Profiles of Freshman Physics Students' Views on the Nature of Science

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Abstract: The views on various aspects of the nature of science (NOS) of 179 novice undergraduate physics students were investigated using six open-ended, written probes. These views were consolidated within compact NOS ''profiles,'' which were designed based on the students' responses to the probes. These profiles may be understood as sets of key descriptors, which represented the variation in the views of individual students in a succinct way. The views of 86% of the sample were found to be represented by four profiles, each containing five descriptors. The consequences for the teaching and learning of tertiary science, and advantages for linking NOS views to other research observables were explored. © 2007 Wiley Periodicals, Inc. J Res Sci Teach 46: 248–264, 2009
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Views that people have of the nature of science (NOS) can be understood in terms of ''the epistemology of science, science as a way of knowing, or the values and assumptions inherent to the development of scientific knowledge'' (Lederman, 1992, p. 331). Surveys carried out on the public understanding of science, engineering, and technology show that many people respond to scientific issues by giving vague, unpersuasive answers, thus showing a superficial understanding of the NOS (Laugksch, 2000). Ryder and Leach (1999) provide two main reasons why the development of an adequate understanding of the NOS is useful in science education: the development of students' scientific concepts is dependent on their views on the nature of scientific knowledge; and an appropriate understanding of the NOS will allow students to make more informed decisions on science-based issues in their daily lives.

Science students acquire scientific knowledge from a variety of sources such as science magazines and documentaries, teaching, or through discussions on scientific issues, with the result that views displayed on the NOS are often inconsistent and might be dependent on the scientific context under discussion (Ryder & Leach, 2000). A student may hold different views of the nature of constructing school science knowledge and the nature of more generic science knowledge. In this respect, Hogan (2000) differentiated between proximal and distal images of the nature of science. Proximal views of the nature of science focus on ways in which students use their own experiences in the construction of school science knowledge. In contrast, students' distal images of the nature of science include their views about the strategies and procedures used by scientists and about the outcomes of science as an enterprise. Closely related, Leach, Millar, Ryder, and Séré (2000) suggested that students may draw on different ideas of the NOS depending on the way questions are posed, either as brief decontextualized statements, as contextualized dilemmas requiring scientists to take a decision, or as practical situations where they have to make sense of their own data. The NOS views students hold also depend on the scientific concepts involved (Mortimer, 1995). In particular, Laugksch and Spargo (1999) emphasized that different views of the nature of science are called upon by students in biological and physical science contexts, with Séré et al. (2001) reporting a prevalence of the view that scientific theories deviate from real natural phenomena for biological contexts.

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Much controversy exists in the literature on what constitutes a satisfactory understanding of the NOS. For the purposes of this study we agree with Lederman (1992) that an appropriate understanding of the NOS is characterized by the notion that scientific knowledge involves a combination of both empirical evidence (observations of the natural world) and subjective behavior (scientists' background, experiences, and biases). Furthermore, it is tentative and thus might change under the influence of new information, is partly the product of human creativity, and is socially and culturally embedded. A sound understanding of the NOS should also include an ability to distinguish between observation (data) and inference (result).

Tsai and Liu (2005) developed and tested an instrument with Likert-scale items identifying students' epistemological views of science. They consolidated the items into five dimensions, which partly overlap with Lederman's (1992) aspects of the NOS: the role of social negotiation in science; the creative contribution to science; the theory-laden approach to science; the impact of the cultural context on science; and the changing nature of science. In contrast, McComas, Clough, and Almazroa (1998) analyzed a number of international science curriculum standards and generated 14 consensus statements encompassing desirable NOS learning outcomes of school students. A subsequent Delphi study (Osborne, Collins, Radcliffe, Millar, & Duschl, 2003) explored the NOS themes that should be included in the school curriculum as seen by relevant experts (including historians, philosophers, scientists, and science educators). This expert community generated nine NOS themes, virtually all of which are included in the consensus statements identified by McComas et al. (1998). For a separate study, these statements were condensed to six aspects, which Tao (2003) used as a basis for as many NOS "stories," and he used them for mapping the process that students use for developing their ideas of the NOS. His "science stories" explored various NOS aspects including: the idea that scientific discoveries are for understanding nature; there are questions that cannot be addressed by science and its methods; scientists work in collaboration; experiments are used to test ideas, hypotheses, and theories; scientists need to be systematic and creative; scientific knowledge is tentative; and scientific theories serve to explain phenomena.

Most of the studies carried out on the understanding of the NOS have been aimed at high school and elementary school teachers and students. Studies on undergraduate university science students have been undertaken to a much lesser extent. Tsai (1999) explored how students' NOS views influence their actions and decisions during laboratory activities and project work. She found that students' views on the NOS are related to their views on the purpose of a laboratory activity and their perceptions of the actual and their preferred laboratory environment. Moreover, their epistemological views about science may affect their actions and reasoning during experimental work. "If they perceive science as a collection of proven facts, they will focus on memorizing these "truths" and will attempt to prove them through codified procedures provided by the scientific method" (Tsai, 1999, p. 655). Ryder and Leach (1999) have also shown that students' NOS views play a crucial role in how they deal with an investigative project task.

Previous research investigating the conceptions of the NOS of high school students and undergraduate science students has revealed that they often view science as an objective endeavor (e.g., Moss, Abrams, & Robb, 2001). The scientific enterprise is regarded as the quest for the "truth" and the purpose of the "scientific method" is to prove a hypothesis to be correct. The process of experimental observation is a simple straightforward matter and does not involve human inference such as imagination, creativity, and theoretical background. Moreover, irrespective of being from the secondary or tertiary level, experiments are regarded as the key for distinguishing between scientific and nonscientific knowledge. When probing secondary and tertiary students' conceptions on the relationship between a theory and evidence, it was found that the majority of younger students, 9–16-year-olds, make no distinction between theory and evidence (Leach, Driver, Millar, & Scott, 1997), thus contrasting with university students, who typically view scientific claims and data as separate entities (Ryder, Leach, & Driver, 1999). There is generally no significant difference in the strategies employed by students (Dagher, Brickhouse, Shipman, & Letts, 2004) and adults (Schauble & Glaser, 1990) for relating a theory to evidence.

From a review of the relevant research it is clear that, even among science educators, there is no consensus about the crucial aspects that underpin an appropriate view of the nature of science. More importantly, most of the studies just discussed depict students' understanding of the nature of science as if these different aspects are independent of each other. Although Tsai and Liu (2005) made an attempt to correlate the different dimensions of epistemological views, this has not been attempted at the level of individual students.

This study makes an attempt to describe physics students' views of the NOS holistically. We focus on distal views of the NOS due to the fact that most of the students in the sample have little or no experience with hands-on laboratory work, one of the main influences on proximal views of the NOS (Hogan, 2000). We aim to construct compact NOS "profiles," which may be understood as sets of key descriptors that represent the variation in the views of individual students within the entire sample in a succinct way. Our purpose was to attempt to capture students' views of the NOS within a small number of such profiles, which could then allow the exploration of meaningful relationships between NOS views and other observables, such as views of the nature of scientific measurement.

Methods

Sample

The sample in the study was made up of two groups of first-year physics students at a South African university: "mainstream" and "foundation" students, aged between 17 and 21 years. The mainstream group was comprised of 64 first-year science students who were taking physics either as a major or an elective as part of a 3-year bachelor's of science degree. In general, English is their home language and, typically, they had good academic school science experience, comparable with freshmen in North America and Europe. The foundation group was made up of 115 first-year science students who were in a 4-year bachelor's of science program. The majority of these students come from a socioeconomically and educationally disadvantaged background and have English as their second language. In contrast to the mainstream students, the foundation students generally had poor science teaching at school. These two cohorts of students were chosen because they were easily accessible and had different academic backgrounds, thereby providing opportunities for a diversity of response data.

Design of the Questionnaire

The research instrument, the VASM (Views About Scientific Measurement) questionnaire, was designed to investigate the relationship between views on the NOS and the nature of scientific measurement. The written instrument (see http://www.phy.uct.ac.za/people/buffler/edutools.html) consists of 14 questions (probes), 8 of which deal with scientific measurement and 6 with aspects of the NOS, each question appearing on a separate sheet. Two additional pages requested demographic and academic information from the students. For the present study, only results from the NOS portion of the questionnaire are reported.

Two of the NOS probes were adapted from other instruments. The probe dealing with the nature of scientific knowledge was derived from Moss et al. (2001) and the probe investigating the use of creativity and the scientific method during an experiment was adapted from the VNOS Form A by Lederman and O'Malley (1990). The remaining NOS probes in the VASM deal with the objective or subjective origins of scientific laws and theories; the purpose of scientific experiments in a scientific endeavor; the relationship between scientific experiment and theory; and the precedence of theoretical or experimental results. Social and cultural aspects of the NOS were not included in the VASM.

Structure of the VASM Probes

In a critical review of the methods used in surveys of the images of the nature of science, Lederman, Abd-El-Khalick, Bell, and Schwartz (2000) questioned the validity of data collected through questionnaires with Likert-type items, and suggested the use of more open-ended items requiring qualitative analysis. The open-ended, written probes used in this study take account of Hogan's (2000) suggestion that surveys of distal images of the nature of science require general questions about professional scientists, as opposed to quite specific scenarios as a basis for actions to be taken by the respondents when probing proximal images of the nature of science.

The NOS probes in the VASM were designed and sequenced in an order that allows for a natural flow in the explanations given. Each probe had to be answered in strict sequence to avoid any hints or bias introduced by previous probes. All the probes in the questionnaire have a common style and are based on the same

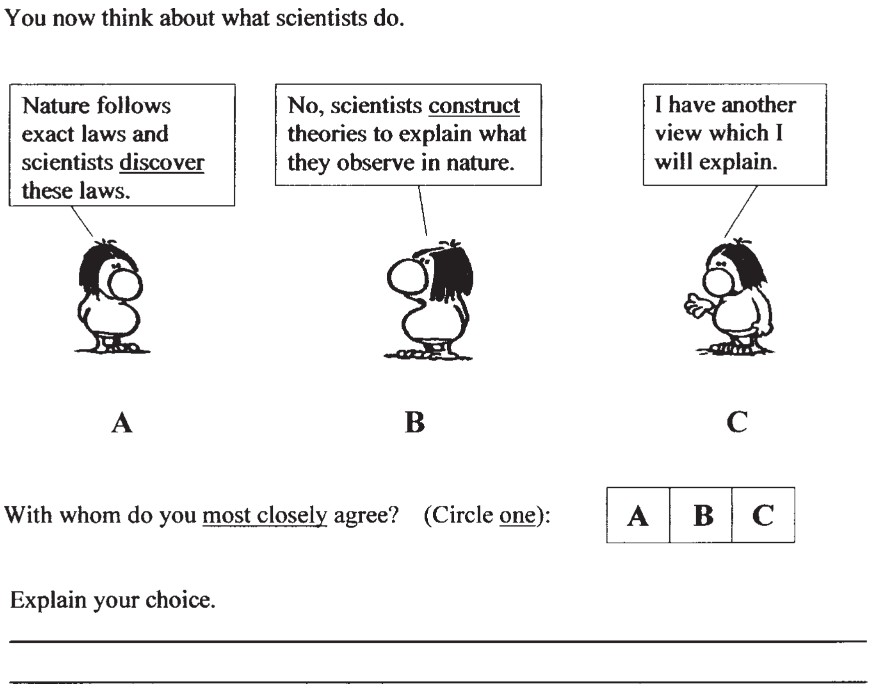

Figure 1. Example of a NOS probe from the VASM questionnaire.

context, which involves taking measurements of the magnetic field of the Earth and comparing these measurements with theories about the composition of the Earth. Each probe presents a scenario followed by a number of different options, which are presented in the form of conversations. Figure 1 illustrates one of the NOS probes in the VASM questionnaire. In this case, the origins of scientific "laws" and "theories" are being discussed. The respondents are requested to select only one of the alternatives provided, which is deemed to be the most appropriate. They are also asked to provide a detailed written justification for their choice. The explanations of their decision provide insight in the underlying reasoning on which their actions are built. By providing the option "I have a different idea" or "I have another view which I will explain" for some probes, respondents are encouraged to formulate alternative choices (with justification) on the issues discussed in the probe.

Studies previously carried out with similar target groups (Allie, Buffler, Kaunda, Campbell, & Lubben, 1998) showed that the use of real-life figures and names can lead to prejudice toward the selection of an option. Consequently, to improve construct validity of the responses, cartoons were used and labeled by letters to present the various options for each question, as they do not refer to any specific gender, race, and culture. Special attention was given to the language used to frame the items. The vocabulary was chosen to be simple and the words were reduced to a minimum. Respondents were asked to complete the set of written probes individually, strictly in sequence, and under examination conditions.

For each of the probes the content validity was improved by peer reviews by university professors (three each from both science and nonscience disciplines) and five postgraduate physics students. Careful piloting with comparable groups of students from different institutions increased the construct validity. Piloting showed that students consider a scientific theory as a provisional idea or a hypothesis, which needs confirmation through experimental testing, and scientific laws as proven and confirmed relationships. In contrast, we take Thagard's (1992) distinction that a scientific law is a description of a relationship based on experimental observations under prescribed circumstances and a scientific theory is an empirically supported explanation of natural phenomena. Because we solicited views of the NOS regarding the *origins* of laws/

theories, the relevant probe was phrased maintaining our distinction between law and theory, and underlining the key words *discover* and *construct.* In the analysis of the student responses we did not differentiate between the use of the terms *theory* and *law.*

Analysis

To improve criterion validity of the analysis, a coding scheme was independently generated for each of the probes by two researchers using grounded theory methods (Strauss & Corbin, 1998), especially interpretive analysis (see, e.g., Gall, Borg, & Gall, 1996). The codes were compared and discussed, and agreement was reached on the arrangement and grouping of codes for their mutual exclusivity and logical hierarchy. Similar to previous studies on students' views on measurement (see Buffler, Allie, Lubben, & Campbell, 2001), each category of response was assigned an alphanumeric code that contained a letter (A, B, C,. . .) corresponding to the chosen option (the action) and a two-digit number associated with the underlying reason (justification) given to support the action. Using two digits allowed for subcategories that represented subtle variations to a broad theme. Codes starting, for instance, with A2, B2, C2, etc., represented categories associated with the same broad justification, although they were rooted in different choices of action. Whenever appropriate, the same codes were used across different probes.

The coding scheme was used for both the mainstream and foundation samples and was allowed to evolve as new categories emerged from the data. All the probes were coded by the same researcher. Identically coded responses were compared for consistency, and similarly coded responses for mutually exclusiveness. For each probe, the frequency of different responses was scrutinized and particular categories grouped together to form between five and six main classes of ideas.

To construct the NOS profiles, frequently occurring combinations of particular views were identified across all 179 sets of probes for key aspects of the NOS. Descriptions of these views were then written in a way that captured the essence of the view of each aspect. On the basis of the full set of probes, each student was then assigned to one of these profiles independently by two researchers. The intercoder agreement was 82%. The wording of the profile descriptors evolved during this process to adequately capture the views of the sample. All sets of probes were then revisited to verify that the allocation of each student to a particular profile was reliable and consistent. Less than 5% of the students were re-allocated in this process. It was found that four profiles were sufficient to capture the NOS views of 86% of the students.

Results

Individual Probes

For each NOS probe in the VASM questionnaire, an abridged version of the probe is presented together with a statement on the rationale for its inclusion in the set. The main views of the participants are presented, together with a selection of the students' written response to illustrate the variation within these views.

Views on the nature of scientific knowledge. The first NOS probe in the questionnaire explores the views of students on the qualities that distinguish scientific knowledge from other forms of knowledge. The probe reads:

> You and a group of friends are discussing your views about the nature of scientific knowledge. You wonder what makes certain types of knowledge "scientific."

Table 1 summarizes the main ideas expressed by the sample.

The largest proportion ($47 + 30 = 77\%$) of participants believe that scientific knowledge explains the complex behavior of nature. Only very few students see scientific knowledge as describing natural phenomena, and even then these views are often linked to explanations, as exemplified in the following:

> Scientific knowledge is the understanding of our universe and our environment. This form of knowledge explains to us how living organisms function and live with one another. Scientific knowledge explains to us how nature works by applying various "laws" established through out many centuries. Science deals with the way we see the world and give explanations for bizarre phenomena. (226)

Table 1
Views on the nature of scientific knowledge

Response Type	Number (%)
Scientific knowledge explains or describes the behavior of nature	85 (47%)
Scientific knowledge explains or describes the behavior of nature and is based on experimental evidence	53 (30%)
Scientific knowledge is acquired from scientific disciplines that consist of laws, theories and calculations	14 (8%)
Scientific knowledge is based on facts	8 (4%)
Scientific knowledge involves the use of human inference	4 (2%)
Scientific knowledge leads to progress by providing solutions to problems	3 (2%)
Not able to code response	12 (7%)
Total	179 (100%)

> This is knowledge about the basic facts of life, of the Earth, about the human body and animals and how they work, about matter, and what all things are composed of, about the Earth and how it was formed and how it is changing. (290)

According to 30% of the participants, for knowledge to be considered scientific, experiments that provide evidence are also a necessity, as represented by the following quote:

> It is knowledge that comes from scientific research and is proven to be true. There is experimental evidence to show that the scientific fact is true. (230)

Only 8% of the respondents believe that scientific knowledge includes laws and theories together with mathematical calculations and formulae that characterize science, as highlighted by:

> I think scientific knowledge is some kind of a knowledge that [is] scientific, that means that involves a lot of application of laws, properties, and rules. A person who has acquired scientific knowledge should now know to apply laws and rules. (287)

> Scientific knowledge is knowledge that has to do with discovery in which a lot of measurements and calculations are done. (310)

Views on the origins of laws and theories. The second NOS probe investigates whether laws or theories are creations of the scientist or whether they already exist in nature, waiting to be discovered. In other words, views on the origins of laws and theories in science are explored. The probe reads:

> You now think about what scientists do.
> **A:** Nature follows exact laws and scientists discover these laws.
> **B:** No, scientists construct theories to explain what they observe in nature.
> **C:** I have another view which I will explain.

The views displayed for the origin of laws and theories in science are shown in Table 2.

Table 2
Views on the origin of laws and theories

Response Type	Number (%)
Nature has its own laws and rules which are discovered through experimentation	71 (40%)
Theories are formulated from observations and experiments are used to check the theories	38 (21%)
Theories are simple ways of explaining what has been observed in nature	28 (16%)
Scientists discover the laws of nature and also construct theories	10 (6%)
Scientists make new discoveries in science which improve everyday life	8 (4%)
Scientists model nature by using logic, calculations, and formulae	8 (4%)
Not able to code response	16 (9%)
Total	179 (100%)

The largest percentage of students (40%) display the predominant belief that the laws of nature already exist to be discovered, as described by:

> Basically, laws governing nature have been there or around all the time. It is the scientist's job to discover it [them] and make use of it [them] if needed. For example, gravity was there all along. It was just waiting quietly for Newton to discover and understand it. (285)

According to 21% of the students, scientists formulate theories from observations. These hypotheses are checked through experimentation; for example:

> Scientists observe and question phenomena that occur naturally, for example, an object falls towards the ground when it is dropped. Scientists then suggest a hypothesis or theory to explain or suggest explanation of the observation, for example, the object falls due to the force of the earth on the object. Scientists then design experiments to test the hypothesis to determine whether it is true for all cases, for example, testing the gravitational pull of objects on earth versus objects on the moon. (275)

The belief that theories are constructed for simpler understanding of the complex behavior of nature is displayed by 16% of the participants, such as:

> Scientists observe their surroundings and try to understand it. They develop theories about why things are the way they are. They put logic into things. They write formulae and theories to give the general understanding of a certain situation. (234)

In 6% of the responses, as in the quotation provided next, it is argued that scientists discover the laws of nature but also construct theories. These theories are seen as simpler ways of explaining the outcomes of an experiment or the observations made from nature:

> Well, I actually agree with both A and B as I believe nature follows principles (of which most can be proved scientifically); however, scientists do not always discover these laws—they are sometimes just proved by scientists (through construction of varies justifiable theories). Scientists therefore enable others to observe (read, learn about, etc.) their simplified explanations of something very complicated (or just sound complicated). (348)

Views on the relationship between scientific experiments and theories. Students' views on the relationship between scientific experiments and scientific theories are investigated to determine which one of these has greater priority in the acquisition, construction, and evolution of new scientific knowledge:

> You continue to think about science.
> **A:** New scientific knowledge is based on the results from <u>scientific experiments</u>.
> **B:** No, new scientific knowledge can result from existing <u>scientific theories</u>.
> **C:** I have a different idea.

Table 3 provides an overview of the range of responses of the participants for this probe.

Most students ($21 + 20 + 17 = 58\%$) prioritize scientific experiments over scientific theories for the generation of new scientific knowledge. A scientific experiment is the source of reliable evidence or new worthwhile information:

> Existing scientific theories are not guaranteed to be absolutely true. We might derive some sort of inspiration from accidental happening or existing scientific theories, etc., but to verify it we need substantial proof through scientific experiment. (215)

> Scientific experiments are carried out for many years before it is established that the behavior of a particular object, animal, etc., is considered true and, most important of all, that the conclusion reached from these various experiments is logical. (226)

Table 3
Views on the relationship between scientific experiment and theory

Response Type	Number (%)
The results from scientific experiments must be compared with scientific theories	43 (24%)
The results from experiments are more reliable than theories	38 (21%)
Experiments provide more information about what is being investigated	36 (20%)
Experiments are necessary to prove a hypothesis	30 (17%)
In science highly sophisticated apparatus is used	8 (4%)
Experiments lead to new discoveries in science	5 (3%)
Not able to code response	19 (11%)
Total	179 (100%)

However, the belief that a scientific experiment together with a theory is required for the construction of new scientific knowledge is recognized by about a quarter (24%) of the students. The existing theories provide a framework for current knowledge. These theories can be further explored to yield more and novel information, such as:

> I consider the truth to be a combination of A and B. On the one hand, scientific experiments could suggest new theories, etc., yet most scientific experimentation is to prove/disprove theories. On the other hand, existing scientific theories often are seen to involve complicated mathematics which may not have immediately obvious physical applications/implications, and so continued study and interpretation of existing theories can, and does, lead to new knowledge. (205)

> Again, both A and B are viable. All scientific knowledge is from existing theories. A theory can be further exploited to gain further information, and therefore, new knowledge. Results from new scientific experiments will also add to the ever increasing amount of knowledge. (206)

Views on the purpose of scientific experiments. The role and importance of scientific experiments in a scientific endeavor are explored. The probe, an open-ended question, aims at investigating whether the reliability and validity of scientific knowledge is dependent on scientific experiments only and whether there are always genuine, faultless results:

> You and your friends now talk about scientific experiments.
> What is the purpose of a scientific experiment?

The different categories of reasoning for the purpose of scientific experiment in a scientific endeavor are as shown in Table 4.

Just over half of the students (51%) believe that a scientific experiment is used to prove a hypothesis. Experiments provide reliable evidence (18%) and new information about what is being investigated (11%). The explanations include:

Table 4
Views on the purpose of scientific experiments

Response Type	Number (%)
Scientific experiments are used to provide evidence to prove or disprove a hypothesis	90 (51%)
Scientific experiments yield accurate and reliable outcomes	33 (18%)
Scientific experiments provide information about what is being investigated	20 (11%)
Scientific experiments help to better understand scientific theories	15 (8%)
Scientific experiments lead to progress in science and in everyday life	15 (8%)
Not able to code response	6 (3%)
Total	179 (100%)

> An experiment's purpose is to test or validate theories. It is not good enough to just come up with a new theory without being able to prove the truth in your theory or without being able to show that your theory can be put to practice. Experiments are the way in which we give this proof and demonstrate the usefulness of our scientific theories. (214)

> Someone will have an idea or theory about something scientific; the natural idea would be to put this theory into practice, and see whether it is accurate or not; scientists do this in the form of experiments; repetition of experiments is the way to make sure the theory is correct. (212)

> The purpose of scientific experiment is to prove theories in order to gain knowledge and understanding. Experiments allow us to test the accuracy of our understanding in order to broaden our knowledge of the unknown. (208)

It is argued, although by only 8% of the sample, that scientific experiments lead to new discoveries or improvements in the field of science or in everyday life:

> I think that the main purpose is to improve or make things easier in this modern world. Most experiments are done in order to try something new and improve what we have done at the moment. (291)

It was found that, for individual students, views expressed on the relationship between scientific theory and experiment (Table 3) and on the role of scientific experiments in a scientific enterprise (Table 4) were generally in support of each another. Typically, scientific experiments are required to provide evidence about the system under investigation. Experimental results are generally more accurate than theoretical ones, resulting in evidence that is reliable and in new information that can be used for progress either in science or in everyday life.

Views on the role of creativity in an experiment. The probe explores the use of the scientific method and creativity when conducting an experiment:

> You observe that the scientists are discussing what they should do in their experiments.
> **A:** I think that scientists always strictly follow the "Scientific Method," which prescribes a sequence for carrying out an experiment.
> **B:** No, I think that scientists <u>also</u> use their creativity when carrying out an experiment.

Table 5 presents the different categories of explanations used when considering this question.

The largest proportion of respondents ($28+13+5=46\%$) believe that scientists should use their creativity during an experiment to improve experimental results and increase the explanatory power of current scientific knowledge:

> If scientists followed a "set of rules" they would limit themselves to what they know. Creativity allows them to expand ideas and revolutionize scientific concepts. Without creativity, scientists would be confined to what they know and simply dwell on that. As a matter of fact, science would not develop broadly without creativity. (226)

Table 5
Views on the role of creativity in experiment

Response Type	Number (%)
Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results	62 (35%)
Creativity should be used for more discoveries in science	50 (28%)
Creativity should be used to improve experimental results	23 (13%)
Scientists design their own procedures depending on the type of the experiment	12 (7%)
Both the scientific method and creativity should be used during an experiment	10 (5%)
Only creativity should be used as the scientific method can be faulty	9 (5%)
Not able to code response	13 (7%)
Total	179 (100%)

> If scientists did not use creativity when carrying out experiments then no new discoveries would be made. Some of the greatest discoveries ever were made through the creative manipulation of experiments. (227)

The belief that the scientific method together with the creativity of scientists is used during the experiment was displayed by only 5% of the respondents. Different explanations, as portrayed by the quotations that follow, were given about where both creativity and scientific method is used while conducting the experiment:

> Scientists use their creativity before carrying out an experiment more than during an experiment. I think they should know exactly what they are to do before an experiment by accurate and detailed calculations and so on. They should follow the prescribed steps unless there is suddenly a mistake or accident happening. (215)

> Yes, scientists do follow the scientific method, but this involves creativity to design an experiment, and also to construct and adapt theories once results have been obtained. (273)

Another view is that there are no prescribed steps to be followed when conducting an experiment. Scientists can design their own procedures depending on the type of experiment. This belief was displayed by 7% of the sample:

> Different scientific problems require different solutions—there is no all-encompassing method that can describe uniquely the steps that need to be followed to carry out every experiment. (250)

> In some situations the prescribed procedure is not an efficient way of going about an experiment (e.g., gathering indirect evidence of black holes) and the scientists need to get creative with experimental procedures. (203)

However, 35% of the students suggest that only the scientific method should be used during an experiment, because it is "accurate" and hence ensures the success of the experiment by yielding consistent and reliable results:

> To be creative while performing an experiment, and deviate from the agreed-upon method, would jeopardize the accuracy and correctness of the results. It would also make published results less likely to be accepted by the scientific community. (229)

> The "scientific method" is certainly one of the best methods developed to carry out a clear, accurate experiment and come to a logical conclusion. (276)

Views on precedence of theoretical and experimental results. The last NOS probe deals with what should happen when experimental and theoretical results contradict each other:

> After analyzing their data, the scientists find that their measurement of the Earth's magnetic field does not agree with the value predicted by their theory. You discuss what the scientists should do.
> **A:** I think that the scientists might now have to revise their theory.
> **B:** No, the scientists should reject the value obtained from their experiment.
> **C:** I have another idea about what they should do.

The various explanations received from the sample are summarized in Table 6.

According to 58% (47 + 11%) of the students, a theory must be revised when conflicting experimental results are obtained, because the theory is based on particular assumptions. Some students suggest repeating the experiment first:

> Theory is just an assumption, so that it never will be perfect, so there is a need to revise their theory by means of using the result they got from measurement. (228)

Table 6
Views on precedence of theoretical and experimental results

Response Type	Number (%)
Experimental results are more reliable than theoretical results	85 (47%)
Both theories and experiments must be checked	27 (15%)
The theory must be changed if after repeating the experiment the experimental and theoretical results still contradict each other	19 (11%)
The experiment is inaccurate (involve errors) and must be repeated	24 (13%)
A theory can never be changed. It has been proved by previous experiments	5 (3%)
Experimental and theoretical results must be the same	4 (3%)
Not able to code response	15 (8%)
Total	179 (100%)

> They should check all their results, redo the experiment (and have others do it), and if it still doesn't fit with the theory they should revise the theory. (225)

Only 15% of the sample believed that both the theory and the experiment need to be checked as the origin of the mismatch cannot be ascertained:

> Both the experiment's results and the theory should be checked as we do not know which is producing the error. (202)

In some instances (13%) it was stated that experiments may involve inaccuracies and approximations and hence priority should be given to the theoretical results:

> Theory is more accurate than readings because readings can be influenced by external sources. (264)

NOS Profiles

The four profiles that emerged from the data are shown in Table 7, and have been labeled ''modelers,'' ''experimenters,'' ''examiners,'' and ''discoverers,'' respectively. These profiles are not hierarchical but our judgment is that the ''modelers'' hold the most appropriate views of the NOS, as defined by Lederman (1992). Five descriptors were used to define each profile, each of which referred to a particular probe, except for probes 3 and 4, which were considered together. It was found that the views of 86% of the sample could be captured by these four profiles. A student was allocated to a particular profile if all five responses were consistent with the descriptors for that profile. All four profiles contain the idea that scientific knowledge explains or describes the behavior of nature and that scientific theories are generated, tested, validated, or revised in the light of experimental results.

The students associated with Profile 1 (the ''modelers'') realize that hypotheses and scientific theories are constructed by scientists, and experimental evidence is required to validate these theories. Theories are simple ways of explaining the complex behavior of nature. Creativity plays an important role in constructing hypotheses or theories, and during experimentation. When there are discrepancies between theoretical and experimental results, both the theory and the experimental data need to be scrutinized.

Profile 2 (the ''experimenters'') differs from Profile 1 in two aspects. The ''experimenters'' believe that scientists should still use experimental evidence to test hypotheses, but should strictly use the scientific method, and not their creativity, when doing experiments. The results from these rigorous experiments carry a higher precedence over theories.

Profile 3 (the ''examiners'') differs from Profile 2 in three aspects. The ''examiners'' are convinced that the laws of nature are fixed and stable. These laws are out there to be discovered (and not constructed) by scientists. Experimental work is essential but not informed by hypotheses or theories. Scientists may use both the scientific method and their imagination. Experimental data unearth the laws of nature, and the results from experiments carry a higher precedence over theories.

Table 7
Student NOS profiles

Probe	Aspect of the NOS	Profile 1: "Modelers"	Profile 2: "Experimenters"	Profile 3: "Examiners"	Profile 4: "Discoverers"
1	The nature of scientific knowledge	Scientific knowledge explains or describes the behavior of nature and is based on experimental evidence.	Scientific knowledge explains or describes the behavior of nature and is based on experimental evidence.	Scientific knowledge explains or describes the behavior of nature and is based on experimental evidence.	Scientific knowledge explains or describes the behavior of nature.
2	The origin of laws or theories	Scientific theories are constructed from observations for better understanding of the complex behavior of nature.	Scientific theories are constructed from observations for better understanding of the complex behavior of nature.	Nature has its own laws that are discovered through observation.	Nature has its own laws that are discovered through observation.
3/4	The purpose of scientific experiments in relation to theories	Theories are tested, validated, and revised through experimentation.	Theories are tested, validated, and revised through experimentation.	Theories are tested, validated, and revised through experimentation.	Theories are tested, validated, and revised through experimentation.
5	The role of creativity in scientific experimentation	Scientists may use their creativity when undertaking experiments to be successful by making new discoveries and improvements.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results.	Scientists may use their creativity when undertaking experiments to be successful by making new discoveries and improvements.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results.
6	The precedence of theoretical and experimental results	If experimental results and theories disagree, then both need to be checked.	If experimental results and theories disagree, then the experimental results are likely to be correct.	If experimental results and theories disagree, then the experimental results are likely to be correct.	If experimental results and theories disagree, then both need to be checked.

Table 8
Distribution of NOS profiles (n = 179)

NOS Profile	Foundation Students	Mainstream Students	Total
Profile 1: "Modelers"	43 (37%)	35 (55%)	78 (44%)
Profile 2: "Experimenters"	21 (18%)	8 (13%)	29 (16%)
Profile 3: "Examiners"	25 (22%)	9 (14%)	34 (19%)
Profile 4: "Discoverers"	7 (6%)	6 (9%)	13 (7%)
Unclassifiable	19 (17%)	6 (9%)	25 (14%)
Total	115 (100%)	64 (100%)	179 (100%)

Profile 4 (the "discoverers") differs from Profile 3 in two aspects. Although the "discoverers" also believe that the laws of nature are out there to be discovered (and not constructed) by scientists, only experiments using the scientific method can be used to generate these laws (or theories). If experimental data conflict with a previously established theory, then both the theory and the experimental data need to be checked.

In summary, the profiles differ mainly with respect to the origin of scientific knowledge, the experimental methods considered correct, and the relative importance that experimentation plays in the relationship to theory.

Distribution of NOS profiles. Table 8 shows the distribution of assigned profiles for the two cohorts of students: the foundation students and the mainstream students.

The largest percentage of the students (44%) expressed NOS beliefs, which are consistent with the "modelers" profile, with a larger percentage among the mainstream students (55%, compared with 37% of the foundation students). On the other hand, the "discoverers" profile represents only 7% of the sample. The 14% of unclassifiable students consisted of a larger percentage of the foundation students (17%) than the mainstream cohort (9%).

A two-tailed test for differences between proportions of the foundation and mainstream students classified as "modelers" in Table 8 yields a z-value of -2.24, indicating that a significantly larger proportion of mainstream students have a "modelers" profile than foundation students at the 5% significance level. A similar test for proportions for the other profiles suggests that there is not a significant relationship between the type of student (foundation or mainstream) and their NOS profile.

Discussion

The four profiles suggested by the data were found to accommodate the views on the NOS of 86% of the respondents in the sample, indicating that these profiles are an effective tool for describing such views holistically. The four proposed profiles overlap only in part with the three forms of epistemological reasoning proposed by Leach et al. (1997), who explored students' views on the nature of scientific knowledge and the relationship between scientific theory and experimental data. They suggested that data-related reasoning is the most advanced form of epistemological reasoning: scientists' beliefs (theories) and the data they collect are related and influence one another, which is consistent with our "modelers" profile. On the other hand, radical relativist reasoning, characterized by the notions that the interpretation of data is an individual's prerogative and that experimental data should be used to judge any conclusions right or wrong, did not emerge as a significant NOS profile. However, Moss et al. (2001) also identified data-focused reasoning where data collection is seen as a form of "testing" and data analysis and conclusions as a form of "comparison." Our profiles therefore seem to refine the categories identified earlier, and encompass additional elements such as views on the contribution of imagination and creativity to scientific knowledge, and the precedence of theory and experimental evidence when these conflict with each other.

The present study focused only on mapping students' distal images of science (i.e., their views on the scientific enterprise as operated by scientists). Hogan (2000) suggested that distal images of science interact with students' proximal images of science (i.e., their views on the ways of developing their own understanding of science), and Vhurumuku, Holtman, Mikalsen, and Kolsto (2006) reported several ways in which these are related to each other. However, the relationship with students' proximal images of science is not applicable to our study because the majority of students in the sample had little or no hands-on experience with experimental work.

Many of the introductory physics students in our sample displayed quite sophisticated views of the NOS. Close to half (44%) of the students in the study were classified as "modelers," the most appropriate view of the NOS according to Lederman (1992). Because we could find only one more study reporting on students' holistic views of the NOS (Leach et al., 1997), we therefore compared this outcome with studies reporting independent aspects of the NOS. The relatively sophisticated NOS views of the "modelers" hinge on a combination of four distinguishing aspects. First, they appreciate the notion that scientific knowledge is constructed by scientists as an explanation of the complex behavior of nature. Second, the "modelers" see scientific theories as explanations of observations of natural phenomena, but which need to be validated experimentally to gain explanatory power. This validation requirement contrasts with the findings of Dagher et al. (2004), who found that, at the beginning of an undergraduate astronomy course, most of the North American undergraduates in their sample considered a scientific theory as an idea with some evidence, or as a tentative explanation of observations. Only at the end of the course did the majority of students see a theory as an explanation of phenomena based on experimental evidence. Third, the "modelers" acknowledged that systematic ("scientific") methods together with creativity and imagination play a role in developing a theory or hypothesis, executing the experiment and interpreting the measurements. This finding contrasts markedly with the findings of Moss et al. (2001) for North American science students, who emphasized the need for strictly following the scientific method, and even science teachers, who do not usually recognize the use of creativity and imagination in science (Abd-El-Khalick & Lederman, 2000). In contrast, it is notable that three-quarters of the sample of Zimbabwean pre-university students (Vhurumuku et al., 2006) who provided views on the nature of scientific observations suggested along "Feyerabendian" lines that such observations may come from a variety of sources including dreams, chance, creativity, and imagination. Finally, for the "modelers," in case of a conflict between theory and experimental evidence, they realized that both theory and experimental procedure and data need scrutiny. This is in line with the findings of Vhurumuku et al. (2006). In contrast, the outcome of the study by Ryder and Leach (2000) revealed that most of the European students in their sample suggested more weight should be given to experimental data (evidence) for the construction of scientific knowledge. Their study revealed that much emphasis is laid on the quality and quantity of data to prove a system, or on repeating experiments for accuracy and reliability of data.

The finding of a relatively high proportion of students in this sample (44%) with a "modelers" profile needs further consideration. Two suggestions, different for each of the subgroups of students, can be made, possibly explaining this high proportion of students with a profile closest to Lederman's (1992) definition of a desirable view of the NOS. For the mainstream students, typically with good school experience of practical science teaching, Tsai's (1999) observation may be relevant. She observed that not only can epistemological views influence students' views of measurement, but also that experiences with experimental measurement may result in different epistemological views of science. In addition, Laugksch and Spargo (1999) found that a good grounding in the school subject of physical science (as opposed to life science) is directly related to a higher scientific literacy in South African students, including their views of the NOS. They attributed this to the fact that, in the physical science curriculum, many concepts are approached from a historical perspective. For instance, teaching the model of the atom requires a familiarization with the idea of the indivisible particles of Dalton and Thompson's discovery of the electron, to the nuclear atom of Rutherford and Bohr's orbital model. For the foundation students in the sample, comprising mainly black students, the similarity of the findings to those from a study of Zimbabwean students (Vhurumuku et al., 2006) may suggest a cultural influence on several aspects of views of the NOS (see also Sutherland & Dennick, 2002). An emphasis, across African cultures, on inclusiveness and consensus rather than competition (Nsamenang, 1999; Ramos, 2002; Venter, 2004), and a predominant culturally determined interaction pattern of cooperation (Jegede, 1997), may encourage the view of equal status of experimental data and theory in the construction of scientific knowledge, and thus highlight the need to reconsider both in case of a conflict. Similarly, the anthropological description of the African worldview being centered around people rather than objects (Horton, 1982) may explain students' acknowledgment of the role of human creativity and imagination in the development of scientific knowledge.

If one of the aims of an introductory physics course is to provide students with opportunities to actively consider their views of the nature of science, in particular the relationship between experiment and theory in physics, then we suggest that the "modelers" profile provides a framework within which to structure teaching and learning activities to meet this objective. For example, we suggest the inclusion of specific activities within existing introductory courses similar to the course for introductory astronomy described by Dagher et al. (2004). Here the introduction of the concept of the evolution of the universe was used to focus and contrast the Steady State and the Big Bang theories, serving as a model for the broader discussion on the nature of scientific theories. Furthermore, the scenario wherein two groups of scientists draw different conclusions from the same graphical representation of a series of measurements due to the application of different theories (for details, see Ryder & Leach, 2000) may be included in an introductory physics laboratory course to foreground the need for reviewing both the theory and experimental results in cases where conflict arises. In our own laboratory course (Allie & Buffler, 1998) we provide students with opportunities to choose between two competing theories using their own experimental data. Equally, students resolve an authentic dilemma through experimentation, including appropriate data analysis. We recognize the need to introduce practical activities where either the data available or the proposed theory may need further scrutiny, even possible rejection.

The identification of the four profiles in this study, which feature distal views of the NOS, invites parallel research into students' profiles for proximal views of the NOS. This in turn will contribute to the debate on the extent to which distal and proximal profiles of the images of science are interconnected (Hogan, 2000). Also, the NOS profiles identified in this study allow further research into the relationships of the holistic views of the NOS and other cognitive outcomes, such as the relationship between students' NOS profiles and their deep/surface level of learning science (Case & Marshall, 2004), similar to some of the work by Elby and Hammer (2001) on the relationship between students' epistemology of science and their views of the epistemology of learning science. This may offer further insight into the possible relationship between distal and proximal images of science. We also suggest that students' views of scientific measurement (Buffler et al., 2001) may relate to their NOS views, because the findings of this study suggest that the perception of the role of experimentation is important in developing a view of the NOS. Preliminary data (Ibrahim, Buffler, & Lubben, 2007) suggest that this deserves further investigation.

References

Abd-El-Khalick, F., & Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. International Journal of Science Education, 22, 665–701.

Allie, S., & Buffler, A. (1998). A course in tools and procedures for Physics 1. American Journal of Physics, 66, 613–623.

Allie, S., Buffler, A., Kaunda, L., Campbell, B., & Lubben, F. (1998). First year physics students' perceptions of the quality of experimental measurements. International Journal of Science Education, 20, 447–459.

Buffler, A., Allie, S., Lubben, F., & Campbell, B. (2001). The development of first year physics students' ideas about measurements in terms of point and set paradigms. International Journal of Science Education, 23, 1137–1156.

Case, J.M., & Marshall, D. (2004). Between deep and surface: Procedural approaches to learning in engineering contexts. Studies in Higher Education, 29, 605–615.

Dagher, Z., Brickhouse, N., Shipman, H., & Letts, W. (2004). How some college students represent their understandings of the nature of scientific theories. International Journal of Science Education, 26, 735–755.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. Science Education, 85, 554–567.

Gall, D., Borg, W., & Gall, J. (1996). Educational research: An introduction. New York: Longman.

Hogan, K. (2000). Exploring a process view of students' knowledge about the nature of science. Science Education, 84, 51–70.

Horton, R. (1982). Tradition and modernity revisited. In M. Hollis & S. Lukes (Eds.), Rationality and relativism (pp. 201–260). Oxford: Blackwell.

Ibrahim, B., Buffler, A., & Lubben, F. (2007). The relationship between introductory physics students views on the nature of scientific measurement and views on the nature of science. In I. Mutimucuio & M.

Cherinda (Eds.), Proceedings of the 15th annual conference of the Southern African Association for Research in Mathematics, Science and Technology Education (pp. 391–397). Maputo, Mozambique: University Eduardo Mondlane.

Jegede, O. (1997). School science and the development of scientific culture: A review of contemporary science education in Africa. International Journal of Science Education, 19, 1–20.

Laugksch, R. (2000). Scientific literacy: A conceptual overview. Science Education, 84, 71–94.

Laugksch, R., & Spargo, P. (1999). Scientific literacy of selected South African matriculants entering tertiary education: A baseline study. South African Journal of Science, 95, 427–432.

Leach, J., Driver, R., Millar, R., & Scott, P. (1997). A study of progression in learning about 'the nature of science': Issues of conceptualization and methodology. International Journal of Science Education, 19, 147–166.

Leach, J., Millar, R., Ryder, J., & Séré, M.-G. (2000). Epistemological understanding in science learning: The consistency of representations across contexts. Learning and Instruction, 10, 497–527.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29, 331–359.

Lederman, N.G., Abd-El-Khalick, F., Bell, R., & Schwartz, S. (2000). Views on the nature of science questionnaire: Towards a valid and meaningful assessment of learners' conceptions of the nature of science. Journal of Research in Science Teaching, 39, 497–521.

Lederman, N.G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. Science Education, 74, 225–239.

McComas, W.F., Clough, M.P., & Almazroa, H. (1998). The role and character of the nature of science and science education. Science & Education, 7, 511–532.

Mortimer, E. (1995). Conceptual change or conceptual profile change? Science & Education, 4, 267–285.

Moss, D., Abrams, E.D., & Robb, J. (2001). Examining student conceptions of the nature of science. International Journal of Science Education, 23, 771–790.

Nsamenang, B. (1999). An image of the self in African social thought. Newbury Park, CA: Sage.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. Journal of Research in Science Teaching, 40, 692–720.

Ramos, M. (2002). The philosophy of ubuntu and ubuntu as a philosophy. In P.H. Coetzee & A.P. Roux (Eds.), Philosophy from Africa. (2nd ed.). A text with readings (pp. 230–238). Cape Town, South Africa: Oxford University Press.

Ryder, J., & Leach, J. (1999). University science students' experiences of investigative project work and their images of science. International Journal of Science Education, 21, 945–956.

Ryder, J., & Leach, J. (2000). Interpreting experimental data: The views of upper secondary school and university science students. International Journal of Science Education, 22, 1069–1084.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. Journal of Research in Science Teaching, 36, 201–219.

Schauble, L., & Glaser, R. (1990). Developmental perspectives on teaching and learning thinking skills. In D. Kuhn (Ed.), Scientific thinking in children and adults (vol. 21, pp. 9–27). Basel: Karger.

Séré, M.-G., Fernandez-Gonzalez, M., Gallegos, J.A., Gonzalez-Garcia, F., De Manuel, E., Perales, F.J., & Leach, J. (2001). Images of science linked to labwork: A survey of secondary school and university students. Research in Science Education, 31, 499–523.

Strauss, A., & Corbin, J. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory. (2nd ed.). Newbury Park, CA: Sage.

Sutherland, D., & Dennick, R.G. (2002). Exploring culture, language and the perception of the nature of science. International Journal of Science Education, 24, 1–25.

Tao, P.-K. (2003). Eliciting and developing junior secondary students' understanding of the nature of science through peer collaboration instruction in science stories. International Journal of Science Education, 25, 147–171.

Thagard, P. (1992). Conceptual revolutions. Princeton, NJ: Princeton University Press.

Tsai, C.-C. (1999). ‘‘Laboratory exercises help me memorize the scientific truths’’: A study of eight graders’ scientific epistemological views and learning in laboratory activities. Science Education, 83, 654–674.

Tsai, C.-C., & Liu, S.-Y. (2005). Developing a multi-dimensional instrument for assessing students’ epistemological views towards science. International Journal of Science Education, 27, 1621–1638.

Venter, E. (2004). The notion of Ubuntu and communalism in African educational discourse. Studies in Philosophy of Education, 23, 149–160.

Vhurumuku, E., Holtman, L., Mikalsen, O., & Kolsto, S. (2006). An investigation of Zimbabwe high school chemistry students’ laboratory work-based images of the nature of science. Journal of Research in Science Teaching, 43, 127–149.