jelinek, 1998; Ogunniyi, 1983; Olstad, 1969; Shapiro, 1996; Solomon, Duveen, & Scot, 1994).

Nevertheless, the assessment of learners' NOS views remains an issue in research on NOS (Aikenhead, 1988; Lederman, Wade, & Bell, 1998). In the majority of the those 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 (Aikenhead, Ryan, & Desautels, 1989). Moreover, there are concerns regarding the usefulness of standardized instruments for research related to NOS. The purpose of this article is to report on the development of a new open-ended instrument, the Views of Nature of Science Questionnaire (VNOS), and demonstrate the value of VNOS data to research on NOS in science education. More specifically, the article aims to (a) trace the development of the VNOS, which in conjunction with individual interviews aims to provide meaningful assessments of learners' NOS views; (b) outline the NOS framework that underlies the development of the VNOS; (c) present evidence regarding the validity of the VNOS; (d) elucidate the use of the VNOS and associated interviews, and the range of NOS aspects that it attempts to assess; and (e) discuss the usefulness of rich descriptive NOS profiles that the VNOS provides in research related to teaching and learning about NOS. In the present discussion, "meaningful assessments" refer to assessment approaches that serve as an integral aspect of the learning process through providing teachers and learners with information and opportunities to clarify meaning, encourage reflection, and further learning (Zessoules & Gardner, 1991).

Before discussing the VNOS, we will outline the NOS framework that underlies its development and briefly discuss some problematic aspects of standardized and convergent paper and pencil NOS assessment instruments. For a comprehensive review of those latter instruments and an explication of the pros and cons associated with the use of convergent and standardized versus alternative approaches, such as open-ended questionnaires and interviews, to assess learners' NOS views, the reader is referred to Lederman et al. (1998).

NOS

Typically, NOS refers to the epistemology and sociology 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 general, and philosophers, historians, and sociologists of science are quick to disagree on specific issues regarding NOS.

The use of the phrase *NOS* throughout this article instead of the more stylistically appropriate *the NOS*, is intended to reflect the authors' lack of belief in the existence of a singular NOS or agreement on what the phrase specifically means (Abd-El-Khalick & Lederman, 2000a). Such disagreement, however, should not be surprising or disconcerting given the multifaceted and complex nature of science. 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 (see Abd-El-Khalick & Lederman, 2000a, for a broad survey of these changes).

It is our view, however, that many 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 compared with 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 among philosophers, historians, and sociologists of science (Smith, Lederman, Bell, McComas, & Clough, 1997). For instance, currently it would be difficult to reject the theory-laden nature of scientific observations or defend a deterministic/absolutist or empiricist conception of NOS. At such a level of generality, some important aspects of NOS are not 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: scientific knowledge is tentative; empirical; 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 recipelike method for doing science, and the functions of and relationships between scientific theories and laws. These NOS aspects have been emphasized in recent science education reform documents (e.g., AAAS, 1990, 1993; Millar & Osborne, 1998; NRC, 1996).

In this regard, individuals often conflate NOS with science processes. In agreement with aforementioned reform documents, 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; Chiappetta, Koballa, & Collette, 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. In addition, (a) the generalizations presented in the following discussion of the NOS aspects 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; and (b) each of these NOS aspects could be approached at different levels of depth and complexity depending on the background and grade level of students.

The Empirical Nature of Scientific Knowledge

Science is at least partially based on 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 nature 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

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 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 be accessed and/or measured only through its manifestations or effects, such as the perturbations in predicted planetary orbits due to interplanetary 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 include atoms, molecular orbitals, species, genes, photons, magnetic fields, and gravitational forces (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 large 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 other phenomena related to heat and its transfer. More important, theories have a major role in generating research problems and guiding future investigations. Scientific theories are often based on a set of assumptions or axioms and posit the existence of nonobservable entities. Thus, theories cannot be directly tested. Only indirect evidence can be used to support theories and establish their validity. Scientists derive specific testable predictions from theories 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.

Closely related to the distinction between observation and inference is the distinction between scientific theories and laws. In general, laws are descriptive statements of 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. Theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. For example, the kinetic molecular theory serves to explain Boyle's law. Students often (a) hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence; and (b) believe that laws have a higher status than theories. Both notions 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.

The Creative and Imaginative Nature of Scientific Knowledge

Science is empirical. The development of scientific knowledge involves making observations of nature. Nonetheless, generating scientific knowledge also involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, entirely 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 an example. 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 Theory-Laden Nature of Scientific Knowledge

Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work. All these background factors form a mindset that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they interpret their observations. This (sometimes collective) individuality or mindset accounts for the role of theory in the production of scientific knowledge. 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, which are derived from 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 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. Telling the story of hominid evolution, which is central to the biosocial sciences, may illustrate how social and cultural factors affect scientific knowledge. Scientists have formulated differing storylines about hominid evolution. Until recently, the dominant story was centered on the man-hunter and his crucial role in human evolution (Lovejoy, 1981), a scenario consistent with the White male culture that dominated scientific circles until the early 1970s. As feminist scientists achieved recognition in science, the story about hominid evolution started to change. One story more consistent with a feminist approach is centered on the female-gatherer and her central role in the evolution of humans (Hrdy, 1986). Both storylines 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 may be traced 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 those latter stances the criterion of certainty was either replaced with notions of high probability or abandoned altogether) have been debunked, such as Bayesianism, falsificationism, and hypothetico-deductivism (Gillies, 1993). Nonetheless, some of those 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 recipelike stepwise procedure that all scientists follow when they do science. This notion was explicitly debunked: There is no single scientific method that would guarantee the development of infallible knowledge (AAAS, 1993; Bauer, 1994; Feyerabend, 1993; NRC, 1996; 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, although 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 thinking 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. Tentativeness in science does not arise solely from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded. There are 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 irrespective of the amount of supporting empirical evidence (Popper, 1963). For example, to be proven, a law should account for every instance of the phenomenon it purports to describe. 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. Thus, the law can never acquire an absolutely proven status. This equally holds in the case of theories.

Some Problematic Aspects 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, such as the *Test on Understanding Science* (Cooley & Klopfer, 1961), *Nature of Science Test* (Billeh & Hasan, 1975), and *Conceptions of Scientific Theories Test* (Cotham & Smith, 1981). A comprehensive review of these instruments can be found elsewhere (Lederman et al., 1998). These instruments are composed of forced-choice items, such as agree/disagree, Likert-type, or multiple choice.

Some major criticisms have been leveled against the use of standardized instruments to assess learners' NOS views, two of which were related to these instruments' validity—that is, the extent to which the instruments actually assess what they purport to measure (Gall, Borg, & Gall, 1996). First, Aikenhead et al. (1989) and Lederman and O'Malley (1990) argued that such instruments were based on a problematic assumption: namely, that respondents perceive and interpret an instrument's items in a manner similar to that of the instrument developers. They continued that ambiguities, which seriously threaten the 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' NOS views and biases. Being of the forced-choice category, the instruments ended up imposing the developers' views on respondents. In addition, responses to instrument items were usually designed with certain 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 likely an artifact of the instrument in use than a faithful representation of the respondents' conceptions of NOS.

A notable exception among convergent instruments is the Views on Science–Technology–Society (VOSTS) questionnaire developed by Aikenhead, Ryan, and Fleming (1989). The VOSTS is an inventory of multiple choice items. Each item consists of a statement with several related reasoned viewpoints or positions. A student-centered process was used to develop these viewpoints or positions, which were derived from Canadian high school students' responses to VOSTS items and follow-up interview questions. By substituting student response patterns to positions derived from a theoretical viewpoint, Aikenhead et al. (1989) were able to construct an empirically based instrument with a high degree of validity (Ryan & Aikenhead, 1992), thus addressing to a significant extent the above two criticisms. Nonetheless, when used outside the Canadian context in particular and the Western context in general, those criticisms of convergent instruments would apply to the VOSTS. In a sense, from the perspective of non-Canadian and non-Western students, the various VOSTS positions would create a situation not substantially different from the one in which the responses are imposed by researchers or instrument developers. In addition, the forced-choice nature of the VOSTS items limits the space of answers available to respondents. Indeed, when given the choice, several Lebanese science teachers indicated that their views on the NOS issues elicited by some VOSTS items were either not represented among, or were combinations of, the provided viewpoints. Other teachers chose to express viewpoints totally different from the ones presented in the VOSTS (see Abd-El-Khalick & BouJaoude, 1997).

A third criticism relates to the usefulness of standardized instruments. These instruments are suitable for large-scale assessments and generating aggregate measures of the adequacy of learners' NOS views. However, such instruments are generally limited to labeling participants' views as adequate or inadequate—mostly by assigning student views cumulative numerical values—rather than elucidating and clarifying such views. However, instrument developers did not clarify what numerical value on such instruments constituted an adequate view of NOS (Lederman, 1986). As such, the use of standardized instruments limits the feasibility of drawing meaningful conclusions regarding the nature of 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.

Development of the VNOS

VNOS–Form A

In response to the discussed state of affairs and with the aim of eliciting, clarifying, and probing learners' NOS views in depth, researchers (e.g., Driver, Leach, Millar, & Scott, 1996) started to use alternative approaches to assessing students' NOS views, such as open-ended questions and interviews. 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. An open-ended questionnaire was used to avoid the problems inherent in the use of standardized forced-choice instruments. In contrast to forced-choice items used in these latter instruments, open-ended items allow respondents to elucidate their own views regarding the target NOS aspects (Driver et al., 1996). Moreover, given the concern with the meanings that participants ascribed to the target NOS aspects, and the researchers' interest in elucidating and clarifying participants' views, it was imperative to avoid misinterpreting their responses to the open-ended items. As such, individual semistructured interviews were used to validate 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 on 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 items were not validated during the interviews. Participants either were unable to interpret the intended meaning of these three items or found them to be vague. For example, one item asked participants whether scientists use imagination and creativity when performing scientific experiments and investigations. This item was intended to assess whether students believed scientists use 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, Lederman and O'Malley (1990) reported inferences based on participants' responses to four items, whose validity was substantiated during individual interviews. However, even with those items, the problem of researchers misinterpreting students' responses could not have been avoided without interviews. For example, in response to an item that asked participants to distinguish between scientific theories and laws, students consistently used the word *prove*. 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 "prove" in an absolute sense, but rather in a sense consistent with the way scientists use it. Thus, although the item was valid in its assessment of targeted student views, interpretation of student meaning (without interviews) led to an erroneous 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 assess students' NOS perceptions validly 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 theory-laden NOS, and the functions of and relationship between theories and laws. Initially, the administration of the VNOS-B (Figure 1) was intended to elicit participants' NOS views and create a context in which those views could be discussed. This administration was followed with in-depth individual interviews with all participant teachers. During those interviews, participants were provided their questionnaires and asked to explain their responses, 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 (VNOS-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 those 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 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 those studies assigned to a certain NOS aspect were observed. Follow-up interviews remained crucial for valid interpretations of participants' questionnaire responses. However, as the researchers became more cognizant of the meanings that participants 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 after 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. As part of an investigation into the decision making of NOS experts and nonexperts, Bell (1999) assessed the construct validity of the VNOS-B. If the instrument had construct validity, respondents with assessed thorough understandings of NOS should respond much differently from those assessed to possess naive understandings. A sample of adults was purposively selected to participate in the study. Secondary students were not selected for the principle reason that the study required one group to have expert understandings of NOS. This criterion ruled out the vast majority of adolescents, if not all (Aikenhead, 1973, 1987; Bady, 1979; Gilbert, 1991; Lederman & O'Malley, 1990; Mackay, 1971). The expert group was composed of nine individuals with doctoral degrees in science education, or history 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 selected to be comparable to those of the expert group, except for their expected levels of NOS understandings. Those 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 issues related to NOS.

Each participant completed the VNOS-B. Next, participants were individually interviewed to provide them with opportunities to clarify and elaborate on their written responses. The completed questionnaires and interview transcripts were separately analyzed to generate two independent profiles of participants' NOS views. Finally, the two profiles were systematically 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 NOS understandings at a rate nearly three times higher than those of the novice group (Table 1). These results

Table 1
Comparison of expert and novice group responses to the VNOS-B

NOS Aspect	Expert Group ($N=9$)		Novice Group ($N=9$)	
	n^a	%	n^a	%
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				
Nonhierarchical 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 (theory-ladenness)				
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%)

[a]Number of participants in each group with informed views of the target NOS aspect.

lent strong support to the construct 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 NOS. 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, and observation. Several expert group participants focused 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. All of the expert group participants tended to view empirical evidence as supportive but not able to prove scientific claims in any absolute sense. In addition, 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 indicated that scientific knowledge is based solely on empirical evidence, which in their view makes science an objective endeavor. Indeed, 67% of the novice group participants spoke of science as a search for objective truth and emphasized empiricism to the exclusion of personal and subjective attributes and factors, such as opinion, interpretation, speculation, and human bias and values.

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. Whereas all were confident that scientists understand much of what atoms are like, none believed that scientists know the structure of the atom in any absolute sense of the term. The expert group rejected the notion that scientists obtained their understandings of atoms through direct observations and ascribed a role for indirect evidence and inference in the construction of atomic models. By comparison, 67% of the novice group participants held similar views. The remaining 33% held the naive view that atomic models have been developed through direct observation.

Nature of Scientific Theories. In response to VNOS-B 1, all expert group participants indicated that theories change and almost all ascribed theory change to new technologies and data 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. Of the 9 participants, 8 cited the explanatory function of scientific theories in their responses to the question concerning the usefulness of learning scientific theories, and most (78%) argued that theories provide a framework for current knowledge and/or for future investigations.

In contrast, 78% of the novice group participants stated that theories do change and cited the accumulation of new evidence as the single reason for theory change. During 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 distinct but equally valid forms of scientific knowledge. Thus, the misconception of a hierarchical relationship between theories and laws was nonexistent. Only one participant viewed scientific laws as being certain in an absolute sense of the word. The others believed that all forms of scientific knowledge are tentative.

Of the 9 novice group participants, 7 (78%) explicitly stated the misconception that scientific theories become laws when proven through repeated testing. The remaining 2 also believed that laws were proven true and theories were tentative, either because not enough data are available or because scientists are unable to design experiments or apparatus to test theories adequately. None of the novice group participants contrasted the descriptive role of laws with the explanatory nature of theories, thus differing markedly from the majority of the expert group respondents who viewed scientific theories as nonobservable inferred explanations and scientific laws as descriptions of patterns or relationships among observable phenomena.

The Creative and Imaginative NOS. Expert group participant responses to VNOS-B 4 and 5 reflected the belief that creativity permeates the scientific process, from the inception of a research question to setting up and running an investigation to the interpretation of the obtained results. All of the expert group participants viewed creativity in science in terms of resourcefulness in carrying out experiments and in inventiveness in interpreting data and coming up with inferences and theories. None of those 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 indicated that only four participants (44%) viewed creativity and imagination as integral to science. In addition, all novice group participants expressed a belief in a single scientific method. For them, 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.

The Theory-Laden NOS. 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 responses reflected an objective view of science through a focus on inadequacies or differences in the data the astronomers were using. About 56% of those participants noted that subjectivity is a part of science, especially in regard to interpreting data. However, they believed that subjectivity, although 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. 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, which establishes rules of practice and evidence. These rules have 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, which affect the kind of science that is done (Table 1). Such influence is mediated by various factors, including 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. An expert panel composed of three science educators, a historian of science, and a scientist examined the 10 items to establish their face and content validity. The panel had some comments and suggestions for improvement and the items were modified accordingly. In addition to assessing respondents' views of the NOS

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?

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 (VNOS-C).

aspects targeted by the VNOS-B, the VNOS-C (Figure 2) also aimed to assess views of the social and cultural embeddedness of science and the existence of a universal scientific method. In addition, Abd-El-Khalick developed an interview protocol to probe participants' views further on relevant NOS issues. These questions were asked during follow-up interviews either as individual questions or sets of interrelated questions. Some were asked after interviewees' explication of their responses to a certain item on the VNOS-C. Alternatively, others were asked only when interviewees expressed certain ideas regarding NOS. Coupled with the VNOS-C responses, those interview questions allowed assessing respondents' views of the general aim and structure of scientific experiments, the logic of theory testing, and the validity of observationally based (compared with experimentally based) scientific theories and disciplines.

VNOS-C was administered to college undergraduates and graduates, and preservice secondary science teachers (Abd-El-Khalick, 1998). 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, those 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 broadly as "procedures used to answer scientific questions." 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?"

Also, mostly in response to the first and second items, many participants noted that scientific knowledge is proven or that 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 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. To elucidate how this view relates to the case of observational sciences, interviewees were asked a set of questions: "Let's consider a science like astronomy (or anatomy). Can (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 NOS and the role that theories and associated expectations play in guiding scientific research. Two of those questions followed interviewees' explication of their responses to VNOS-C 2: "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 asked, "Some claim that such expectations would bias the results of an experiment. What do you think?" In addition, on noting that theories change in their responses to VNOS-C 4, 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 theories 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?"

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 responses to VNOS-C 6 on atomic structure were not informative regarding students' views of the role of inference and creativity in science: "Have we ever seen an atom?" If they responded in the negative, interviewees were asked, "So, where do scientists come up with this elaborate structure of the atom?" Interviewees who thought that scientists have actually seen an atom were asked to elaborate on their answers. Similarly, on noting that scientists were certain about the notion of species in their responses to VNOS-C 7, interviewees were asked, ''There are certain species of wolves 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 scientific names?''

To assess whether participants thought of creativity and imagination in scientific investigation more as resourcefulness 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 dinosaur extinction controversy (VNOS-C 7), many interviewees noted that the controversy was unjustified given that the evidence supports both hypotheses. In that case, they were asked, ''It is very reasonable to say that the data are 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 publish very pointed papers in this regard. Why is that?''

In addition to undergraduate and graduate college students, the VNOS-C was also administered to preservice elementary teachers (Abd-El-Khalick, 2001) and preservice and inservice secondary science teachers (Abd-El-Khalick & Lederman, 2000b; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Schwartz, Lederman, & Crawford, 2000). Abd-El-Khalick (1998, 2001) established the validity of the VNOS-C by systematically comparing and contrasting participants' NOS profiles that were independently generated from separate analyses of the questionnaires and corresponding interview transcripts. 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, 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, 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 subsections of an item, and provide supportive or illustrative examples when asked to. The VNOS should not be used for summative assessment purposes in any manner because 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.

After administration of the VNOS, a reasonable sample of respondents should be individually interviewed. During those interviews, respondents are provided their questionnaires and asked to explain and justify their responses. Follow-up 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 interviews. At this point, researchers could interview subsamples of respondents. We now find interviewing 15–20% of our participants sufficient to gauge subtleties of meaning associated with a certain group of respondents or a certain context. Interviewees could be chosen randomly or purposively depending on the purpose of administering the VNOS.

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. As noted above, this can be achieved by systematically comparing NOS profiles 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 questionnaire data could be analyzed. When several researchers are involved in analyzing VNOS responses, it is crucial to establish interrater agreement or reliability. Such agreement could be established by having all researchers independently analyze the same subset of data and then compare their analyses. Discrepancies could be resolved by further consultation of the data (especially interview data) or consensus. Analyses of all questionnaire and interview data should only proceed after establishing such reliability (see Abd-El-Khalick et al., 1998).

The 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 these 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 one to check for deep understanding of an NOS aspect versus superficial reiteration of key terms by examining the consistency, or lack thereof, in respondents' answers across VNOS items. For example, in response to VNOS-C 4, respondents might indicate that scientific theories are subject to change without providing examples. Such response could reflect 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 biological species, one could hardly infer that they have internalized the tentativeness of scientific knowledge. By the same token, if respondents demonstrate an understanding of the creative and imaginative NOS in their responses to, say, VNOS-C 6, 7, 8, and 10, it would be safe to infer that they have developed a solid understanding 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, they should be judged to hold informed views.

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 strongly to suggest certain NOS views (see Lederman & O'Malley, 1990). Nonetheless, care should be exercised not to load respondents' words and phrases with high-inference meanings or impose on respondents' views consistent structures unless such inferences are supported with interview data. Indeed, in many cases we found that respondents' views were fluid, fragmented, and compartmentalized (Abd-El-Khalick, 1998). For instance, some of our participants indicated in their responses to VNOS-B 5 that scientists use 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 those seemingly contradictory views, it became evident that those participants lacked an overarching consistent framework for their NOS views.

Most VNOS items ask respondents to provide examples to support their views. Those examples should be carefully examined and factored in when assessing respondents' 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 (Abd-El-Khalick, 1998). 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 that are explicated in the questionnaire are inconsistent with the views they express during individual interviews. This latter use of interview data, however, assumes good interviewing practices, such as observing extended-wait time, avoiding directive cues, and testing initial hypotheses about an interviewee's conceptions through nondirective follow-up or probing questions.

Illustrative Examples of Responses to the VNOS

Table 2 presents illustrative examples of responses to the VNOS items and interview questions. These examples are verbatim quotes selected from the responses of participant undergraduate and graduate college students, and preservice and inservice elementary and secondary science teachers in our various studies. The examples illustrate our respondents' views of several important NOS aspects. These views are presented along continua from more naive toward more informed understandings. The presented views of the target NOS aspects are necessarily interrelated, and one quotation that is used to illustrate naive (or informed) views of one NOS aspect could as well be used to illustrate naive (or informed) views of another. The assignment of the quotations is, in that sense, somewhat arbitrary and intended only to make the presentation of respondents' NOS views manageable.

The examples presented in Table 2 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 naive from informed NOS views and, more important, provide insight into respondents' thinking about the target NOS aspects. In addition, 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 NOS profiles respectively. The kind of data generated by using the various VNOS versions clearly surpass the cumulative numerical data generated by using standardized convergent paper and pencil NOS assessment instruments in several respects. First, VNOS data explicate what respondents actually think about NOS and the reasons underlying their thinking. Respondents' reasoning could be examined further during follow-up interviews. Second, given the noncategorical and rich nature of the VNOS responses and their sensitivity to subtle differences in respondents' views, the VNOS allows assessing (a) changes, even small

Table 2
Illustrative examples of responses to VNOS Items

NOS Aspect	More Naive 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. (Form C: Item 1) Science is concerned with facts. We use observed facts to prove that theories are true. (Form B: Item 6)	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 . . . science involves abstraction, one step of abstraction after another. (Interview follow-up on Form C: Item 1)
The scientific method	Science deals with using an exact method. . . . That way we know we have the right answer. (Form B: Item 4) Science has a particular method of going about things, the scientific method. (Form C: 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 . . . That's how we may say we do science, but [it is different from] . . . the way that we actually do science. (Interview follow-up on Form C: Item 1)
General structure and aim of experiments	An experiment is a sequence of steps performed to prove a proposed theory. (Form C: Item 2) Experiment is everything that involves the act of collecting data and not necessarily manipulation. (Interview follow-up on Form C: Item 2)	An experiment cannot prove a theory or a hypothesis. It just discredits or adds validity to them. (Form C: Item 2) An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same. (Form C: 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 Form C: Item 2)	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 Form C: 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. (Form C: Item 3)	Experiments are not always crucial . . . Darwin's theory of evolution . . . cannot be directly tested experimentally. Yet, because of observed data . . . it has become virtually the lynchpin of modern biology. (Form C: Item 3)

Table 2
(*Continued*)

NOS Aspect	More Naive Views	More Informed Views
Tentative NOS	If you get the same result over and over and over, then you become sure that your theory is a proven law, a fact. (Form B: Item 3) Compared to philosophy and religion . . . science demands definitive . . . right and wrong answers. (Form C: Item 1)	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. (Form B: Item 1)
Difference and relationship between theories and laws	Laws started as theories and eventually became laws after repeated and proven demonstration. (Form B: Item 3) 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. (Form C: 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. (Form C: Item 5)
Scientific theories		
Nature of	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. (Form C: 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. (Form B: Item 3)
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. (Form C: Item 4)	Theories set a framework of general explanation upon which specific hypotheses are developed. Theories . . . also advance the pool of knowledge by stimulating hypotheses and research. (Form C: 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. (Form C: 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 on Form C: Item 5)
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. (Form B: Item 5)	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. (Form C: Item 10)

Table 2
(*Continued*)

NOS Aspect	More Naive Views	More Informed Views
Inference and theoretical entities	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. (Form B: 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. (Form B: Item 2)
	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. (Form C: Item 7)	Species is . . . a human creation. It is a convenient framework for categorizing things. . . . 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 subspecies. (Interview follow-up on Form C: Item 7)
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. (Form C: Item 8)	Both conclusions are possible because there 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. (Form C: Item 8)
	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. (Form B: 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. (Form B: Item 7)
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 U.S. and are still atoms in Russia. (Form C: 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 of the church sort of favored the geocentric model. (Form C: 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 Form C: 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. (Form C: Item 9)

ones, in learners' NOS views as a result of instructional interventions; and (b) the interaction between learners' views and the specifics of the instructional activities undertaken in these interventions from diagnostic and cognitive perspectives. This latter assessment is surely informative in terms of modifying and enhancing the effectiveness of such interventions.

Conclusions

Establishing the validity of an instrument is an ongoing 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. Because its open-ended nature, the VNOS differs from typical paper and pencil instruments. Whereas face and content validity of the various versions of the instrument have been determined repeatedly, its principle source of validity evidence stems from the follow-up interviews. 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 assessing the NOS understandings of a wide variety of respondents.

The most significant question to be asked of the present instrument would be, Isn't the VNOS just another paper and pencil NOS instrument? A 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 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 instruments, the VNOS could be 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 follow-up interviews with all or a reasonable sample of respondents cannot be overemphasized.

The VNOS comes in response to 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 emphasis on learners' 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 (Zessoules & Gardner, 1991) and NOS in particular. Indeed, these calls ignore much of what we learned from research on teaching and learning about NOS over the past 30 years (Lederman et al., 1998). 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 at evaluating students' beliefs. Thus, we hope that the effort represented in the VNOS along with the concerted efforts of many researchers who have used and continue to use open-ended questions, interviews, and/or other alternative ways to assess NOS understandings (e.g., Brickhouse, Dagher, Letts, & Shipman. 2000; Driver et al., 1996; Ryder, Leach, & Driver, 1999) would lead the way toward achieving more valid and meaningful assessments of students' and teachers' NOS views.

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