Assessing preservice elementary teachers' views on the nature of scientific knowledge: A dual-response instrument

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Contents

Abstract

This paper presents the development and revision of a dual-response instrument entitled, "*Student Understanding of Science and Scientific Inquiry* (SUSSI)." Built on the most recent science education reform documents and existing literature on the nature of science, SUSSI blends Likert-type items and related open-ended questions to assess students' views on the nature of scientific knowledge development in terms of six aspects: observations and inferences, tentativeness, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods. This combined quantitative and qualitative approach is a form of triangulation, which can increase confidence in the findings and help us obtain a fuller understanding of the respondents' views on the nature of scientific knowledge.

Introduction

According to the existing literature, understanding of the nature of science (NOS) as one of the goals of science instruction in the USA can at least be traced to the beginning of the 20th century (Central Association of Science and Mathematics Teachers, 1907). In the most recent science education reform movements, scientific inquiry and NOS have again been identified as critical elements for developing scientific literacy of all learners at K-16 levels (American Association for the Advancement of Science, 1993; National Research Council, 1996). However, NOS studies consistently show that neither students nor schoolteachers have adequate understanding about how science research is conducted or how scientific knowledge develops (e.g., Aikenhead 1987; Cooley & Klopfer, 1963; Lederman, 1992; Rubba & Anderson, 1978; Abd-El-Khalick & Lederman, 2000a, 2000b). This has concerned science educators, curriculum developers, and science education researchers at both national and international levels. Furthermore, the assessment of learners' NOS views remains an issue in research. A valid and meaningful instrument, which can be used as either a summative or formative assessment tool in small and/or large scale studies, is needed to track learners' growth and promote evidence-based practice in the learning and teaching of science. This has led to the development of the SUSSI instrument. It is envisioned that SUSSI can create a shared frame of reference for discussing issues related to learning and teaching the nature of scientific knowledge development.

Relevant Research on the Nature of Science and Assessment Tools

Learning and Teaching of the Nature of Science in School

In the science education literature, NOS typically refers to the epistemology and sociology of science, or the values and beliefs inherent in scientific knowledge and its development (Lederman, 1992; Ryan & Aikenhead, 1992). Whereas there are still many disagreements about NOS among philosophers, historians, sociologists and science educators, research has shown that consensus does exist regarding the basic aspects of NOS most relevant to school science curricula (e.g., McComas & Olson, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). For instance, Osborne et al. (2003) conducted a Delphi study to determine the extent of consensus on teaching NOS topics in school as perceived by a group of acknowledged international experts including science educators, scientists, historians, philosophers, and sociologists of science. This expert community reached a consensus on the following NOS themes: Scientific Methods and Critical Testing, Creativity, Historical Development of Scientific Knowledge, Science and Questioning, Diversity of Scientific Thinking, Analysis and Interpretation of Data, Science and Certainty, and Hypothesis and Prediction. The ninth theme of consensus was on "Cooperation and Collaboration," although it was found to be less stable than the others. Moreover, in an analysis completed by McComas and Olson (1998), similar themes are also consistently highlighted in the national science curriculum standards documents from different countries.

In light of the abovementioned studies, we chose to focus our research on the following essential, non-controversial components of the nature of scientific knowledge development (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). These aspects have been emphasized in the aforementioned science education reform documents, and have been widely discussed in the NOS empirical studies (e.g., AAAS, 1990, 1993; Aikenhead & Ryan, 1992; Chen, 2006; Kuhn, 1970; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman, 2004; McComas & Olson, 1998; National Science Teachers Association, 2000):

- Tentativeness of Scientific Knowledge: Scientific knowledge is both tentative and durable. Scientific knowledge is reliable; however, it may be abandoned or modified in light of new evidence or reconceptualization of existing evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.

- Observations and Inferences: Science is based on both observations and inferences. Both observations and inferences are guided by scientists' prior knowledge and perspectives of current science. Multiple perspectives can lead to multiple valid inferences.

- Subjectivity and Objectivity in Science: Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher's personal factors and social background.

- Creativity and Rationality in Science: Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world. Scientists use their imagination and creativity throughout their scientific investigations.

- Social and Cultural Embeddedness in Science: Science is part of social and cultural traditions. People from all cultures contribute to science. As a human endeavor, science is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.

- Scientific Theories and Laws: Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws.

- Scientific Methods: There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is constructed and developed in a variety of ways including observation, analysis, speculation, library investigation and experimentation.

Assessment of the Nature of Science

In the last decades, both quantitative and qualitative questionnaires have been developed and used in conducting NOS related research. Examples of traditional quantitative instruments include the Test on Understanding Science (Cooley & Klopfer, 1961), Science Process Inventory (Welch, 1966), Nature of Science Scale (Kimball, 1967), Nature of Scientific Knowledge Scale (Rubba, 1977), and Modified Nature of Scientific Knowledge Scale (Meichtry, 1992). These instruments contain multiple-choice or Likert-type questionnaires and were usually written from perspectives of experts. Jungwirth (1974) and Alters (1997) criticized that those experts did not adequately represent perspectives of scientists, philosophers, and science educators. Moreover, items on these instruments often assumed that all scientists had the same view and behaved in the same way. Views of NOS in these instruments were oversimplified and over generalized.

Furthermore, traditional instruments were developed based on an assumption that students perceive and interpret the statements in the same way as researchers do. However, research has indicated that students and researchers used language differently and this mismatch has almost certainly led to misinterpretation of students' views of NOS in the past (Lederman & O'Malley, 1990). Aikenhead, Fleming, and Ryan (1987) also found that students may agree upon a statement for very different reasons. Therefore, traditional instruments often failed to detect the respondents' perceptions and interpretations of the test items. It was suggested that empirically derived, multiple-choice responses could reduce the ambiguity to a level between 15% and 20% (Aikenhead, 1988). Accordingly, Aikenhead and Ryan (1992) developed an instrument entitled the Views on Science-Technology-Society (VOSTS) over a six-year period. They analyzed 50 to 70 paragraphs written by Canadian students (grades 11-12) in response to two statements representing both sides of an NOS issue, to ensure that all VOSTS items represent common viewpoints possessed by students. Furthermore, "VOSTS items focus on the reasons that students give to justify an opinion" (p.480). The reasons underlying the students' choices of items are particularly meaningful for teachers to make informed decisions in teaching and for researchers to interpret students' beliefs appropriately. Nevertheless, several problems were found with the use of VOSTS. For instance, some VOSTS items appeared redundant, and/or had ambiguous positions and overlapping meanings (Chen, 2006). Researchers also pointed out that respondents might have combinations of views that would not be reflected in the multiple-choice format (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Abd-El-Khalick & BouJaoude, 1997; Chen, 2006). This particular problem may be resolved by using the Likert scale and scoring model proposed for the use of VOSTS by Vazquez-Alonso and Manassero-Mas (1999). Their proposed scale and scoring scheme allow researchers to draw maximum information of the VOSTS items because respondents circle their views on all items, and create data that can be applied to inferential statistics.

Most recently, two multi-dimensional NOS assessment tools were developed by Tsai and Liu (2005), and Chen (2006), respectively. Tsai and Liu's instrument, using a 5-point Likert scale, was designed for assessing high school students' epistemological views of science (SEVs). The development of SEVs was based on both the existing literature and interview data collected by the researchers. The SEVs instrument consists of five subscales: the role of social negotiation in science, the invented and creative reality of science, the theory-laden exploration of science, the cultural impact on science, and the changing features of science. Chen (2006) also reported the development of a NOS assessment tool, the Views on Science and Education Questionnaire (VOSE), built on selected VOSTS items by incorporating a 5-point Likert scale. Chen modified and clarified certain ambiguous VOSTS statements based on the interviews of both American and Taiwanese preservice secondary science teachers. The latest version of VOSE was administered to 302 college students majoring either in natural science or language arts at two research universities in Taiwan. Both instruments demonstrated satisfactory validity and reliability when tested with samples in Taiwan.

Currently, the most influential NOS assessment tools on views of NOS perhaps are the Views of Nature of Science questionnaires (VNOS), developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). There are several forms of VNOS (e.g., Form A, B, C, D). With certain variations in length and complexity of language used in the questionnaires, all VNOS instruments consist of open- ended questions accompanied by follow-up interviews. For instance, the VNOS C is composed of 10 free-response questions and takes 45-60 minutes for undergraduate and graduate college students to complete the survey. This presents a challenging task to respondents with limited knowledge of NOS and writing skills**.** Most often, students who are not equipped to fully express their own ideas in an open-ended format tend to respond in a few words or simply leave several items blank. This limits the potential of using VNOS instruments alone as either formative classroom assessment forms or accurate research tools. Other supplementary research methods such as follow-up interviews are necessary to clarify the participants' beliefs.

In summary, significant efforts have been made to modify and/or develop instruments aimed at increasing validity and minimizing the chance of mis-interpretation of respondents' perceptions over the past four decades. It appeared that the open-ended questionnaires accompanied interviews would yield valid and meaningful assessment outcomes. However, it may not appropriate as a standardized tool in large-scale assessments. On the other hand, previous research suggested that empirically derived assessment tools would significantly reduce the ambiguity caused by the problem of language. We therefore have developed the SUSSI instrument, by combining both quantitative and qualitative approaches to assess students' views about how scientific knowledge develops.

Methodology

Student Understanding of Science and Scientific Inquiry (SUSSI) was developed to evaluate NOS views of preservice teachers. SUSSI was based on the conceptual framework presented in the NOS literature, and the most current national science education reform documents. The procedure for validating SUSSI consisted of four phases: (1) Selection of standards- and literature-based NOS items, (2) Pilot test and interviews, (3) Expert review and field test, and (4) Further revision and field test.

Phase I - Selection of standards- and literature-based NOS items.

Target ideas germane to NOS were gathered from the national and international Standards documents (e.g., AAAS, 1993; NRC, 1996; McComas & Olson, 1998), and three existing NOS instruments, VOSTS (Aikenhead & Ryan, 1992), VNOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and VOSE (Chen, 2006). The target NOS ideas reflected tentativeness, empirical basis, observations and inferences, creativity and imagination, social and cultural embeddedness, scientific theories and laws, and multiple methods of scientific investigations. The NOS ideas were modified into 58 Likert scale items and 10 open-ended questions. The items and questions were developed based on empirically derived instruments such as VOSTS, VOSE and students' responses on VNOS. Following is one of the questions with five Likert items and an open-ended question.

Question 6. Do you think that scientists *discover* scientific theories (e.g. atomic theory) just like gold miners discover gold, or that scientists *invent* scientific theories somewhat like artists invent sculptures?

A. Scientists <u>discover</u> theories that are embedded in nature.

B. Scientists <u>discover</u> theories from experimental facts.

C. Some scientists may <u>discover</u> theories by chance, but other scientists may <u>invent</u> theories from facts they already know.

D. Scientific theories were <u>invented</u> by scientists to explain the observed or perceived natural phenomena.

E. Scientific theories were <u>invented</u> and tested by scientists.

Please ***explain*** the difference between discovering scientific theories and inventing scientific theories. If you can, please use an example to illustrate your idea.

Phase II - Pilot test and interviews.

Between the summer and the fall semester of 2004, SUSSI was pilot-tested with 40 American preservice elementary teachers. In addition, 20 preservice elementary teachers were interviewed. The interview data were used to further modify certain Likert statements and translation phrases. For instance, in the sample question (No. 6) shown above, participants tended to select the choice of "agree" or "strongly agree" when responding to the statements 6A (Scientists <u>discover</u> theories that are embedded in nature) and 6B (Scientists <u>discover</u> theories from experimental facts). During the interviews, however, it was found that the preservice teachers did not necessarily all fail to recognize the invented and creative nature of scientific knowledge. Some of them did not read the focus question (or the heading statement) where the term "discover" was defined. They chose "agree" or "strongly agree" mainly because they were familiar with the phrase "scientific discovery" frequently used in everyday language. Therefore, in the revised version, the original statements 6A and 6B were replaced with "Scientific theories exist in the natural world and are uncovered through scientific investigations."

Phase III - Expert review and field test.

The revised SUSSI was reviewed by an expert panel of nine international science educators who are currently engaged in either NOS research or teaching. The panel's comments and suggestions for improvement were used to modify the items. In 2005, the revised SUSSI was administered again to 60 American undergraduate students. The administration time was about 30 - 40 minutes.

To analyze the Likert items, a taxonomy of views about NOS was created based on the existing literature. All 58 Likert items were classified into two groups: positive or negative items. The statements marked as '+' represented views consistent with the current National and International Science Education Reform documents, whereas the items with '-' signs represented common student naïve understandings of NOS that are not consistent with the Standards documents (Appendix B). For each of the 'positive' Likert items, student responses were assigned with numbers ranging from one to five (from 'strongly disagree= 1' to 'strongly agree=5'). The scores were assigned in a reverse order for each 'negative' Likert item. Meanwhile, a scoring guide for independently analyzing students' constructed responses to the open-ended questions in the SUSSI was also developed. The rubric was used to analyze the consistency between the students' responses to the Likert items and their constructed responses (see Table 1 for example). Student responses to each Likert item were rated as "Consistent" (C) or "Not Consistent" (NC) with constructed responses to each associated open-ended question. A code "NA" was assigned when student-constructed responses did not address any content related to the examined Likert item. Likert items in SUSSI that were identified as "Not Consistent" were removed and/or modified. Finally, the overall structure of the SUSSI and certain items were modified to enhance clarity and readability (Appendix A).

Phase IV - Further revision and field test.

The current SUSSI targeted six NOS themes: Observations and Inferences, Tentative Nature of Scientific Theories, Scientific Laws vs. Theories, Social and Cultural Influence on Science, Imagination and Creativity in Scientific Investigations, and Methodology in Scientific Investigations. Each theme consists of four Likert items, involving both the most common naïve ideas and informed views, and an open-ended question (Appendix A).

During the data analysis phase, the taxonomy created earlier was used again for classification of the 24 Likert items, and a new scoring guide was developed for analyzing students' constructed responses to the open-ended questions associated with each of the six themes (see Table 1). Student responses on at least five completed surveys were first coded by three members of the research team, and an average inter-rater reliability higher than 80% was achieved. The coding of the remaining responses was completed by two research team members using the common rubric.

Table 1: *Sample SUSSI Scoring Guide for Evaluation of Constructed Responses*

Not Classifiable (NC)	Naïve View (1)	Informed View (3)
There is no response; they state that they do not know; the response does not address the prompt; **OR** the response cannot be classified based on the rubric descriptions.	Scientists observations **and/or** interpretations are the same no matter which scientist observes or interprets because scientists are objective or because observations are facts.	Scientists observations **and** interpretations may be different because of their prior knowledge, personal perspectives, or beliefs.
OR		
	The response includes contradictions of basic assumptions concerning the nature of science or self-contradicting statements.	

Sample

This study adopted a convenience sampling technique, and involved 209 preservice elementary teachers who were enrolled at two American universities, one in a rural area and the other in an urban area. The participants were either majoring in elementary education (K-6) or had dual majors in elementary (K-6) and special education (K-12).

Results and Discussion

Both validity and reliability are important indicators of the quality of any quantitative instrument. However, due to the empirical components involved in the development of SUSSI, the conventional concepts of validity and reliability may not apply well (Aikenhead & Ryan, 1992; Rubba, Schoneweg Bradford, & Harkness, 1996) because an empirically based instrument is developed from a qualitative perspective which focuses more on credibility, trustworthiness and authenticity of data (Erlandson, Harris, Skipper, & Allen, 1993) than on consistency across constructs and measurements. Therefore, both quantitative and qualitative internal validity and reliability issues were examined in this study.

Validity. The face validity and content validity were evaluated by a panel of nine experts (seven science educators and two scientists) who were teaching NOS and/or who were knowledgeable about NOS-related research. The agreement level of each Likert scale item was between 78% and 100%. Credibility, trustworthiness, and authenticity of SUSSI were achieved by modifying existing items drawn from empirical studies and literature, and by analyzing the data from multiple sources, i.e., the participants' selected responses to the Likert items, the participants' constructed responses to the open-ended questions, and follow-up interviews. In the current study, we will focus our report on the data analysis results based on the participants' selected and constructed responses.

By reviewing the completed survey forms, we found that the participants did not provide their constructed responses to all open-ended questions. To code the data, we first randomly assigned each of the American respondents' surveys a numerical number between 1 and 209. Then we scored the first 60 constructed responses by each theme, using the scoring guide described in the Methods section (Table 1). The selection of 60 constructed responses for each theme appeared to be sufficient in our case, as no completely new explanations or examples emerged after about 50 constructed responses were analyzed. For the Likert scale items, the respondents' views were classified as Naïve Views if none of the four responses received a score > 3 within each theme; the respondents' views were classified as Informed Views if all four responses received a score >3 within each theme. Finally, the percentage of the "naïve/informed" views based on the analysis of the participants' responses to the Likert items was compared with those based on the analysis of the open-ended questions, by theme.

It was found that three items (3D, 6A, and 6D) in SUSSI yielded results not supported by the constructed responses. First, 3D states that "Scientific theories explain scientific laws". About 47% of the respondents chose to "agree/strongly agree" with the statement. However, none of the participants mentioned or explained such a relationship in their constructed response section. This lack of understanding was confirmed during the follow-up interviews. When asked about why they thought that "scientific theories explain scientific laws," the interviewees often replied "I do not know." In addition, 33% of the participants responded "uncertain" to this statement. This level of uncertainty was the highest among all of the 24 Likert scale items. This suggested that this item should either be modified or removed. Secondly, for 6A and 6D, about 91% of respondents agreed that scientists use a variety of methods to produce fruitful results (6A), and 83% of participants agreed that experiments are not the only means used in the development of scientific knowledge (6D). However, a closer examination of the participants' constructed responses in the open-ended sections revealed that a number of the respondents equated the term "different methods" with different steps within the scientific method, or with different experiments. Moreover, very few respondents were able to provide valid examples of different types of scientific methods. For instance, one preservice teacher agreed with both Likert statements 6A and 6D. However, when asked to explain whether scientists follow a single, universal scientific method, the same student responded that "for most experiments I do think that all scientists use the scientific method because it is the way you are supposed to conduct experiments." No evidence indicated that this student was aware of any alternative types of methods in addition to experimentation, or the scientific method. We therefore proposed to remove the item 6D and modify the item 6A to "scientists use different types of methods to conduct scientific investigations" (see Appendix A). Table 2 presents the comparison of the participants' responses to the Likert items and open-ended questions by theme, excluding the three items discussed above.

Table 2: *Comparison of the American Preservice Teachers Responses to the Likert Items and Open-Ended Questions by Theme*

Target Aspect	Naïve Views (%)		Informed Views (%)	
	LR*	CR**	LR	CR
Observations and Inferences [1A-D]	2	3	35	35
Tentativeness [2A-D]	0	3	40	5
Scientific theories and laws [3A-C]	90	98	0	0
Social and cultural embeddedness [4A-D]	5	8	21	7
Creativity and Imagination [5A-D]	48	42	15	10
Scientific methods [6B-C]	30	33	13	14

Note: *LR = Responses to the Likert items; **CR=Constructed responses to the open-ended questions. The percentage was calculated based on 60 responses per theme.

For the Likert items, the student views were classified as Naïve Views if none of the four responses received a score > 3 within each theme; the student views were classified as Informed Views if all four responses received a score >3 within each theme.

The constructed responses to the open-ended questions were classified according to the rubric described in the methodology section and Table 1.

By reviewing the data presented in Table 2, for those classified as "naïve views," high levels of agreement between the responses to the two different types of items by each theme were consistently demonstrated. For those classified as "informed views," it was found that the percentage of informed views of responses in the constructed section was lower than that in the Likert responses section. This was partially due to the fact that most constructed responses were too brief to fully answer the open-ended questions. In addition, identified slight mismatches between the Likert items and the open-ended question in certain themes might also have contributed to the observed discrepancies. For instance, within the "tentativeness" theme, while the Likert items addressed both the evolutionary and revolutionary aspects of the tentative nature of scientific theories, in the open-ended section participants were asked to explain why they thought scientific theories change or do not change. Therefore many respondents answered whether or not they thought theories would change, without mentioning the nature of the change (i.e., cumulative, on-going modifications and/or replacement of old theories with new ones). According to our scoring rubric, for a constructed response to be classified as an "informed view," the student was expected to explain both whether and how theories may be changed, i.e., evolutionary and revolutionary/reinterpretation aspects. We therefore proposed to modify the open-ended question by asking respondents why they think scientific theories do not change, or how (in what ways) scientific theories may be changed (see Appendix A).

Reliability. When we selected the six target aspects of NOS in our study, we anticipated that these aspects were not independent, but were in fact inter-related. In the Delphi study conducted by Osborne et al. (2003), nine themes emerged from the participating experts' comments. The authors also confirmed that many participating experts felt that some of the NOS ideas were intertwined and not resolvable into separate propositions. In Tsai and Liu's (2005) study, five subscales were identified in an exploratory factor analysis. Meanwhile, the correlation analysis also revealed that several factors are significantly correlated to each other.

Our study further confirmed the interdependency between certain NOS aspects. An examination of Table 3 revealed that the preservice teachers' understanding of the "observation and inference" (theory-laden NOS) aspect was correlated with their views of the "tentative," the "social and cultural embedded" nature of science, and methodology of science. This suggests that the respondents who possess informed views of the theory-laden NOS were more likely to recognize the tentativeness, methodology of scientific investigations, and social/cultural influences on the development of scientific knowledge. This seems plausible because if someone understands that the development of scientific knowledge depends on both observations and inferences, and that perspectives of current science and the scientist guide both observations and inferences, then it would become more natural to recognize that multiple perspectives may contribute to valid multiple interpretations of observations, and that scientists may use different methods to conduct scientific investigations. Moreover, scientific theories/laws may therefore change in light of new observations/interpretations and be influenced by social and cultural factors.

In our study, we calculated the overall Cronbach alpha for the entire instrument ($\alpha = 0.69$), the Cronbach alpha values for each subscale, and the correlation coefficients among the subscales (Table 3). According to Hatcher and Stepanski (1994), for social studies, a Cronbach alpha as low as 0.55 can still be recognized and accepted for statistical consideration. Considering there is only a small number of items in each subscale, the results indicate that SUSSI achieved a satisfactory level of internal consistency. According to Table 2, the percentage of respondents who demonstrated informed views on all Likert statements within the theme of "scientific theories and laws" was zero. Likewise, no constructed responses were classified as "informed" views according to the scoring guide. Among the NOS themes under study, the participants showed the highest level of misunderstanding and confusion about the nature of scientific theories and laws. This result is not very surprising and is consistent with what was reported in the literature (McComas, 1998). In Table 3, it was also found that the subscale alpha values for the themes of "theories and laws" and "scientific methods" appeared lower than those for the other themes, and the participants' responses to these two themes were significantly correlated ($r=0.61$, $p<0.01$). However, we decided to keep those items because of the demonstrated high consistency between the Likert and the open-ended responses as presented in Table 2, and because both aspects represented the two most widely held misconceptions of NOS (McComas, 1998). For instance, understanding the nature of theories is critical to the current controversy over the teaching of evolution in schools. People who reject evolution as "just a theory" are demonstrating the common misunderstanding of the nature of scientific theories. We believe that this aspect of NOS should be emphasized in science textbooks as well as in assessment.

Table 3: *Cronbach Alpha Values for Each Subscale and the Correlations among the Subscales of SUSSI* (n=209, overall α = 0.69)

SUSSI Aspects	Observations and Inferences	Tentativeness	Scientific theories and laws	Social and cultural embeddedness	Creativity and Imagination	Scientific methods
	(1A, 1B, 1C, 1D)	(2A, 2B, 2C, 2D)	(3A, 3B, 3C)	(4A, 4B, 4C, 4D)	(5A, 5B, 5C, 5D)	(6B, 6C)
	(α = 0.61)	(α = 0.56)	(α = 0.48)	(α = 0.64)	(α = 0.89)	(α = 0.44)
Observations and Inferences	1	.16*	0.037	0.26**	0.083	0.14*
Tentativeness		1	0.021	0.24**	0.029	0.028
Scientific theories and laws			1	-0.12	-0.02	0.61**
Social and cultural embeddedness				1	0.14	0.01
Creativity and Imagination					1	0.1
Scientific methods						1

Notes: * $p<0.05$; ** $p<0.01$

Conclusions and Implications

In comparison to the existing NOS instruments, SUSSI has several advantages. First, the efficacy of the SUSSI instrument is relatively high because it provides multiple ways for researchers to examine the trustworthiness and authenticity of data, i.e., students first select their responses given in the Likert format and then explain what they actually think about the nature of science and scientific inquiry by providing examples. Current research in learning, teaching, and assessment has repeatedly pointed to the importance of engaging students' pre-conceptions in instruction (National Research Council, 1999, 2001, 2005). SUSSI can be used as a formative or diagnostic assessment tool to improve student learning by informing educators about their students' thinking and reasoning and guiding teachers instructional decisions. For those who know little about the nature of science and scientific inquiry, their constructed responses in the pre-assessment may be brief or missing. However, transformations of student views as a result of effective instructional interventions will be evident when the student is able to provide valid examples and make consistent claims in a post assessment. Secondly, SUSSI can also be used as a summative assessment tool to measure students' achievement in their understanding of NOS related issues. The quantitative feature of SUSSI allows the use of inferential statistics to determine effects of any instructional interventions in small or large-scale studies. Moreover, student constructed responses can provide insight into why the findings based on student responses to the Likert items are (or are not) of statistical significance. The dual-response structure of SUSSI enables teachers and/or researchers to assess students' understanding of NOS-related content with increased confidence. Thirdly, most students can complete the SUSSI instrument in about 30 minutes. While we found that the presence of the Likert statements and associated writing prompts helped students to construct more focused responses related to the target NOS aspects, other researchers may be concerned that the student constructed responses were influenced by their reading of the Likert statements. In our view, such issues become less problematic when the respondents are asked to explain their views with valid examples rather than a simple rephrasing of the Likert statements. Research on learning and assessment has suggested that writing can play a powerful role in student learning. When asked to write about their views of NOS and scientific inquiry, students' understandings of the SUSSI target ideas become explicit. Students' views of the NOS issues can also serve as class discussion prompts in science instruction. Such explicit approaches have been considered as more effective in fostering the development of "adequate" concepts of the nature of science and scientific inquiry (Adb-El-Khalick & Lederman, 2000a, 2000b), when compared to the effects of a traditional lecture-laboratory approach in science, and/or other implicit approaches that focus on developing process skills without explicit discussion of NOS related issues.

As pointed out by Lederman (1998), "a functional understanding of the NOS and scientific inquiry by teachers is clearly prerequisite to any hopes of achieving the vision of science teaching and learning specified in the various reform efforts." In our current study, we have chosen pre-service teachers as target population. Because we believe that the learning and teaching of NOS related issues will be improved only when the schoolteachers demonstrate informed views of the nature of science and scientific inquiry and are able to demonstrate their understandings in action. We suggest that more diverse samples drawn from various populations be used to further validate the SUSSI instrument. Meanwhile, more authentic tools should be adopted to assess whether the teachers are able to translate their understanding of the nature of science and scientific inquiry into learning opportunities for students.

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Appendix A

Student Understanding of Science and Scientific Inquiry Questionnaire

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement (SD= Strongly Disagree; D = Disagree More Than Agree; U = Uncertain or Not Sure; A = Agree More Than Disagree; SA = Strongly Agree).

1. Observations and Inferences

A.	Scientists observations of the same event may be different because the scientists prior knowledge may affect their observations.	SD	D	U	A	SA
B.	Scientists observations of the same event will be the same because scientists are objective.	SD	D	U	A	SA
C.	Scientists observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D.	Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA

With examples, explain why you think scientists observations and interpretations are the same OR different*.

2. Change of Scientific Theories

A.	Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B.	Scientific theories may be completely replaced by new theories in light of new evidence.	SD	D	U	A	SA
C.	Scientific theories may be changed because scientists reinterpret existing observations.	SD	D	U	A	SA
D.	Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA
With examples, explain why you think scientific theories change OR do not change over time. [Suggested revision: With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.]						

3. Scientific Laws vs. Theories

A.	Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B.	Unlike theories, scientific laws are not subject to change.	SD	D	U	A	SA
C.	Scientific laws are theories that have been proven.	SD	D	U	A	SA
D.	Scientific theories explain scientific laws**.	SD	D	U	A	SA
With examples, explain the difference between scientific theories and scientific laws. [Suggested revision: With examples, explain the nature of and difference between scientific theories and scientific laws.]						

4. Social and Cultural Influence on Science

A.	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	SD	D	U	A	SA
B.	Cultural values and expectations determine <u>what</u> science is conducted and accepted.	SD	D	U	A	SA
C.	Cultural values and expectations determine <u>how</u> science is conducted and accepted.	SD	D	U	A	SA
D.	All cultures conduct scientific research the same way	SD	D	U	A	SA

	because science is universal and independent of society and culture.					
With examples, explain how society and culture affect OR do not affect scientific research.						

5. Imagination and Creativity in Scientific Investigations

A.	Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B.	Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C.	Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.	SD	D	U	A	SA
D.	Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	SD	D	U	A	SA
With examples, explain why scientists use OR do not use imagination and creativity. [Suggested revision: With examples, explain how and when scientists use imagination and creativity **OR** do not use imagination and creativity.]						

6. Methodology of Scientific Investigation

A.	Scientists use a variety of methods to produce fruitful results. [Suggested revision: Scientists use different types of methods to conduct scientific investigations.]	SD	D	U	A	SA
B.	Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C.	When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D.	Experiments are not the only means used in the development of scientific knowledge**.	SD	D	U	A	SA
With examples, explain whether scientists follow a single, universal scientific method OR use different methods. [Suggested revision: With examples, explain whether scientists follow a single, universal scientific method **OR** use different types of methods.]						

Note:

* The space for completing the open-ended responses was reduced to save space here.
* * The Likert statements are subject to further revision.

Appendix B

Taxonomy of Views about Nature of Science and Scientific Inquiry

(NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002)

Aspect	**Explanation/Description**	**Items**
Observations and Inferences	Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.	1A (+); 1B (-); 1C (-); 1D (+)
Tentativeness	Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.	2A (+); 2B (+); 2C(+); 2D (-)
Scientific theories and laws	Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Scientific Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.	3A (-); 3B (-); 3C (-); 3D (+)
Social and cultural embeddedness	Scientific knowledge aims to be general and universal. As a human endeavor, science is influenced by the society and culture in which it is practiced. Cultural values and expectations determine what and how science is conducted, interpreted, and accepted.	4A(-); 4B(+); 4C(+); 4D(-)
Creativity and Imagination	Science is a blend of logic and imagination. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Scientists use their imagination and creativity throughout their scientific investigations.	5A(+);5B(+); 5C (-); 5D (-)

Scientific methods	Scientists conduct investigations for a wide variety of reasons. Different kinds of questions suggest different kinds of scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding. There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observation, analysis, speculation, library investigation and experimentation.	6A (+); 6B (-); 6C (-); 6D (+)