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## Abstract

The use of concept maps as instruments for assessing preservice teachers' epistemologies of science (their ideas of the nature of scientific knowledge) was evaluated in this study. Twenty-three preservice elementary teachers' responses to the Views of the Nature Of Science (VNOS) questionnaire were compared to concept maps created in response to the general probe, "What is science?" While VNOS responses allowed a richer analysis of the content and quality of the participants' epistemologies, the concept maps provided information about structural changes of participants' epistemologies as well as how those epistemologies relate to their overall conceptions of science as a field of study. Both instruments also revealed important connections between NOS tenets, which were more numerous on the concept maps but more informative on the VNOS, and between NOS tenets and pedagogical issues. Implications for assessment of students' epistemologies of science in classrooms are discussed.

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## Introduction

It is widely agreed that scientific literacy involves not just understanding scientific ideas, but understanding the nature of scientific knowledge, or having an informed epistemology of science (AAAS, 1990, 1993; National Research Council, 1996). Thus, a host of education reform efforts include improved instruction assessment aimed at helping students adopt sophisticated ideas about the structure and function of scientific knowledge (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Meichtry, 1993). Here we describe the application of concept maps, a common assessment tool, toward the assessment of students' epistemologies of science.

## Epistemology of Science

The term epistemology is defined differently in different bodies of literature. Epistemology was first conceived as a branch of philosophy concerned with the nature of knowledge and knowing. Psychologists use the term slightly differently, often referring to the term personal epistemology as a *students' beliefs about* the nature of knowledge and knowing. One of the first such lines of research was William Perry's (1970) longitudinal study of college students which resulted in the development of a scheme for characterizing students' epistemologies. According to this scheme, individuals move from ideas about knowledge as certain, unproblematic, and either wrong or right, through a radical relativist phase in which all knowledge is seen as equally valid due to its tentativeness, and finally come to recognize that while knowledge is inherently uncertain, the merits of competing claims can and should be evaluated based on a non-arbitrary set of standards.

Although Perry's research was not discipline specific, it laid a foundation for classifying students' epistemologies of science. Carey, Evans, Honda, Jay, and Unger (1989), for example, used data from interviews with 7th graders to develop a parallel scheme, at the lowest level of which scientific knowledge is viewed as being unproblematic and "read" directly from nature. Students progress toward more sophisticated ideas about theories being mental constructs relying on human interpretation of indirect evidence and finally, at the highest level, recognize that theories must explain all of the available evidence and therefore sometimes must change to accommodate new evidence. Other researchers (Elby, 2001; Hofer & Pintrich, 1997) have used epistemology as an overarching term for a students' beliefs about *learning*. Elby (2001) developed an instrument to measure students' "epistemological beliefs," part of which asks students about the relative merits of conceptual vs. algorithmic learning.

The phrase nature of science (NOS) is closely related to the philosophical treatment of the term epistemology, applied specifically to the realm of science. It is widely used to refer to the nature and function of scientific knowledge (Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, 1992). What constitutes a sophisticated understanding of NOS, or epistemology of science? Scientific developments in the 20th century convinced philosophers to reinterpret strict logical positivism which claims that science can uncover objective "truths" in nature. While most philosophers of science now recognize science as a constructive endeavor in which human interpretation plays a necessary role, many students still have a positivist view of science. Although there is some disagreement among scientists and philosophers of science about what, exactly, constitutes a sophisticated epistemology of science, Smith and colleagues argue that such disagreements are irrelevant to elementary, secondary, and perhaps even tertiary levels of instruction, and that sufficient consensus exists among such scholars to define a relatively robust set of NOS learning goals for schools (M. U. Smith, Lederman, Bell, McComas, & Clough, 1997). By studying consensus views among philosophers of science, Lederman and colleagues identified a set of tenets that, together, constitute a sophisticated epistemology of science. These are: a) evidence forms the basis of scientific theories (empirical NOS); b) there is no single method that automatically generates scientifically valid knowledge (myth of scientific method); c) the practice of interpreting evidence is infused with the backgrounds, expertise and values of the scientist (theory-laden NOS); d) science and society are tightly intertwined and influence each other (social/cultural embededness); e) most scientific practices require the scientist to exercise creativity and imagination (creative and imaginative NOS); f) scientific theories are subject to change based on the accumulation of new evidence and re-interpretations of existing evidence (tentative NOS); g) theories and laws are different kinds of knowledge and one does not become the other (theories vs. laws); and h) the construction of scientific theories requires interpretation of evidence (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & O'Mally, 1990).

These tenets are consistent with the developmental frameworks described above, wherein a sophisticated epistemology involves recognition of the tentativeness of knowledge due to the roles of interpretation and human interaction in generating that knowledge. In fact, Akerson, Buzzelli, and Donnelly (2007) found that students who had naïve conceptions of NOS relative to Lederman's tenets were generally found to be at the lower levels of Perry's (1970) scheme while those who had more sophisticated conceptions were generally higher on that scheme. Furthermore, the NOS tenets echo the national standards for NOS learning goals set out by the national research council (National Research Council, 1996). The NOS framework will be used to define a sophisticated epistemology in this study, where the word epistemology is used in the philosophical sense to mean the nature of knowledge and knowing, specifically tied to scientific knowledge.

## Assessment of Students' Epistemologies

Research has shown that college undergraduates consistently hold, and sometimes leave college with, naïve epistemologies. Perry's findings, for example, suggested that most students do not attain the most sophisticated levels of his epistemological scheme by the time they graduate from college (Perry, 1970). Smith and Wenk (2006) found that the highest epistemological level in Carey's (1989) scheme reached by a group of 35 freshmen was level 2 (3 is the highest), and only one third of the students reached that level. Several studies conducted within Lederman's NOS framework suggest college students and preservice teachers hold inadequate conceptions of the nature of science (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Lederman, 1992), and that even those who gain sophistication in their NOS conceptions have difficulty retaining and applying them (V. Akerson, Morrison, J. and McDuffie, A., 2006). Further, Abd-El-Khalick (2001) has shown that explicit NOS instruction can result in students adopting "anything goes" epistemologies similar to Perry's naïve-relativistic developmental phase.

A first step in designing instructional strategies geared toward fostering sophisticated epistemologies is to effectively assess students' incoming ideas about science. Here we operate under the framework that a sophisticated epistemology of science involves understanding multiple facets of the nature of science in a coherent, connected way. We therefore use Lederman's NOS framework to define and assess a students' epistemologies because it allows for the measurement of each of these dimensions, rather than placing students on a single spectrum as in Perry's (1970) and Carey's (1989) schemes.

A number of Likert and multiple choice instruments have been developed to assess students' epistemologies throughout the years (e.g. Billeh & Hasan, 1975; Cooley & Klopfer, 1961; Cotham & Smith, 1981). However, these types of instruments assume students interpret the questions and statements in the same way the instructor or researcher using the instrument does, which is not likely to be true. Furthermore, responses to such instruments usually only reveal to what degree a students' views agree with the researchers', rather than giving a holistic view of the students' epistemologies. Recognizing such limitations, Lederman and colleagues developed an open-ended instrument called the Views of the Nature Of Science (VNOS) questionnaire (Lederman et al., 2002). The VNOS questionnaire, when paired with appropriate interview strategies, can give the researcher or instructor more nuanced insights into a student's ideas regarding the eight tenets compared to multiple choice or Likert-type instruments. However, even when combined with interview data, the VNOS requires a great deal of inference on the researcher's part to make sense of the responses.

A limitation of many assessment tools is they do not adequately probe the connections students make between topics. It is well documented that "experts" in a realm chunk ideas together in meaningful ways instead of filing individual pieces of information away to recall piecemeal (e.g. Miller, 1956). We argue that a sophisticated epistemology should therefore include not only nuanced views with respect to individual tenets, but also a recognition of how different aspects of science are related to each other. However, few studies have explored the links students make between different facets of their epistemologies of science. Southerland, Johnston, Sowell, and Settlage (2005) constructed conceptual ecologies representing five graduate students' epistemologies of science based on multiple data sources. They identified common links between facets of the nature of science and suggested a certain hierarchy of ideas, wherein gaining understanding of certain ideas would facilitate development of overall sophisticated epistemologies more than understanding certain other tenets. Schwartz, Lederman, and Crawford (2004) recognized the importance of making connections between NOS tenets, looking for "a demonstrated shift from viewing aspects of NOS as separate components to realizing the interrelationships of the aspects" (p. 625) as evidence for sophisticated epistemologies. These researchers did uncover some connections, illustrating another advantage of such open-ended questionnaires over forced-choice instruments. Nevertheless, we wondered to what extent concept mapping, which explicitly requires students to make connections between different facets of their understanding, could complement the VNOS.

## Concept Mapping

Concept mapping has been in existence for more than two decades (J. D. Novak & Gowin, 1984). At their most basic level, concept maps consist of a number of concepts related to a topic, connected to each other via links in a hierarchical or web-based form. In many cases, the links themselves are labeled to describe in words the relationship they represent. Concept maps have been used widely as a tool to assess student understanding (Edmondson, 2000). They are somewhat unique among assessment tools because in addition to assessing the *quality* of the student's understanding (through the number and relationships between concepts and examples), they make the *structure* of that understanding transparent (through the way in which the concept map is organized; Mintzes, Wandersee, & Novak, 2001; Joseph D. Novak, 1984). Importantly, these two facets (quality and structure) seem to be related. In one study, comparison of students' interview responses with the their concept maps revealed that the students who drew more complex maps had a deeper understanding of the content – that is, the structure of a student's understanding seemed to be positively correlated with the sophistication of his or her understanding (Markham & Mintzes, 1994).

Researchers have created several ways to use concept maps to assess student understanding. Novak (1984) describes three important facets of a concept map: 1) propositions, which consist of pairs of concepts connected by linking words, the quantity and validity of which are related to the quality of the individual's understanding of the topic; 2) the levels of hierarchy in a map, which are related to the extent to which the individual subsumes, or groups, more specific knowledge under more general knowledge; and 3) crosslinks, or links between concepts in different branches of the map, which are evidence of knowledge integration, or the extent to which the individual recognizes the connectedness of the ideas within a topic. In a later framework, the number of concepts and examples were added to the facets of a concept map that portray the quality of an individual's understanding, and branching was defined as being reflective of the degree of knowledge differentiation, or the extent to which specific components of concepts are identified (Markham & Mintzes, 1994).

Concept mapping has also been used to reveal the extent of reorganization of a student's knowledge structure. Rummelhart and Norman (1978) have described three types of changes in the way individuals reorganize knowledge: accretion, in which new knowledge is added to existing knowledge structures, tuning, in which the accuracy of the knowledge structure is changed, and reconstruction, in which new knowledge structures replace the old ones. In a similar vein, Carey (1987) called the addition of new knowledge into an existing knowledge structure weak conceptual change and a reconstruction of the knowledge structure strong conceptual change. Jones and Vesilind (1994) used these ideas to assess concept maps drawn by preservice teachers. They defined the set of concepts connected to the central, or level-one concept in a concept map, superordinate concepts. Changes in superordinate concepts indicated the extent to which the teachers reconstructed their conceptual frameworks.

Here we describe a study in which concept mapping was used to assess students' epistemologies of science. The use of concept mapping in this study was similar to that described by Spector, Strong, and La Porta (1998), in which students constructed and modified concept maps about the nature of science throughout the duration of a course. In that study, concept mapping was used primarily as a learning tool. However, to our knowledge the effectiveness of concept mapping as a tool to assess students' epistemologies has not been explicitly investigated. To this end, we undertook a mixed-methods approach in which we compared students' concept maps about the nature of science to their responses on the VNOS questionnaire. The guiding questions for this study were, What are the strengths and weaknesses of concept mapping as a tool for assessing preservice teachers' epistemologies of science? and, What new capabilities can concept mapping offer for assessing preservice teachers' epistemologies of science?

## Method

In this study, preservice elementary teachers in one section of a science methods course responded to the VNOS questionnaire and engaged in a concept mapping activity both before and after instruction in the nature of science. The responses to both instruments were compared to gain more understanding of how concept mapping functions as a tool to assess students' epistemologies of science.

### *Context of study*

The second author was the instructor for the science methods course in which this study was conducted. Developing sophisticated epistemologies of science is a major goal of this course. Inquiry based activities (Lederman & Abd-El-Khalick, 1998) and readings (AAAS, 1990, 1993) were used to explicitly teach NOS ideas. All twenty-three study participants were enrolled in the same section of the methods course and were pursuing a K-8 certificate.

### *Data collection*

All data collection and analysis was carried out by the first, third, fourth and fifth authors. All participants responded to selected items from the VNOS-C questionnaire (Lederman et al., 2002) before and after instruction in the nature of science. Eight students who held a broad range of views were then chosen to participate in semi-structured interviews to ensure the validity of researchers' interpretations participants' written responses. All interviews were audio recorded and transcribed for analysis.

Near the beginning of the course, participants were instructed in concept mapping and generated practice concept maps in groups of 3-4. The participants then brainstormed words or phrases related to the following questions: What is science? What is the scientific world view? What is scientific inquiry? Who does science and how do they do it? The groups generated concept maps based on the brainstormed ideas. After instruction in the nature of science, groups were given back their initial posters and instructed to make changes by adding, moving or removing concepts and links. After each concept mapping task, the groups sketched their maps and turned them in to the researchers for analysis.

### *Data analysis*

Data from the VNOS questionnaire and concept mapping activity were compared in three phases (Table 1). In phase I we used each instrument to normatively assess the quality of each participant's epistemology. We then explored the participants' epistemologies descriptively in phase II. Finally, in phase III explored to what extent each instrument could give information about the structure, or connectedness, of participants' epistemologies.

Table 1
*Description of data analysis activities for each instrument in each phase of data analysis.*

| | Purpose | VNOS | Concept maps |
|---|---|---|---|
| Phase I | Normative (quality of students' epistemologies) | Naïve/informed coding of each NOS tenet | Scoring based on the number of concepts, valid relationships and examples |
| Phase II | Descriptive (nature of students' epistemologies) | Generation and coding of emergent themes | Generation and coding of emergent themes |
| Phase III | Structural (structure of students' epistemologies) | Identification of links between NOS tenets; | a) Identification of links between NOS tenets; b) Scoring based on the number of branches, levels of hierarchy and crosslinks; c) Identification of changes in superordinate concepts |

*Phase I.* In the phase I, responses to the VNOS and related interview questions were blinded and coded independently by two authors after at least 90% interrater reliability was reached in training sessions. Each of the participants was coded naïve or informed with respect to the first six of the eight NOS tenets described in the introduction. Interview responses were used to establish validity of the coding procedure. The scoring rubric and interview procedure were adapted from Lederman et al. (2002) and Bell et al. (2005). The codes were then used to generate an overall epistemology profile of "naïve," "emergent" or "informed." If a participant expressed informed understandings of 5-6 of the six tenets, he or she was given an overall code of "informed." For 3-4 informed codes, the participant was given an "emergent" overall code, and "naïve" for 0-2 (Bell et al., 2005). Finally, the VNOS responses of one student who exhibited a large overall shift (naïve to informed) were examined for ideas that seemed key to her epistemological change. The quality of students' epistemologies was judged on their concept maps by the number of *a)* concepts, *b)* examples and *c)* valid relationships (only connections with valid linking terms were counted).

*Phase II.* Both VNOS responses and concept maps were thoroughly searched for emergent themes in this phase (Strauss & Corbin, 1998). Because the questions asked in the concept mapping exercises (What is science? What is the scientific world view? What is scientific inquiry? Who does science and how do they do it?) were most similar to the first item on the VNOS questionnaire ("What, in your view, is science? What makes science . . . different from other disciplines of inquiry. . .?" (Lederman et al., 2002)), only emergent themes from the first question were used for comparison with the concept maps. Responses from each instrument were first coded individually then searched for themes generated from coding the other instrument, in order to allow a comparison.

*Phase III.* The final analysis phase consisted of searching the VNOS responses and concept maps for connections between two or more different tenets. The emergent themes from phase two analysis were placed into families based on the six of Lederman's NOS tenets assessed in this study. Using ATLAS.ti, we searched VNOS responses for co-occurrences of two or more tenets in the same statement. Search results were read individually to ensure the links were accurate. We then searched for linkages between the same six NOS tenets on the concept maps. Linker words used to connect two or more concepts related to these tenets served as evidence for how the participants made sense of the relationships between them. Additional measures of structure were taken on the concept maps only. First, the frequency of the structural features of each concept map – branching, hierarchies and crosslinks – were tallied to give a structure subtotal. Second, changes in the second highest level (superordinate) concepts were tracked in order to illuminate the level of conceptual change represented.

*Comparing the VNOS responses and concept maps.* Because the VNOS questionnaires were completed individually and concept maps were completed in groups, we could only compare whole-class results on the two instruments (ie. we did not compare student 1's VNOS responses with her group's concept map because the latter would represent more views than student 1's). In phase I, we compared the naïve/informed code frequencies from the VNOS to the concept, relationship and example scores on the concept maps, which we combined into a concept subtotal. This comparison allowed us to evaluate how well each instrument assessed the students' understandings of the nature of science. We could not quantitatively compare the code frequencies to the concept subtotals because they are different statistics. However, we are able to discuss what each statistic revealed about students' NOS understandings, as well as the strengths and limitations of each measure. In phase II, we compared the emergent codes created for the responses to the first question of the VNOS and propositions (concepts + linker words which form statements) on the concept maps. The frequency of each code on each group of instruments was tallied and compared. Finally, in phase III, we compared the number and types of links between NOS tenets on each instrument. The structure subtotals and superordinate concepts were features unique to the concept maps. Though we didn't have a means for comparing these features to VNOS responses we felt it important to evaluate their contribution to the overall assessment of students' epistemologies and thus discuss them as stand-alone features.

## Results

The findings with respect to each of the three phases of data analysis are described below. In quotations from VNOS responses, participants are identified individually by a number. In quotations from the concept maps, the seven concept mapping groups are assigned letters A-G.

*Quality of participants' epistemologies*

*VNOS.* The pre- and post-instruction VNOS codes are shown in Table 2. Modest gains were observed for all but one tenet. None of these gains were found to be statistically significant through a chi-square test in which the distribution of students holding naïve and informed views with respect to each tenet was compared before and after instruction. The overall codes, shown in Table 3, reveal 6 of the 23 participants adopted more informed views as a result of instruction. In contrast, one student moved from an informed to emergent profile after instruction.

Table 2
*Pre- and post-instruction NOS beliefs of participants by tenet, as assessed through analysis of responses to the VNOS questionnaire.*

| | Informed | | Naive | |
|---|---|---|---|---|
| NOS Tenet | Pre | Post | Pre | Post |
| Creativity & Imagination | 9 (39%) | 10 (43%) | 14 (61%) | 13 (57%) |
| Empirical NOS | 4 (17%) | 6 (26%) | 19 (78%) | 17 (74%) |
| Myth of Scientific method | 5 (22%) | 4 (17%) | 17 (74%) | 18 (78%) |
| Social/cultural embededness | 12 (52%) | 14 (61%) | 10 (43%) | 8 (35%) |
| Tentative NOS | 19 (83%) | 21 (91%) | 4 (17%) | 2 (9%) |
| Theory-laden NOS | 11 (48%) | 16 (70%) | 11 (48%) | 7 (30%) |

*Note.* The percentage of naïve and informed responses on each questionnaire do not always total 100% because in some cases we did not find evidence to justify the assignment of either code.

Table 3
*Overall NOS profiles before and after instruction, as assessed by the number of tenets coded informed on the VNOS questionnaire.*

| Overall Profile | Pre | Post | Δ from N | Δ from E | Δ from I |
|---|---|---|---|---|---|
| Informed | 2 (9%) | 5 (22%) | 2 (9%) | 2 (9%) | N/A |
| Emergent | 9 (39%) | 10 (43%) | 2 (9%) | N/A | 1 (4%) |
| Naive | 12 (52%) | 8 (35%) | N/A | 0 (0%) | 0 (0%) |

To illustrate the subtleties that can be revealed by the VNOS and to illustrate some of the coding employed, one participant's epistemology is here described in more depth. This participant (17), given the alias Phoebe, is one of the two who exhibited an overall naïve to informed shift. Phoebe's VNOS responses signified major shifts in her thinking about three tenets: the myth of scientific method, the theory-laden nature of science, and the social-cultural embededness of science. Therefore, the discussion is focused around these three issues.

Phoebe's initial VNOS responses revealed an accurate conception of an experiment as, "a means of showing a cause and effect relationship. Experiments rely on a controlled environment where the researchers manipulate the variables to discover the effect on the outcome" (response to item 2). However, when asked whether experiments are necessary for the development of scientific knowledge (item 3), Phoebe initially said, "Yes, because an experiment is the only way of knowing for sure if there is a cause and effect relationship between two variables." After instruction, Phoebe appeared to broaden her conceptions about scientific investigations, stating,

> I no longer think the development of scientific knowledge always requires an experiment. An experiment is a great and necessary tool for discovering cause and effect relationships. However, observation is another tool that is used to develop scientific knowledge. For example, scientists have discovered much about the universe through observation and rational thought.

Phoebe was initially given a naïve code in the scientific method category because she did not recognize the utility of observational studies. Her later response, however, was given an informed code in the same category. Phoebe's shift in thinking seemed to hinge first on a correct conception of what an experiment is, and secondly on her ability to recognize that there are instances in which experiments are impossible or inappropriate.

Changes in Phoebe's perception of the theory-laden nature of science (that scientists bring their own experiences and values to bear in collecting and interpreting data) seemed tightly related to changes in her thinking about the social and cultural embededness of science. When asked how scientists using the same evidence can come to different conclusions about what caused the extinction of the dinosaurs (item 5), Phoebe responded, "Some scientists might come to one conclusion using the evidence and some another." Her lack of inclusion of a mechanism for how this might happen resulted in a naïve code for the theory-laden category. After instruction, Phoebe revised her answer to this question, stating, "Scientists come from different parts of the world and their culture could also play a role in how they analyze evidence." Her inclusion of the idea that scientists' cultures could play a role in analyzing evidence indicates an understanding of the interpretive role of the scientist, and that this comes in part from the different backgrounds, experiences, and values of the scientists involved in a study. This response provided a basis for informed codes for both the theory-laden category and the socio-cultural category. Furthermore, when asked whether science is universal or infused with certain cultural values (item 6) at the end of the class, Phoebe responded,

> I still believe science is intended to be universal, but cultural values do play a role. For example, during the Middle Ages scientists believed that men carried all the genetic material for their children, this reflected the culture at the time.

This response indicates some understanding of the way a scientific theory may influence cultural norms. Phoebe therefore recognized the interplay between science and a society's culture both in the context of a scientist conducting a study and in the larger sense of a theory influencing a culture. This set of responses formed the basis for an informed code in the socio-cultural category whereas at the beginning of the course Phoebe had a more simplistic view:

> I believe science is universal. Science relies on observation and reproducible data. If scientists in China perform an experiment that shows a new drug is effective in fighting cancer, scientists in other countries must be able to perform the same experiment and get the same result.

Although her statement is not incorrect, it reveals a lack of understanding of the more nuanced interplays between science and the society in which it is embedded.

This narrative illustrates the type of information that can be obtained using the VNOS questionnaire. We were able to ascertain some of the major facets of Phoebe's epistemology that changed as a result of instruction. These included increased understandings of the importance of observational studies in science, the role of interpretation in science, and the interplay between scientific theories and cultural norms.

*Concept maps.* Sample concept maps are shown in Figures 1 and 2. The attribution of the number of concepts and/or valid relationships in a concept map to the extent of the mapper's understanding of the topic is well established (Liu, 2004; Markham & Mintzes, 1994; Joseph D. Novak, 1984). We therefore used scores generated by counting the number of concepts, valid relationships and examples to obtain information about the extent of participants' understanding of the nature of science (Table 4). We observed a statistically significant gain (using a Wilcoxon t-test for nonparametric data) in the number of valid relationships. We also observed a non-statistically significant gain in the number of concepts represented. The number of examples, however, decreased. The concept subtotal (concept, relationship and examples scores totaled) was higher at the end of instruction than the beginning for each concept map, and the increase in the mean was statistically significant.

*Figure 1*. Pre-instruction concept map created by group E.

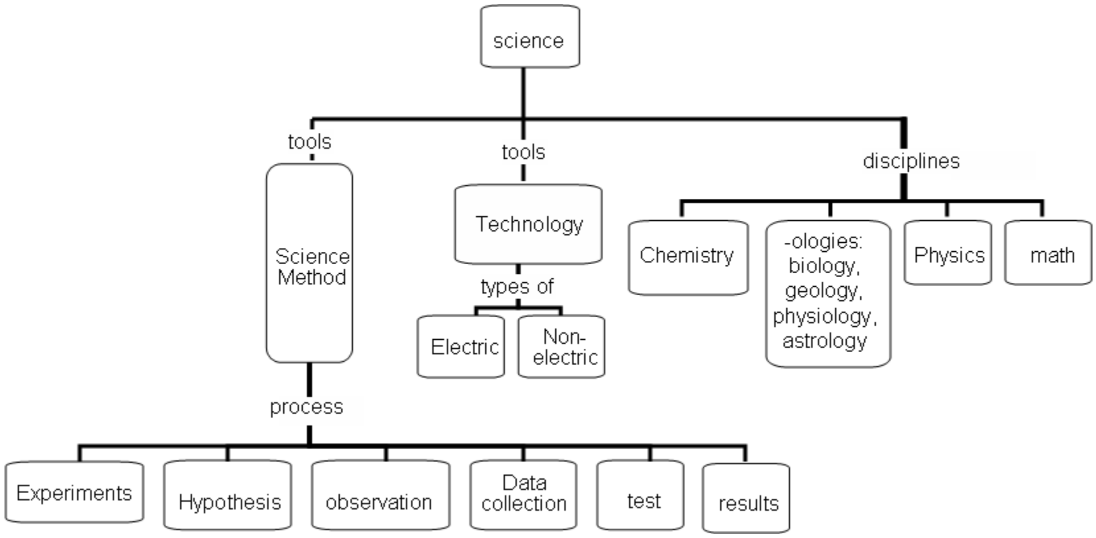


*Figure 2.* Post-instruction concept map created by group E.

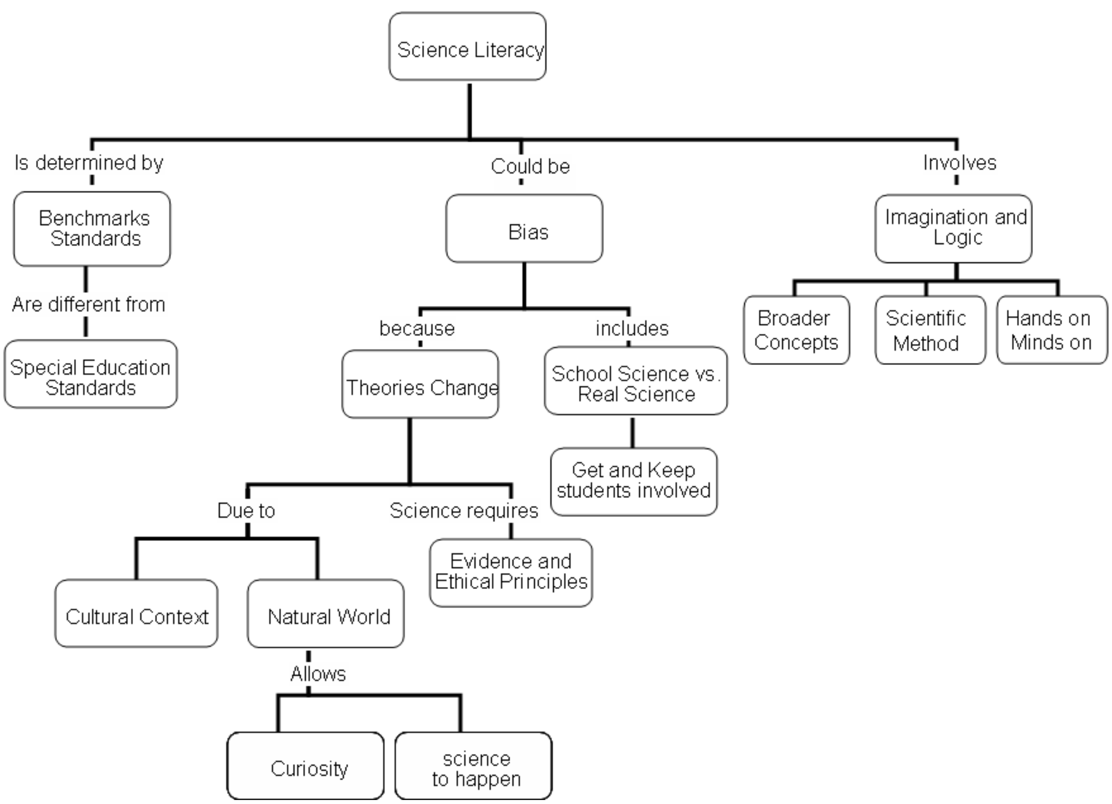

Table 4
*Average concept map scores.*

| | Pre-instruction | | Post-instruction | |
|---|---|---|---|---|
| | Mean score | Std. Dev. | Mean score | Std. Dev. |
| Concepts | 16.9 | 8.3 | 27 | 7.8 |
| Relationships | 6.4 | 4.9 | 19.6* | 8.9 |
| Examples | 5.4 | 4.7 | 1.9 | 4.9 |
| **Concept Subtotal[a]** | **36** | **10.7** | **48.0*** | 14.9 |
| Branching[b] | 13.9 | 5.7 | 17.5 | 5.5 |
| Hierarchies[c] | 16.4 | 5.6 | 24.3 | 7.3 |
| Crosslinks[d] | 5.7 | 11.3 | 15.7 | 22.3 |
| **Structure Subtotal[a]** | **36** | **13** | **58.2** | 23.1 |

[a]Subtotals were calculated as means of individual concept map subtotals, not by adding the mean scores for each category. [b]One point was awarded to the first branch, and three points were awarded for every subsequent branch. [c]Five points were awarded for each level of hierarchy. [d]Ten points were awarded for each crosslink (Markham & Mintzes, 1994). *$p < 0.05$

*Description of participants' epistemologies*

Many themes emerged from the qualitative analysis of both VNOS responses and concept maps. We sorted these themes into five categories: a) the goals of science; b) elements of scientific inquiry; c) elements of scientific knowledge; d) other elements unique to science; and e) elements of science teaching and learning. Frequencies of themes related to each category on the questionnaires and maps are shown in Table 5.

Table 5
*Responses to VNOS item 1 and concept map entries referencing one or more themes related to five emergent categories identified in the two instruments.*

| Category | VNOS item 1 | | Concept Maps | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Goals of science | 15 (65%) | 5 (22%) | 4 (57%) | 2 (29%) |
| Elements of scientific inquiry | 14 (61%) | 18 (78%) | 6 (86%) | 7 (100%) |
| Elements of scientific knowledge | 14 (61%) | 7 (30%) | 6 (86%) | 7 (100%) |
| Other elements unique to science | 0 (0%) | 1 (4%) | 7 (100%) | 2 (29%) |
| Elements of science teaching | 0 (0%) | 3 (13%) | 0 (0%) | 7 (100%) |

The goals of science category includes statements or concepts related to the purpose(s) of science. Many participants saw the goal(s) of science as studying the world and/or asking questions. Responses such as, "I believe science is understanding the world and what makes up the world" (20**,** pre-VNOS) were common on the first VNOS item. Themes related to scientific processes were grouped into the elements of scientific inquiry category. In this category, participants commonly referenced the roles of creativity and/or imagination, curiosity, experiments, hands-on activities, inquiry, scientific method, objectivity, observation and reasoning in generating scientific knowledge.

The category elements of scientific knowledge includes themes related to ways in which scientific knowledge is different from other types of knowledge. The most common themes in this category referenced the importance of evidence, facts, hypotheses and theories. Many pre-instruction concept maps and responses to the first VNOS item included references to evidence: "Science, in general, takes empirical evidence to support theories" (1, pre-VNOS). Several post-instruction concept maps and VNOS responses included tentativeness as a defining element of scientific knowledge: "science is different from other inquiry based disciplines because it is ever-changing and uses imagination, logic and evidence to come up with theories" (9, post-VNOS).

On many of the concept maps participants indicated miscellaneous facets of science that, to them, distinguished it from other disciplines. These themes were grouped into the category other elements unique to science. The most frequent of these were entries on the concept maps related to various science disciplines (biology, geology, etc.) and technology. Some concept maps also included references to science materials, such as test tubes or microscopes. Only one response to VNOS item one fell into the other elements category: "Science also goes hand-in-hand with math and technology" (14, post-VNOS).

The final category included themes related to science teaching and learning. Although most responses in this category were found in the concept maps, there were a few responses to VNOS item one that incorporated such ideas, for example, "Science is something that has students and those studying it investigate things through inquiry based curriculums (*sic*) that inquire rather than answer linear questions" (16, post-VNOS).

*Structure of participants' epistemologies*

In the previous section we describe the evidence related to the quality and descriptions of participants' epistemologies as assessed through the VNOS questionnaire and the concept maps. Here, we describe evidence related to the structure of the participants' epistemologies.

*Concept maps.* The number of branches, hierarchies and crosslinks found in each concept map are reflective of the degree of knowledge differentiation, subsumption and integration, respectively (Markham & Mintzes, 1994). Mean scores in each category increased from pre- to post-instruction (Table 4), as did, consequently, the structure subtotal. Although none of these gains were found to be statistically significant through a Wilcoxon t-test, we observed a statistically significant ($p < 0.05$) increase in the overall mean total score from 64.7 to 106.0.

We also examined the second-level, or superordinate concepts for evidence of reconstruction of students' epistemologies (Jones & Vesilind, 1994). In all cases most of the superordinate concepts on the post-instruction concept maps were different than those on the pre-instruction maps (Table 6). The most commonly added superordinate concepts were related to teaching and learning, consistent with the descriptive data above.

Table 6
*Changes in superordinate concepts on concept maps.*

| Group | # Superordinate concepts | | Superordinate concepts lost | | Superordinate concepts gained | |
|---|---|---|---|---|---|---|
| | Pre | Post | Number | Percent | Number | Percent |
| A | 2 | 4 | 1 | 50 | 3 | 75 |
| B | 3 | 3 | 2 | 67 | 2 | 67 |
| C | 9 | 8 | 9 | 100 | 8 | 100 |
| D | 2 | 4 | 1 | 50 | 3 | 75 |
| E | 6 | 6 | 5 | 83 | 5 | 83 |
| F | 4 | 6 | 3 | 75 | 5 | 83 |
| G | 4 | 1 | 4 | 100 | 1 | 100 |

*Links between NOS tenets.* We searched both the concept maps and responses to all of the questions on the VNOS questionnaire for links between the NOS tenets assessed in this study. Only 6 links were found in the VNOS responses, all but one in post-instruction responses. Links involving some mention of evidence, which we grouped under the empirical NOS tenet, were most common in responses to the VNOS questionnaire. An example such a link is: “Inferences must be made from the evidence, and at times the evidence may be subjective” (19, post-VNOS item 6), in which the empirical NOS is linked to the theory-laden NOS.

Although links between NOS tenets on concept maps were more numerous (3 pre, 17 post) than those found in the VNOS responses, they were not as descriptive because arguments on concept maps consist only of concepts and linker terms. Group D, for example, linked the tentative and empirical NOS tenets in this sequence of concepts and linkers (linker words underlined): “Changing of theories <u>through</u> inquiry <u>demands</u> evidence” (post-concept map).

*Links between NOS tenets and ideas related to teaching science.* The introduction of concepts related to teaching and learning on all of the post-instruction concept maps provided the opportunity to analyze how the participants’ epistemologies were connected to their notions of teaching and learning science. We therefore searched each post-instruction concept map for connections to concepts related to the tenets assessed with the VNOS questionnaire. Three (43%) of the post-instruction concept maps included such connections. Two of these maps included the idea of bias, which was interpreted to be related to the theory-laden nature of science, whether or not the use of this term represented an informed view of this tenet. Group A included the concept “teaching own biases,” on their post-instruction maps. Group C connected the idea of tentativeness to inquiry-based education on their post-instruction map: “Views on nature of science <u>includes</u> education <u>with</u> inquiry [which] <u>leads to</u> changing theories.” Other links were made between science education, evidence and creativity.

We compared participants’ ideas about teaching and learning from the concept maps to those from their responses to the VNOS questionnaire. Only three (13%) participants connected ideas related to teaching and learning science to NOS tenets in their responses to the first VNOS item. One participant referenced the empirical nature of science as an important element in a student’s experience: “Students should be allowed to experiment with many things throughout their ‘scientific’ career, and be allowed to explore evidence on their own rather than always being told by the teacher what is right and wrong” (15, post-VNOS item 2). The idea of bias, interpreted as a facet of the theory-laden nature of science, was cited with reference to teaching by one participant: “Educationally I have found that your opinions of science will be imposed upon the students that you teach. The biases and opinions of every concept will be instilled in the students, including their scientific curiosity” (18, post-instruction VNOS item 5). Finally, one participant expressed the importance of creativity in teaching science: “It is important for teachers to foster imagination and creativity in their students. Students should think of science as fun and exciting, not boring and dogmatic” (17, post-VNOS item 7).

## Discussion

The aim of this study was to compare the types of information about students' epistemologies that can be gained using concept maps versus the open-ended VNOS questionnaire, and to assess the strengths and weaknesses of each instrument. To this end, we compared epistemological views of 23 preservice elementary teachers on concept maps to their responses to the VNOS questionnaire before and after instruction in the nature of science. We analyzed the data from both instruments according to three basic considerations: a) quality, b) description and c) structure of participants' epistemologies.

### *Quality of Participants' Epistemologies*

We observed modest gains in the number of informed codes on five of the six NOS tenets assessed on the VNOS. Although none were statistically significant, the concurrent gains in five of the tenets provides initial evidence that participants' epistemologies increased in sophistication. Lack of large gains is consistent with other studies that suggest it is difficult to change students' epistemologies in one course (e.g. (V. Akerson, Morrison, J. and McDuffie, A., 2006)), especially when NOS is not the only focus of a course, as was the case in this study.

Our case-study of Phoebe illustrates another level of normative analysis that is possible with VNOS responses. The set of questions on the VNOS were designed to give a more holistic profile of an individual's epistemology than can be gained through forced-choice instruments (Lederman et al., 2002). We were able to see, for example, that Phoebe's changing ideas about the nature of science hinged upon knowledge about experiments and correlational studies, as well as the ways in which culture and science influence each other, both on a personal level (the individual scientist) and a societal level (theories influencing culture).

The concept maps gave us valuable information about the quality of the participants' epistemologies, but the nature of this information was different from the VNOS responses. We observed a statistically significant gain in the mean concept subtotal score from the concept maps, the main component of which was the number of valid relationships between concepts. Linking words enable students to form propositions or arguments from their chains of concepts (Joseph D. Novak, 1984). Because the number of valid links increased more than the number of concepts or examples (examples, in fact, decreased), we can infer that the largest change in participants' epistemologies was not in their ability to assimilate ideas about NOS piecemeal, but to form new propositions using ideas that were already part of their epistemologies.

We are cautious in comparing the quantitative results from the VNOS and concept maps because they were arrived at differently. While several different concepts and arguments may have contributed to a single VNOS code, each concept, relationship and example was counted individually on the concept maps. However, the purpose of this study was not to establish the validity of either instrument (prior studies support each instrument's validity – see, for example, Lederman et al. (2002) and Markham & Mintzes (1994)), but rather to explore the different types of information each can provide in assessing students' epistemologies of science. Both instruments can be coded in such a way as to provide a quantitative measure level of sophistication of a student's epistemology (number of informed codes on the VNOS vs. concept subtotal on the concept maps). Our data initially suggest these measures are consistent with each other, in that both revealed gains, though we cannot say with confidence that the VNOS gains reflected increased sophistication of participants' epistemologies, as they were not statistically significant. Further studies would have to be done with larger sample sizes to rigorously establish the correlation of the two instruments' quantitative measures. As illustrated by the analysis of Pheobe's responses, the VNOS may also be used to identify key ideas around which students' epistemologies seem to hinge, resulting in a more nuanced picture of the changes that take place when a student goes from a naïve to an informed epistemology. The concept maps, on the other hand, were more useful in identifying to what extent students assimilated new propositions about the nature of science (illustrated by the concepts and examples included on the maps) vs. reworking existing propositions (illustrated by the links).

*Descriptions of participants' epistemologies*

The VNOS normative codes and concept map scores were augmented with emergent themes analysis of the concept map concepts and VNOS item one responses. Of the five categories into which the emergent themes were grouped, three were related to participants' epistemological commitments: the goals of science, the nature of scientific inquiry and elements of scientific knowledge. In these first three categories there was some degree of consistency between VNOS responses and concepts on the concept maps, in that themes initially identified from one instrument were almost always observed in the other.

The two other categories into which we grouped the themes, other elements unique to science and issues of teaching and learning, were represented differently on the two instruments. Most of the pre-instruction concept maps consisted of entire branches made up of concepts we grouped into other aspects unique to science, such as lists of scientific disciplines and instrumentation. However, neither the pre- nor the post-instruction VNOS responses revealed attempts at defining science as a collection of disciplines or specialized instruments. This distinction may stem from a difference in the level of scaffolding in each task. While the concept mapping task simply required students to map their idea of science, VNOS item one more specifically probes students to think about the difference between science and other disciplines. Perhaps because of the differences in the specificity of the prompts, the concept maps, as they were used in this study, seemed to reveal the relative prominence of a students' epistemology of science in their overall conception of science as a field of study. The VNOS responses, on the other hand, seemed to give more detailed information about the epistemologies themselves.

We attributed differences in representation of themes related to the teaching and learning of science on the two instruments to differences in scaffolding as well. The instruction that occurred between implementation of both instruments was directed towards increasing pre-service teachers' knowledge of science teaching methods in addition to helping them adopt more sophisticated epistemologies. Therefore, it is reasonable to expect students' ideas about teaching methods to be incorporated into their responses to both instruments. While all of the post-instruction concept maps included themes related to teaching and learning science, only 13% of the responses to VNOS item one included such themes. As above, this evidence suggests students felt less constrained by the concept mapping activity and included ideas they may not have seen as relevant to VNOS item one.

In summary, participants used similar ideas on both instruments when describing their epistemologies. The major difference was the degree to which participants included ideas that were not necessarily part of their epistemologies. Because of the less specific nature of the concept mapping task when compared with the more probing VNOS items, we were unable to get as detailed a picture of the participants' epistemologies from their concept maps as we were with their responses to the VNOS questionnaire. However, we were able to get a broader sense for how they think about science – whether it be as a way of knowing, as a collection of disciplines, or as a subject to be learned. This is significant because whether or not a student has a sophisticated epistemology of science may not matter if the student primarily thinks about science as a collection of sub-disciplines instead of as a way of knowing or generating knowledge. Furthermore, the concept maps can lend some insight into how seemingly non-epistemological ideas such as scientific disciplines or teaching and learning practices influence or are influenced by participants' epistemologies of science. Thus, using concept maps we can learn more about how students' epistemologies influence their outlook on science as a discipline and how science should be taught and learned.

*Structure of participants' epistemologies*

Because of the proposed importance of students' cognitive structures to their ability to understand and apply knowledge (Bransford, Brown, & Cocking, 2000; Markham & Mintzes, 1994), we took several measures of cognitive structure on both the concept maps and the VNOS responses. The degree of branching, number of hierarchies and number of crosslinks factored into the structure subtotal on the concept maps. This subtotal increased for six of the seven post-instruction maps when compared to the pre-instruction maps. The concurrent increases in the structure and concept subtotals support the theory that as the sophistication of a student's understanding increases, so too does the complexity of the structure of his or her understanding (Markham & Mintzes, 1994). The largest gain from the structure sub-categories was in the number of hierarchies used. Since the number of hierarchies represent the extent of knowledge subsumption (Markham & Mintzes, 1994), we can infer that the largest structural changes in participants' epistemologies involved more clustering of specific ideas under overarching ideas, a structuring skill that seems to be positively related to an individual's degree of expertise with a topic (Miller, 1956). Furthermore, we found that 50 – 100% of the superordinate concepts on the post-instruction concept maps were different from those on the pre-instruction maps. Therefore, we conclude that the higher degree of structure on the post-instruction concept maps is indicative of a reorganization of the participants' epistemologies, rather than added levels of organization to an existing core structure (Jones & Vesilind, 1994).

Because none of the structure gains were statistically significant, we cannot dismiss the possibility that these gains were due to chance. The small sample size for the concept maps made it difficult to establish statistical significance, and further studies with individual concept maps are recommended. However, we are able to get a picture for the type of information the concept maps can reveal about students' epistemologies and how that information can be used to supplement VNOS analysis. Concept maps are unique among assessment tools in enabling an instructor or researcher to analyze the degree and type of a students' cognitive reorganization, information which we expect to be helpful in addressing questions related to the process by which students' epistemologies of science change.

In order to gain more descriptive information about some of the structural features of participants' epistemologies, we investigated two different types of connections on participants' concept maps and in their VNOS responses. First, we searched both instruments for connections between the six NOS tenets assessed in this study. Second, we searched both instruments for connections between epistemological ideas and issues related to the teaching and learning of science. Both types of links were found on both instruments to increase after instruction, suggesting students were more able to see interdependencies among the NOS tenets and to integrate these tenets into their conceptions of teaching science as a result of instruction. The increase in NOS-teaching links may have been due to increasingly sophisticated epistemologies, knowledge of teaching practices, and/or the links between them as a result of instruction. We cannot, from our evidence, make a causal claim about this increase. We found that both types of connections were more common on the concept maps than they were in responses to the VNOS questionnaire. This did not surprise us, since concept maps are designed to show links between concepts. However, because participants were limited to linker words in expressing the logic behind their linkages in the concept maps, these were often less informative than connections found in the VNOS responses. Thus, while the concept maps in this case gave us a snapshot of the types of connections students made, the VNOS responses, though fewer, helped us to better understand the nature of some of these connections.

*Limitations of this study and suggestions for future research*

One limitation of this study is that we did not interview the groups about their concept maps. We recognize some of the concepts and relationships expressed on the concept maps would have been better understood by the researchers if students were asked to explain their concepts and links in an open-ended way. However, we also recognize limitations posed by time and class size make it difficult for some teachers to interview students about concept maps they create. Thus, our findings can shed light on the strengths and weaknesses of concept maps as an assessment tool for epistemologies of science in an authentic classroom context.

Another limitation is that while students answered the VNOS items individually, they participated in the concept mapping activity in groups. Because we cannot be sure to what extent each individual's views were represented on the concept maps, we were unable to do pairwise comparisons. We would therefore suggest that a future study include individual concept mapping exercises, so that such comparisons can be done.

A final limitation is that any time two or more instruments are used on the same sample, there is a chance that one of the instruments could be acting as a treatment in addition to its role as an assessment tool. Indeed, research has suggested concept mapping can be used as a learning tool as well as an assessment instrument (Joseph D. Novak, 1998; Prezler, 2004). Such a treatment effect could be responsible for some of the similarities between responses to the two instruments that were cited above, especially considering that they were administered within a week of each other both before and after instruction. However, we did uncover some important differences between the two instruments, such as the prevalence of concepts related to science disciplines on the concept maps compared with their absence on the VNOS, so we believe this treatment effect was minimal. The extent to which concept maps can help students develop their epistemologies of science is nonetheless a rich topic for further exploration.

## Conclusion

Because of the small sample size used in this study we are careful not to generalize our findings to a larger population of preservice teachers. Instead, we wish to use these findings to suggest potential roles for concept mapping in assessing students' epistemologies of science. One important finding from this study is that the concept maps, while giving us less specific information about facets of students' epistemologies of science (their ideas about the nature of scientific knowledge) compared to the VNOS, gave us information about how those epistemologies were situated within their overall ideas about science. One potential hybrid use of the two instruments would therefore be to use concept maps to probe students' initial conceptions of science without leading them too much into a certain framework of thinking about science. The VNOS can then be used as a follow-up tool, either as a written questionnaire, an interview, or both, to provide more information about the quality of students' epistemologies.

We also found that because of the less structured nature of the concept mapping probe, students more often included their ideas about teaching and learning science on their concept maps then they did in their VNOS responses. Concept maps can therefore be used in methods courses to probe how preservice teachers' epistemologies of science relate to their ideas about teaching science. Such an approach would be especially powerful if the preservice teachers were interviewed about the nature of the links between epistemology concepts and teaching concepts.

Finally, we found that the concept maps provided useful information about the structure of participants' epistemologies that the VNOS questionnaire did not. To what extent the participants' epistemological ideas were integrated, differentiated and/or subsumed under other concepts can be much more easily accessed through concept maps than through written responses to a questionnaire. Furthermore, the superordinate concepts can be used to assess the extent of a student's cognitive reorganization, which in this case is related to reorganization of his or her epistemology. Although students' responses on the VNOS didn't provide such detailed structural information, they did provide a richer, more detailed look at their epistemologies. Thus, concept maps, as used in this study, gave detailed information about the types of structural changes in a student's epistemology while the VNOS responses gave us more insight into the nature of those changes. Both instruments revealed important strengths and weaknesses and, when combined, can provide a powerful assessment of students' epistemologies.

References

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans*. New York: Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

Abd-El-Khalick, F. (2001). *Embedding nature of science instruction in preservice elementary science courses: Abandoning scientism but. . .* Journal of Science Teacher Education, 12(3), 215-233.

Abd-El-Khalick, F. (2005). *Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning*. International Journal of Science Education, 21(1), 15-42.

Abd-El-Khalick, F., & Akerson, V. L. (2004). *Learning about nature of science as conceptual change: Factors that mediate the development of preservice elementary teachers' views of nature of science*. Science Education, 88(5), 785-810.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). *The nature of science and instructional practice: Making the unnatural natural*. Science Education, 37(6), 563-581.

Abd-El-Khalick, F., & Lederman, N. G. (2000). *Improving science teachers' conceptions of nature of science: A critical review of the literature*. International Journal of Science Education, 22(7), 665-701.

Akerson, V., Morrison, J. and McDuffie, A. (2006). *One Course is Not Enough: Preservice Elementary Teachers' Retention of Improved Views of nature of Science*. Journal of Research in Science Teaching, 43(2), 194-213.

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2007). *Early childhood teachers' views of nature of science: The influence of intellectual levels, cultural values, and explicit reflective teaching*. Journal of Research in Science Teaching, 45(6), 748-770.

Billeh, V. Y., & Hasan, O. E. (1975). *Factors influencing teachers' gain in understanding the nature of science*. Journal of Research in Science Teaching, 12, 209-219.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How People Learn: Brain, Mind, Experience, and School*. Washington, D.C.: National Academy Press.

Carey, S. (1987). *Conceptual change in childhood*. Cambridge, MA: MIT Press.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). *'An experiment is when you try it and see if it works': A study of grade 7 students' understanding of the construction of scientific knowledge*. International Journal of Science Education, 11, 514-529.

Cooley, W., & Klopfer, L. (1961). *Test on understanding science (Form W)*. Princeton, NJ: Educational Testing Service.

Cotham, J., & Smith, E. (1981). *Development and validation of the conceptions of scientific theories test*. Journal of Research in Science Teaching, 18, 387-396.

Edmondson. (2000). *Assessing science understanding through concept maps*. In Assessing Science Understanding: Academic press.

Elby, A. (2001). *Helping physics students learn how to learn*. Physics Education Research, 69(7), S54-S64.

Hofer, B. K., & Pintrich, P. R. (1997). *The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning*. Review of Educational Research, 67(1), 88-140.

Jones, M. G., & Vesilind, E. (1994, April 4-8). *Changes in the structure of pedagogical knowledge of middle school preservice teachers*. Paper presented at the International Meeting of the American Educational Research Association (AERA), New Orleans.

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. (1998). *The nature of science in science education: Rationales and strategies*. The Netherlands: Kluwer Academic Publishers.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). *Views of Nature of Science Questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science*. Journal of Research in Science Teaching, 39, 497-521.

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

Liu, X. (2004). *Using concept mapping for assessing and promoting relational conceptual change in science*. Science Education, 88(3), 373-396.

Markham, K., & Mintzes, J. J. (1994). *The concept map as a research and evaluation tool: Further evidence of validity*. Journal of Research in Science Teaching, 31(1), 91-101.

Meichtry, Y. J. (1993). *The impact of science curricula on student views about the nature of science*. Journal of Research in Science Teaching, 30(5), 429-443.

Miller, G. A. (1956). *The magical number seven, plus or minus two. Some limits on our capacity to process information*. Psychological Review, 63, 81-87.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (2001). *Assessing understanding in biology*. Journal of Biological Education, 35(3), 118-124.

National Research Council (1996). *National Science Education Standards*. Washington DC: National Academy Press.

Novak, J. D. (1984). *Application of advances in learning theory and philosophy of science to the improvement of chemistry teaching*. Journal of Chemical Education, 61(7), 607-612.

Novak, J. D. (1998). *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. Mahwah, N.J.: Lawrence Erlbaum Associates.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York: Cambridge University Press.

Perry, W. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart & Winston.

Prezler, R. (2004). *Cooperative conept mapping*. Journal of College Science Teaching, 33(6), 30-35.

Rummelhart, D., & Norman, D. (1978). *Accretion, tuning and restructuring: Three modes of learning*. In Cotton, J. & Klateky, R. (Eds.), Semantic factors in congnition (pp. 37-53). Hillsdale, NJ: Erlbaum.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). *Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry*. Science Teacher Education, 88(4), 610-645.

Smith, C. L., & Wenk, L. (2006). *Relations among three aspects of first-year college students' epistemologies of science*. Journal of Research in Science Teaching, 43(8), 747-785.

Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). *How great is the disagreement about the nature of science? A response to Alters*. Journal of Research in Science Teaching, 34, 1101-1104.

Southerland, S. A., Johnston, A., Sowell, S., & Settlage, J. (2005). *Reinvoking conceptual ecologies: Inservice teachers' conceptual change in nature of science*. Paper presented at the International meeting of the National Association for Research in Science Teaching (NARST), Dallas, TX.

Spector, B., Strong, P., & La Porta, T. (1998). *Teaching the nature of science as an element of science, technology and society*. In McComas, W. F. (Ed.), The Nature of Science in Science Education: Rationales and Strategies (pp. 267-276). Dordrecht: Kluwer Academic Publishers.

Strauss, A., & Corbin, J. (1998). *Basics of Qualitative Research* (2 ed.). Thousand Oaks, CA: SAGE Publications, Inc.