To What Degree Can Explicit Classroom Interventions Change Pre-service Elementary Teachers’ Conceptions of Nature of Science?

by

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Introduction

During numerous professional development workshops for middle school and high school teachers, we have found that teachers often fail to differentiate science from non-science. In particular, teachers faced problems when they approached teaching evolutionary theory in their classrooms. Many teachers expressed concern about whether to include alternative “theories” to evolution and feared offending students or students’ parents. In a qualitative study including surveys, focus groups, and individual interviews, we identified a systemic lack of understanding of the philosophical nature of science (NOS) among the science teacher participants (Bloom, 2008; Bloom & Weinburgh, 2006, 2007). We believe this lack of distinction between science and non-science, along with the concerns faced by teachers in presenting content such as evolutionary theory, may result, in part, from a lack of understanding of nature of science.

What is Nature of Science?

Lederman (1992) describes NOS as the epistemology and sociology of science, the values and beliefs inherent to scientific knowledge and its development, and science as a way of knowing. For decades, the American Association for the Advancement of Science (AAAS) has emphasized the need for teachers (and subsequently their students) to gain an understanding of NOS (AAAS, 1993). Despite the importance being placed on NOS instruction, a clear picture of what characteristics describe NOS has been elusive (Abd-El-Khalick, 2000; McComas, Clough, & Almazroa, 1998; Schwartz & Lederman, 2002). Alters (1997) attempted to validate the tenets of NOS commonly held by science educators by surveying philosophers of science; he found that philosophers of science have many strong criticisms of some of the tenets and that even among them there exists disagreement about what characterizes NOS. Although there is much debate over a clear representation of NOS, a review of the literature reveals a short list of commonly-held tenets considered relevant to K-12 science teachers and learners (AAAS, 1993; Lederman & Abd-El-Khalick, 1998; NRC, 1996; Smith & Scharmann, 1999). In this study, the researchers focus on the following seven characteristics of NOS.

Scientific Knowledge is Tentative

Although scientific knowledge is based upon observations (empirical evidence), the explanations behind these factual components are tentative and subject to change as new information is acquired. Scientific knowledge changes in two distinct ways: (1) new knowledge is acquired and is added to the canonical knowledge and (2) current knowledge may be replaced when new technology or discoveries disprove it. Examples of science changing in the additive sense include the discovery of new disease-causing microbes and/or new treatments to cure them, the discovery of new fossilized remains of an unknown dinosaur, or better technological advances such as CT scanning allowing scientists to see internal structures that were previously unknown. Examples of scientific knowledge changing in a revisionary way include the discovery of bacteria living in hostile environments such as the stomach (previously thought
impossible), the discovery that continental plates were not stationary but are, rather, moving at a gradual pace, and that neural cells in the brain can regenerate to some degree.

**Scientific Knowledge is Based on Empirical Evidence**

All scientific knowledge must be, at least partly, based upon empirical evidence. Empirical evidence is any evidence that is measurable or observable. Any way of knowing that lacks empirical evidence is not counted as scientific knowledge. Although many people involved in science (researchers, teachers, philosophers) recognize that empirical evidence is useful in developing new scientific knowledge, they may lack the understanding that empirical evidence (of some sort) is a requirement of science. Ways of knowing that lack empirical evidence could be religion (based on faith) or philosophy (based on laws of logic).

**Scientific Knowledge is Subjective and Theory-Laden**

Scientific knowledge is based upon theories and is, therefore, somewhat subjective. Although many scientists may dislike such a characterization of science, those who care to look deeper realize that they are viewing their particular field through a metaphorical set of lenses created by the paradigm in which they have been trained. The theories under which they have studied have an influence upon the interpretations they make of the phenomena that they observe. Anyone who has been educated about Darwinian processes of evolution will interpret his or her observations in light of that particular paradigm. This theory-laden quality allows for consistency in science, but can also fuel dogma in science which can impede new interpretations of scientific facts.

**Scientific Knowledge is Created by Scientists**

Scientific knowledge, although grounded in empirical evidence, is oftentimes furthered by human imagination and creativity. Too many times, science educators believe that scientists routinely use an orderly series of steps to uncover new ideas and fail to realize that creativity and imagination can be integral to uncovering new ideas and breaking free from scientific dogma. While many recognize that scientists use creativity in designing experiments and presenting their findings, they often fail to realize that scientific discoveries are actually new knowledge created by the scientist who presents it to the scientific community. A recent example is Bassler’s discovery at Princeton University; her research on chemicals secreted by bacteria (called autoinducers) has revealed a previously unknown bacterial capability known as quorum sensing. This newly created knowledge describes bacteria as being able to sense levels of these chemical signals and act collectively in expressing their genes based upon the size of the bacterial population within the host organism (Bassler, 2008).

**Scientific Knowledge is Socially and Culturally Embedded**

Scientific knowledge proceeds based upon contributions from a community of scientists. Through collaboration and sharing, any individual within the community benefits from the knowledge acquired by all. Furthermore, each member of the community is a product of the culture in which he/she lives and is, therefore, influenced by that culture. Knowledge about stem-cell culturing is proceeding at differential rates in different cultures; faster in Europe and Asia, slower in the U.S. (due, in part, to the culture of our citizens). As another example, research into women-specific health issues developed long after research into those that plague both genders (or specific to men) were well-researched.
Scientific Knowledge is Based on Observations and Inferences

Observations of natural phenomena that exist in nature are measurable, identifiable phenomena that are directly accessible to the senses. In other words, they are empirically based. Inferences, on the other hand, go beyond the senses and demand that observers make explanations that are not directly accessible by observation (Lederman, 2006). Inferences often extend upon past observations, theoretical background, cultural perspective, and social norms and involve some degree of creativity. Both observations and inferences are integral to scientific progress and the growth of scientific knowledge. For example, with advanced technology in plate tectonics, scientists can observe the movement of land masses. Using this knowledge, scientists infer that the continents would have been connected as a supercontinent in the past (unobservable).

Scientific Knowledge is Based on Laws and Theories

The distinction between laws and theories parallels the distinction between observations and inferences. Laws are general descriptions that explain observable phenomena such as the Law of Gravity; gravitation or gravity is the tendency of objects with mass to accelerate toward each other. While the Law of Gravity describes this phenomenon, it does not explain it. A theory, on the other hand, contains an inferred explanation of the observable phenomena (McComas, 1997). The Theory of Evolution, for example, attempts to explain the diversity of life on Earth by identifying natural selection as a mechanism to account for the observed phenomena.

With mounting evidence that a lack of NOS understanding can translate into difficulties for the teacher in the classroom and/or that science teachers need a better understanding of NOS (AAAS, 1993; NRC, 1996; Smith & Scharmann, 1999), this research investigated if pre-service teachers can develop a more authentic understanding of NOS prior to entering the classrooms through explicit NOS instruction in a science-methods teacher preparation course.

Methods

Participants

This study was conducted at a private university in Texas that serves approximately 9,000 students. Seventy-four early childhood through 4th grade (EC-4) pre-service teachers enrolled in a one-semester science methods course were included in this study. All were female and all were in their junior year of college pursuing a career in early childhood education. There were 64 Caucasian, 8 Hispanic and 2 African Americans course participants. As a requirement of the EC-4 program, all had previously taken at least two college-level lab science courses from a variety of disciplines including biology, geology, chemistry, physics, and environmental science.

Procedures

The researchers measured the participants' understanding of NOS at the beginning of the semester using the VNOS-D questionnaire developed by Lederman and Kishfe (2002). This instrument asks the following seven open-ended questions:
1. What is science?
2. How is science different from the other subjects you are studying?
3. Scientists produce scientific knowledge. Some of this knowledge is found in your science books. Do you think this knowledge may change in the future? Explain your answer and give an example.
4. (a) How do scientists know that dinosaurs really existed?
   (b) How certain are scientists about the way dinosaurs looked?
   (c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?
5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.
   (a) Do you think weather persons are certain (sure) about these weather patterns?
   (b) Why or why not?
6. What do you think a scientific model is?
7. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?
   a. If NO, explain why?
   b. If YES, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

The researchers conducted intervention efforts including classroom activities, discussions, and lectures. These interventions were designed to exemplify the major tenets of NOS and debriefings were conducted after each intervention to ensure that participants received clear communication of how these tenets were exhibited.

At the end of the semester, the participants were post-tested with the VNOS-D. Comparisons between the pre- and post-assessments were made to see if their views of NOS had changed.

Interventions
The researchers conducted numerous inquiry-based activities and lectures throughout the science methods course which were designed to exemplify NOS characteristics. Several of them are described here.

Seeds Activity. Students in the EC-4 class participated in an activity with various fruits including okra, apples, avocados, green beans, and red peppers. The students divided into groups and made observations about the fruit and predictions about the nature and number of seeds they would find inside them. A variety of fruits with varying numbers of seeds were randomly distributed throughout the class with each fruit type being represented in at least two groups. Each group used science process skills to examine and record information about their set of fruit. Each group made hypotheses as to what they might find inside their fruit and then dissected the fruit and recorded the number and description of the seeds they found. Each group then related to the class some of their findings and compared them with other groups who also had the same fruits. After all groups had compared their findings, the researchers asked them to make general statements about their fruits that could adequately predict what they might find if they were to dissect more of the same fruits. The instructor of record emphasized some of the
characteristics of NOS -- specifically that scientific statements are based upon empirical evidence, that scientific findings must be repeatable, that scientific knowledge is tentative, that scientists make inferences from their prior observations, and that scientists make hypotheses after seeing patterns emerge in their observations. The instructor of record discussed these tenets of NOS in the subsequent lecture entitled "The Three Legs of Science".

*Three Legs of Science Instruction.* In "A Leg (or Three) to Stand On", Weinburgh (2003) discusses the three important components to quality science instruction. Traditionally, teachers have focused on either emphasizing process skills with "hands-on" activities or have focused more on content knowledge delivery (using worksheets and lectures). Weinburgh addresses a need for not only blending these two methodologies, but also adding the "third leg" of good instruction, which is presenting nature of science as well. In the lecture following the seeds activity, the researchers discussed NOS with the students, emphasizing the importance of recognizing science being: a human endeavor (social and cultural), based upon evidence (empirical), constantly revised and corrected (tentative), repeatable, and based upon patterns observed in nature.

*Checks Lab.* The "Checks Lab" (Crue, 1932) was perhaps the most explicit opportunity to deliver NOS to the students in the EC-4 class. In the checks lab, the students once again divided into groups and each group was given an identical set of 16 canceled checks. Each group randomly pulled four checks from their set and began to make observations and record any evidence that they found. Once they had recorded the information from their checks, they made up a story that they believed adequately accounted for the data they had collected. After constructing their story, they drew another four checks and began to use the new information they gleaned from them to revise their story. Finally, they took four more checks and finished revising their story so that it accounted for all the data they had collected from their 12 checks. Once all groups had prepared their story, they began to share them with the rest of the class. Because none of the groups could view all 16 checks and because of the random drawing of the checks, each group potentially had information the other groups did not. Because of this, their stories varied quite dramatically. When one group found flaws in another group's story, its members would use their data to contradict the story being presented and add to the body of knowledge now shared by the class. Finally, as a class, the groups shared all their information and came up with the most plausible story to fit the collective data. In a debriefing of this activity, the instructor showed the students how this activity was very similar to how science progresses. All groups were asked to make inferences based upon their observations. Each group became aware that its story was tentative at best, because there were always more checks waiting to be drawn that could alter the story. They were encouraged to see that their cultural backgrounds influenced how they interpreted their data and that they were, in fact, creating the story to explain the observations they made. Two of the researchers led this activity and "wrapped-up" by explicitly discussing each of the seven tenets upon which this study focused.

*Dinosaur Activity.* In the dinosaur activity, students were presented an envelope filled with approximately 25 slips of paper, each of which contained a printed piece of information. Although they initially appeared to the students to be unrelated pieces of information, they were, in fact, pieces of a fragmented set of empirical evidence that supports the currently held theory of how dinosaurs became extinct. The students used the information to come up with an answer to the question "How did dinosaurs become extinct?" Students worked in groups and began
arranging their data slips in such a way that they could create a story that answered the question. This activity emphasized the process of making inferences based upon (provided) observations. While no clear answer to the question was provided, each group was capable of sorting the data slips in such a way that all groups came to a similar conclusion that an asteroid had hit the earth and resulted in some sort of problem for dinosaurs eventually leading to their extinction. The various stories differed to some degree in how they interpreted their data, but they were all using the same set of information to create their story. This activity displayed several tenets of NOS. The students had to make inferences based upon prior observations made by other researchers. They had to create the explanation of what caused the extinction of the dinosaurs. Their individual social and cultural backgrounds influenced how they interpreted their data to create their story (especially seen with students who believe the “Young-Earth” “hypothesis”). Though they based their stories on empirical evidence, they admitted to being tentative because they did not have all the information needed to be 100% confident. This activity also exemplified how scientists can hold contradictory theories even though they use the same evidence and it was a convenient opportunity to discuss the distinction between theories and laws and their non-hierarchical relationship.

Data Analysis

Establishing Inter-rater Reliability

The VNOS-D consists of 7 open-ended questions and, therefore, must be graded qualitatively. There is no single prescribed methodology for analyzing it, but the literature suggests that interviews of each respondent are necessary in order to adequately gauge each individual’s level of understanding of the seven tenets which the VNOS measures (Lederman, Abd-El-Khalick, & Bell, 2002). With such a large number of participants, the researchers attempted to develop a method for analyzing the VNOS in a semi-quantitative, albeit subjective, way. Each individual VNOS-D was read and the respondent was graded on each tenet separately. For each tenet, the respondent received a +1 score if their answers reflected an authentic understanding or a -1 if they exhibited a naïve understanding or a misconception. If no evidence was seen in either direction, they received a zero (neutral) score. Table 1 provides examples of responses that would result in a positive score or a negative score.

<table>
<thead>
<tr>
<th>Tenet</th>
<th>Informed Response</th>
<th>Naïve Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentativeness</td>
<td>Scientific knowledge is continually changing as new evidence is discovered; information in textbooks today may turn out to be incorrect.</td>
<td>Scientific knowledge will grow, but because scientific knowledge in textbooks was developed with rigorous science, it will not likely change.</td>
</tr>
<tr>
<td>Empirical</td>
<td>Scientists use evidence such as bones and fossils as well as current living reptiles to determine what dinosaurs must have looked like.</td>
<td>Scientists have to guess what dinosaurs must have looked like since no one was there to see them.</td>
</tr>
<tr>
<td>Subjectivity</td>
<td>Scientists are influenced by current scientific theory as they interpret new evidence.</td>
<td>Scientists evaluate new evidence purely objectively to avoid bias.</td>
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Creativity

| Scientists must use creativity in all aspects of their research; from designing an experiment to evaluating their evidence and making conclusions. | Scientists may use creativity in designing their experiments, but they must be purely objective in their interpretation of their results. |
| --- |

Social and Cultural Embeddedness

| Scientists are somewhat guided by the social values of the society in which they live. |
| Science research is not constrained by anything other than the scientist’s imagination. |

Observations and Inferences

| Scientists must use observations that they can make to understand or predict things they cannot see directly. |
| Scientists can only make statements about things which they can see or measure. |

Theories and Laws

| Scientific laws describe phenomena in nature while theories attempt to explain those phenomena. |
| Scientific hypotheses can result in theories being formed; if a theory is well tested it may be called a law of science. |

In order to determine inter-rater reliability, all three scorers selected and graded 10 participants’ VNOS-D’s and then compared the scores. The primary researcher (first author) compared his scores to those of the other two scorers. There was initially a 27% match with one scorer and a 58% match with the other for a total match of 42%. To identify scoring discrepancies and increase inter-rater reliability, the team discussed scoring in depth, gave explanations for the discrepancies between and among scorers, and reached an agreement on how answers should be scored. Another eight VNOS-D’s were distributed for grading, and an 83% match was found between the secondary researchers and the primary researcher.

**Scoring the VNOS-D**

The remaining VNOS-D’s (54 pre-assessments and 48 post-assessments) were distributed among the scorers so that each VNOS-D would be graded by two of the three. For each tenet on each of the tests, the average score between the two graders was calculated and that became the respondent’s score for that tenet. Each respondent could receive one of the following scores for each tenet:

- **+1** – Both scorers agreed they had an authentic understanding of the tenet
- **+0.5** – One scorer believed the respondent had an authentic understanding while the other did not see evidence of it
- **0** – Neither scorer saw any evidence of authentic understanding of the tenet
- **-0.5** – One scorer believed the respondent had a misconception or naïve view of the tenet while the other scorer did not see evidence of this
- **-1** – Both scorers agreed that the respondent had a naïve understanding or a misconception of the tenet

After establishing inter-rater reliability, the researchers had only 54 subject’s pre-assessment VNOS-D’s left to use for comparison purposes. The results listed in this section

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refer only to those 54 individuals whose pre-assessment was not used for inter-rater reliability purposes and the 48 post-assessment VNOS’s.

Results

To analyze the data, the researcher observed how many of the respondents received a positive score for each individual tenet (either a +0.5 or a +1; indicating that they had an authentic understanding of the tenet in question) and how many received a negative score (either a -0.5 or a -1). Prior to any interventions, the EC-4 students demonstrated some understanding of each of the tenets except the ability to distinguish between theories and laws. Table 2 identifies the number of participants who had informed or naïve views of each tenet.

The most understood tenet held by the students prior to interventions (98%) was that science is based (at least somewhat) on empirical evidence. Sixty three percent of the students held informed views that scientific knowledge was tentative and subject to change. Less than half of the students conveyed an informed view of each of the other tenets being studied.

While the number of misconceptions or naïve views of all seven tenets was relatively low, high percentages of students conveyed no knowledge (informed or naïve) for all tenets other than empirical. These data indicate that these characteristics of NOS are not a part of the students’ general conception of what characterizes science.

Table 2. VNOS-D Pre-Assessment Results

<table>
<thead>
<tr>
<th>Pre-VNOS-D Results (n=54)</th>
<th>Informed View of Tenet (Positive Scores)</th>
<th>Naïve View of Tenet or Misconception (Negative Scores)</th>
<th>No Indication of Knowledge or Misconception (Neutral Scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative</td>
<td>34 (63%)</td>
<td>12 (22.2%)</td>
<td>8 (14.8%)</td>
</tr>
<tr>
<td>Empirical</td>
<td>53 (98.1%)</td>
<td>0 (0%)</td>
<td>1 (1.9%)</td>
</tr>
<tr>
<td>Subjective</td>
<td>26 (48.1%)</td>
<td>6 (11.1%)</td>
<td>22 (40.7%)</td>
</tr>
<tr>
<td>Creative</td>
<td>23 (42.6%)</td>
<td>6 (11.1%)</td>
<td>25 (46.3%)</td>
</tr>
<tr>
<td>Social and Cultural</td>
<td>5 (9.3%)</td>
<td>1 (1.9%)</td>
<td>48 (88.9%)</td>
</tr>
<tr>
<td>Observation and Inference</td>
<td>27 (50%)</td>
<td>3 (5.6%)</td>
<td>24 (44.4%)</td>
</tr>
<tr>
<td>Theories and Laws</td>
<td>0 (0%)</td>
<td>12 (22.2%)</td>
<td>42 (77.8%)</td>
</tr>
</tbody>
</table>

After the semester-long intervention efforts of the researchers, a shift was observed in the students’ conception of many of the tenets under review. Table 3 identifies the number of participants who conveyed informed or naïve views of each tenet in the post assessment.
Table 3. VNOS-D Post-Assessment Results

<table>
<thead>
<tr>
<th>Post-VNOS-D Results (n=48)</th>
<th>Informed View of Tenet (Positive Scores)</th>
<th>Naive View of Tenet or Misconception (Negative Scores)</th>
<th>No Indication of Knowledge or Misconception (Neutral Scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative</td>
<td>47 (97.9%)</td>
<td>0 (0%)</td>
<td>1 (2.1%)</td>
</tr>
<tr>
<td>Empirical</td>
<td>48 (100%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Subjective</td>
<td>35 (72.9%)</td>
<td>2 (4.2%)</td>
<td>11 (22.9%)</td>
</tr>
<tr>
<td>Creative</td>
<td>19 (39.6%)</td>
<td>10 (20.8%)</td>
<td>19 (39.6%)</td>
</tr>
<tr>
<td>Social and Cultural</td>
<td>8 (16.7%)</td>
<td>0 (0%)</td>
<td>40 (83.3%)</td>
</tr>
<tr>
<td>Observation and Inference</td>
<td>36 (75%)</td>
<td>1 (2.1%)</td>
<td>11 (22.9%)</td>
</tr>
<tr>
<td>Theories and Laws</td>
<td>6 (12.5%)</td>
<td>2 (4.2%)</td>
<td>40 (83.3%)</td>
</tr>
</tbody>
</table>

Informed Views

In the post assessment, 100% of the students conveyed an informed view of the empirical nature of science. High levels of informed views were also observed for three other tenets: tentative, observation and inference, and subjectivity. Over half of the students’ responses indicated that they understood the tentative nature of science (97.9%), the use of observations and inferences in science (75%), and the subjectivity with which scientists interpret their observations (72.9%).

Less than half of the students conveyed informed views of creativity (39.6%), social and cultural embeddedness (16.7%), and the distinction between theories and laws (12.5%). Equally significant was the lack of naive views conveyed in the post-assessment. While 20.8% of the students conveyed misconceptions or naive views of the creative aspect of science, less than 5% demonstrated naive views of any of the other tenets being observed. Figure 1 displays the change in students’ informed conceptions.

Figure 1: Comparison of Pre- and Post- Intervention Positive Scores (%)
Naïve Views

In their post assessment, the students displayed marked improvement through their decline in conveying naïve views or misconceptions of the tenets in question. Figure 2 displays the change in students’ naïve views or misconceptions of the seven tenets based upon their negative scores. It should be noted that there was no indication of naïve views of the empirical nature of science in either the pre- or post-assessment.

Figure 2: Comparison of Pre- and Post-Intervention Negative Scores (%)

Discussion

The data collected in this study shed light on several aspects of pre-service teachers’ conceptions of NOS. The pre-assessment indicates a significant lack of understanding of most of the commonly held tenets of NOS (as indicated by number of responses without a positive or negative score) and some clear misconceptions or naïve views as indicated by their negative scores. After numerous intervention efforts (such as those described in this paper) an improvement in these conditions was seen. Post-assessments reveal an increase in positive scores and a decrease in the number of misconceptions identified. These data indicate that with explicit delivery of authentic representations of NOS and debriefing to clearly explain the tenets being expressed, pre-service teachers can improve their conception of NOS. We hope that an improved view of NOS can translate into more authentic delivery of science in the K-4 classrooms. Despite the positive indications of these data, some significant limitations of the research need to be addressed.
Limitations of Study

In their article "Views of Nature of Science Questionnaire (VNOS): Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science", Lederman, et al. (2002) emphasize the need for interviews to accompany the VNOS itself when researchers attempt to evaluate learners' conceptions of NOS. In our study we conducted no interviews. We hoped to find a way to use this qualitative instrument in a more quantifiable way so larger numbers of learners could be assessed in a manageable amount of time. We believe that our approach has some merit but lacks the accuracy that could be found with interviews and a more qualitative approach to grading of the instrument. In our attempt to gain inter-rater reliability in how we gauged the learners' conceptions of NOS, we found that our individual subjectivity created difficulty in interpreting participants' responses without bias. Indeed, in the first round of grading, we often found that one researcher's perception of their grasp of any particular tenet could diametrically oppose another researcher's perception. We did eventually reach an inter-rater reliability of 83% and believed that we could, at least consistently, grade each VNOS-D similarly enough to move forward with confidence. However, none of the graders believed that their final evaluation of any individual's conception of NOS was altogether accurate. We believe that without more qualitative research, our perception of the students' knowledge can be little more than an arbitrary measurement that reflects our own biases as graders. We do believe that we consistently graded each VNOS-D throughout this study and, therefore, can identify change in the learners' conceptions, but we do not feel that we have accurately identified what they know either before our interventions or after. A clear example of the need for further qualitative analysis through interviews is seen when we evaluate the students' conceptions of the empirical basis of science. Although all participants indicated that scientists use empirical evidence in their work, none clearly articulated that science must be, at least somewhat, based upon empirical evidence. They acknowledged that empirical evidence may be a component of science, but not that it must be. Due to this inability to accurately gauge the true understanding of those being tested using this methodology, we feel that a different tool should be developed that can be used with large groups and can be graded more objectively without the need for qualitative analysis. With a tool such as this, we will be able to assess the conception of NOS held by large groups of individuals.

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