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Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and Further Validation of an Assessment Instrument

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ABSTRACT

This paper presents the revision and validation of the *Student Understanding of Science and Scientific Inquiry* (SUSSI) instrument based on the data collected from pre-service teachers in the USA, China, and Turkey. Built on the current national and international science education standards documents and existing literature in science education, SUSSI blends Likert-type items and related open-ended questions to assess students' understanding about how scientific knowledge develops. It is suggested that SUSSI can be used as either a summative or a formative assessment tool in small or large-scale studies. SUSSI will also be most suitable for conducting cross-cultural comparison studies. The combined quantitative and qualitative methods enhance the sensitivity of the instrument for detecting cultural influences.

Introduction

The purpose of this paper is to report the development, revision, and validation of an instrument entitled *Student Understanding of Science and Scientific Inquiry* (SUSSI). In this project, scientific inquiry is used as a term related to the process by which scientific knowledge is developed, whereas the nature of science (NOS) and scientific inquiry refers to the epistemology of science, the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992, 2004). Understanding of 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 been identified as critical elements for developing scientific literacy of all learners at both national and international levels (American Association for the Advancement of Science, 1993; National Research Council, 1996; McComas & Olson, 1998; Ministry of Education of the People's Republic of China, 2001; Ministry of Education, 2003; Turkish Ministry of National Education-Turkey's National Board of Education, 2005). However, NOS studies consistently show that neither students nor schoolteachers have clear ideas about how science operates 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 become a serious concern for many science educators, curriculum developers, and science education researchers at both national and international levels. Furthermore, the assessment of learners' views of nature of science and scientific inquiry 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 much 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 context to discuss issues related to learning and teaching the nature of science and scientific inquiry, both locally and globally.

Relevant Research on the Nature of Science and Scientific Inquiry Instruments

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. The instruments failed to detect the respondents' perceptions and interpretations of the test items. 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 because of extremely different reasons. 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, in press). 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, in press). But 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 make maximum use of the VOSTS items because respondents circle their views on all items, and create data that can be applied to inferential statistics.

Currently, the most influential NOS assessment tools on views of the nature of science 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 the VNOS instruments as formative classroom assessment forms and/or accurate research tools as anticipated. Other research methods such as follow-up interviews become 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 last 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

SUSSI was developed through a four-phase process. During phase one, the National and International Science Education Standards documents and related literature were examined to select target ideas about the nature of science and scientific inquiry to be included in the instrument. A draft form of SUSSI was developed built on existing instruments and literature and first piloted in the USA and China. In the second phase, a modified version of SUSSI (SUSSI -1^{st}) was produced based on the pilot study and expert reviews. Students were also interviewed for content clarification. During phase

three, SUSSI –1st was administered in the USA (in English), China (Chinese translation), and Turkey (Turkish translation). The results were presented at the Eighth International History, Philosophy, Sociology and Science Teaching Conference (Author, 2005). During the last phase, SUSSI was further revised and the current version (SUSSI-2nd) was administered in the aforementioned three countries again to further examine the validity and reliability of the instrument.

Target Ideas about the Nature of Science and Scientific Inquiry

Whereas the nature of science and scientific inquiry involves a wide variety of topics in history, philosophy, and sociology of science, SUSSI focuses on the following seven essential elements that are emphasized in national and international K-12 science education standards documents and have been widely discussed in literature (e.g., AAAS, 1990, 1993; Aikenhead & Ryan, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas & Olson, 1998; Ministry of Education of the People's Republic of China, 2001; Ministry of Education, 2003; National Research Council, 1996; National Science Teachers Association, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Turkish Ministry of National Education, 2005).

1. Tentativeness of Scientific Knowledge: 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.
2. Observations and Inferences: Science is based on both observations and inferences. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.

3. 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.
4. 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.
5. Social and Cultural Embeddedness in Science: Science is part of social and cultural traditions. People from all culture 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.
6. 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.
7. 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.

Development and Validation of SUSSI Items

Item development and pilot study. SUSSI was built on existing instruments including the VOSTS (Aikenhead & Ryan, 1992), and VNOS (Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002). The first draft form of SUSSI was developed in May of 2004. By blending Likert-type items and related open-ended questions, SUSSI allows participants to rank each Likert statement on a five-point scale (i.e., strongly disagree, disagree more than agree, uncertain/not sure, agree more than disagree, strongly agree) and then explain their reasons in the open-ended section. The original Likert items in SUSSI consisted of both informed views of the nature of science and scientific inquiry as presented in the standards documents and literature, as well as the following common naïve ideas reported in existing empirical studies or other literature (McComas, 1998; Aikenhead, & Ryan, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Chen, in press):

1. Hypotheses become theories that in turn become laws.
2. Theories are unproven ideas but scientific laws are certain and proven.
3. New information is constantly discovered by new technology, this is the only reason that causes scientific theories to change.
4. Scientists "discover" or "found" scientific theories and/or laws embedded in nature.
5. There is a universal step-by-step scientific method that all scientists follow. The scientific method ensures valid and accurate results.
6. The purpose of scientific research is to uncover truth or facts.
7. Scientists do not use their imagination and creativity because these can interfere with objectivity.

8. Scientists use imagination and creativity only when they plan experiments and/or make hypotheses. They do not use imagination and creativity after they started their experiments.
9. Scientists would make same observations and/or interpretations of the same phenomenon because scientist are particularly objective.
10. Experiments are the principal route to scientific knowledge.
11. Science is a solitary or individual pursuit, not influenced by the society and culture.
12. Evidence accumulated carefully will result in sure knowledge.

The SUSSI draft form (10 focus questions accompanied by a total of 58 Likert items) was piloted with 60 Chinese science educators who taught grades 3-16 and 40 American preservice teachers during the summer and the fall semester of 2004. Twenty-five respondents were interviewed and the findings were used to modify and/or further clarify certain ambiguous statements in the survey. For instance, in the questions related to the tentativeness of scientific knowledge, some students focused on scientific facts or information obtained through direct observations, while others thought about scientific theories. Therefore, in the revised version, the term "scientific knowledge" was replaced with "scientific theories" for improved clarity. In addition, the SUSSI was further reviewed for face and content validity by nine international science educators who were either currently engaged in teaching and/or knowledgeable about NOS related research.

The first SUSSI version (SUSSI –1st). SUSSI-1st consists of 10 questions accompanied by a total of 58 Likert items. Each question addresses the aforementioned target ideas about the nature of science and scientific inquiry. There are three equivalent forms of the SUSSI that is in

English, Chinese, and Turkish. During the year of 2005, the first version was administered to 60 American undergraduate students and pre-service teachers who enrolled in science courses, 60 Chinese preservice physics teachers, and 60 preservice Turkish science teachers. The administration time was about 30 – 40 minutes.

To analyze the Likert items, a taxonomy of views about the nature of science and scientific inquiry was created based on the existing literature and later examined by both internal and external reviewers (see Appendix B). 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. 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 reversed order for each 'negative' Likert item. At the meantime, a scoring guide for analysis of students' constructed responses to the open-ended questions in the SUSSI was also developed and used to analyze the consistency between the students' responses to the Likert items and their constructed responses. Student responses to each Likert item was 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 the first version that were identified as "Not Consistent" were removed and/or modified. In addition, the overall structure of the original SUSSI and certain items were revised to enhance the clarity and readability. The more detailed procedures were presented in the paper prepared for the

Eighth International History, Philosophy, Sociology and Science Teaching Conference in England (Author, 2005).

The current SUSSI version. The current version (2nd version) of SUSSI targets on six 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 that represent both most common naïve ideas and informed views consistent with the standards documents and current NOS literature. Six open-ended follow-up questions are embedded within respective themes (refer to Appendix A).

During the data analysis phase, a similar taxonomy (see Appendix B) was used for classification of the 24 Likert items, and a new scoring guide was developed and used to analyze 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 two or more members in the research team, and an average inter-rater reliability of > 80% was achieved. The coding of the remaining responses within each country sample was completed by one or two research team members using the common rubric (see Table 1).

Insert Table 1 about here

Samples

In the current study, three groups of participating pre-service teachers were recruited from the USA, China, and Turkey. A convenience sampling technique was adopted. In the American sample, 209 pre-service teachers majoring in elementary education (K-6) and/or special education (K-12) at two universities (one in rural and the other in urban area) participated

in the study. The Chinese sample consisted of 212 pre-service middle school science teachers majoring in various science disciplines (i.e., physics, chemistry, and biology). In the Turkish sample, 219 pre-service elementary and middle school science teachers (K-8) completed the SUSSI instrument.

Results and Discussion

High validity and reliability are two important indicators of any quantitative instruments of high quality. 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, Bradford, & Harkness, 1996). An empirically based instrument is developed from a qualitative perspective, which focuses more on the trustworthiness and authenticity of data (Erlandson, Harris, Skipper, & Allen, 1993) than on the consistency across constructs and measurements.

Validity

In our SUSSI study, several methods were used for validity examination. First, 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 knowledgeable about NOS related research. The panel's comments and suggestions for improvement were used to modify the items. 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., students' selected responses to the Likert items, students' 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 students' selected and constructed responses. Across the three

samples, we found that some American and Turkish students and many Chinese students did not complete the constructed responses to all open-ended questions. We therefore decided to first sort the survey forms by each country after assigning each survey form a letter associated with a different numerical number between 1 and 219 (e.g., U 1: representing student #1 in the USA sample; C 2: representing student #2 in the Chinese sample; T 51: representing student #51 in the Turkish sample), then we scored the first 60 constructed responses by each theme, by using the scoring guide described in the methods section. Illustrative examples of student responses to the open-ended questions by theme and by country are presented in Table 2. These examples are verbatim quotes selected from the constructed responses of the participants in the study. Organized by themes and questions, the examples illustrate the respondents' views of the nature of science and scientific inquiry on the target aspects along continua from more naïve toward more informed understandings.

Insert Table 2 about here

In the following sections, we examine student responses to both the Likert items and the open-ended questions in more details.

Observations and inferences. Although less than 10% participants across the three samples demonstrated complete naïve views of observations and inferences according to our scale, the number of students who achieved informed understandings of this NOS aspect was unsatisfactory (<46%). The majority demonstrated transitional views that were combinations of both naïve and informed understandings. For instance, while the overwhelming majority (85-96% across all three samples) agreed that scientists would make different inferences or interpretations based on same observations, there are also a significant portion of the group who

believed that observations were facts (15%-51%) and/or scientists would make same observations because they were objective (11%-34%). In general, the participants' responses to the Likert and the open-ended questions were very consistent in this aspect across the three samples (see Table 3), although the percentage of informed views demonstrated in the constructed responses was slightly lower than the ones indicated in the corresponding Likert portion. Such discrepancy was due to the fact that some students discussed either observations or inferences but failed to address both in their constructed responses, while our scoring guide required student responses to address both observations and inferences aspects to be rated as "informed."

Tentativeness. Whereas the majority participants (87-94%) believed that scientific theories were subject to on-going testing and revision, fewer students (69%-79%) agreed that scientific theories might be changed because scientists reinterpreted existing observations in response to the Likert statements. When the constructed responses were analyzed, even fewer (2-15%) mentioned that scientific theories might change as a result of reinterpreting existing data or observations. Less than 5% participants demonstrated complete naïve views on the tentative nature of scientific theories, and the results were highly consistent between the Likert and constructed responses across the three samples (see Table 3). However, the percentages of informed views reflected in the constructed responses were significantly lower than those as demonstrated in the corresponding Likert responses section. Similar patterns were observed across the three samples. This was resulted from a slight mismatch between the Likert items and the open-ended question in this theme: While the Likert items addressed both evolution and revolution aspects of the tentative nature of scientific theories, participants were asked to explain why they thought scientific theories change or do not change in the open-ended section.

Therefore many respondents answered whether or not they thought theories would change without mentioning the nature of 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 "informed view," the student is expected to explain both whether and how theories may be changed (i.e., evolution and revolution /reinterpretation aspects). If we 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," then we would anticipate a greater consistency between the student Likert and constructed responses scores.

Scientific theories and laws. Students demonstrated the most misunderstandings and confusions in this aspect of NOS as reflected in their responses to both the Likert and open-ended questions. In our three samples, 73-91% participants believed that scientific theories were embedded in nature and uncovered by scientists through scientific investigations. Many participants (USA: 85%; China: 48%; Turkey: 95%) believed that scientific laws are proven theories. In response to the Likert item 3D, about 47%-59% participants agreed that scientific theories explain scientific laws. However, little evidence of student understanding of the difference between theories and laws was found in the constructed responses. Many respondents who agreed with the statement of "theories explain laws" also stated that "theories eventually become laws" in the corresponding constructed response section. It appeared that the participants did not really understand the meaning of statement 3D (i.e., scientific theories explain scientific laws). This was also confirmed by selected follow-up interviews. Therefore, we suggest that Likert item 3D be removed.

According to our scoring guide, informed views about the functions of and differences between theories and laws consisted of two main ideas: 1) Scientific theories and laws are two

different types of knowledge. Scientific theories are created by scientists to explain natural phenomena and/or scientific laws; and 2) neither theories nor laws are certain. No single constructed response was classified as "informed" in our samples. By comparing student responses to the Likert and open-ended questions after removal of the item 3D, we found that the participants' views on this aspect were generally consistent (see Table 3). Due to the extremely high proportion of uninformed views demonstrated in this theme, we suggest that the "theories and laws" aspect be eliminated when the SUSSI instrument was used among pre-service elementary teachers. If we want to keep this theme for the secondary science teachers, then we suggest that the open-ended question be modified as "with examples, explain the nature of and difference between theories and scientific laws," in order to achieve a higher level of alignment between the Likert statements and the associated open-ended questions.

Social and cultural embeddedness. Students generally possess transitional views about this NOS aspect. About 10%-58% participants believed that all cultures conducted scientific research the same way and/or scientists were trained to conduct pure and unbiased studies (15%-62%), whereas 30-70% participants across the three samples agreed that the culture and society would influence the development of science. Although the number of participants who demonstrated complete naïve views about this aspect of NOS was relatively low (8% or less for the Chinese and USA samples, 25% or less for the Turkish sample), the number of people with informed views was not high either (21% or less). When the open-ended portions were scored, the number of informed responses was even lower (10% or less) across the three samples. This was because many constructed responses indicated that cultural values and expectations would influence either "what" or "how" science was conducted and accepted but failed to mention both.

We anticipate that such discrepancy in scores between the Likert and constructed responses might be resolved when SUSSI was administered as a post-test after an effective intervention.

Creativity and imagination. Student responses to the Likert and open-ended questions were generally consistent regarding this theme. Fewer Turkish and Chinese participants (9-15%) believed that scientists do not use creativity and imagination than their American counterparts (45-47%) did. In parallel, fewer American students agreed that scientists would use their imagination and creativity when collecting data (41%) and/or interpreting data (33%), in comparison to their Chinese and Turkish counterparts (52-63%). The results presented in Table 3 also revealed that the numbers of "informed" constructed responses were consistently lower than the numbers of "informed" Likert responses across the three samples. This was because we had adopted a stringent criterion to evaluate the student constructed responses in this aspect. According to our rubric, an "informed" response was required to emphasize that scientists use their imagination or creativity throughout their work (or during all phases of their scientific investigations). Many respondents stated that scientists would use their imagination and creativity without specifying "when" or during what phases of scientific investigations. For instance, a number of Chinese students provided concrete examples (e.g., the development of atomic and molecular models, DNA structure, and the periodic table) as evidence of the use of imagination in science without providing further elaboration. Their constructed responses were therefore scored as "2" (transitional views) despite the fact that they demonstrated an informed understanding in responding to the related Likert items.

Scientific methods. About 39-48% American and Turkish participants believed that there is a single, universal step-by-step scientific method that all scientists follow. Meanwhile, the majority of the participants also agreed that scientists would use a variety of methods (84-

91%) and experiments were not the only means used in the development of scientific knowledge (74-83%). A closer examination of the students' constructed responses in the open-ended sections revealed that a number of students equated the term "different methods" with different steps within the scientific method or different experiments. Very few American and Turkish respondents were able to provide valid examples of different types of scientific methods. For instance, one American student agreed with both Likert statements 6A and 6D (i.e., "scientists use a variety of methods" and "experiments are not the only means used in the development of scientific knowledge."). 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.

It appeared that the Likert responses to 6A and 6D provided by the American and Turkish respondents were not consistent with what the respondents' thinking as reflected in their constructed responses to the open-ended question. We therefore suggest that the item 6D be removed. In addition, we suggest that the Likert statement 6A (i.e., "Scientists use a variety of methods to produce fruitful results") be modified as "scientists use different types of methods to conduct scientific investigations." The consistency between the Likert and constructed responses without considering the items 6A and 6D was satisfactory (see Table 3).

In comparison to their Turkish and American counterparts, fewer Chinese respondents (about 13%) believed that there is a universal scientific method and more students (65%) demonstrated informed views in their responses to the Likert items. We also found more valid examples of different scientific methods (i.e., observation, experimentation, etc.) in the student

constructed responses. In Table 3, the percentages of informed views as reflected in the student constructed responses were lower than those as indicated in the Likert responses for both Chinese and Turkish samples. This was due to the fact that some participants' constructed responses were extremely brief. For instance, some people simply stated that "scientists use multiple methods" without providing any examples or justification. We anticipate that the discrepancy between the responses to the Likert statements and the open-ended question would diminish, provided that the respondents were encouraged and/or motivated to write more in their open-ended section.

Reliability

Students' views on the six target aspects of NOS and scientific inquiry are not independent but inter-related. For instance, students' responses to the scientific method question were related to not only the social and cultural embeddedness aspect of NOS, but also the creative and imaginative nature of scientific inquiry. We decided to calculate the overall Cronbach's Alpha for SUSSI rather than by each aspect or factor. The overall Cronbach's Alpha of SUSSI by country is presented in Table 4. The consistency of the alpha values across the three samples suggests that SUSSI can be used as a reliable assessment tool in different cultural settings.

Insert Table 4 about here

Conclusions and Implications

We argue that SUSSI surpasses the existing NOS instruments in several respects. 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 both small and 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 enable teachers and/or researchers to better assess students' understanding of NOS related content without interviewing. Thirdly, most students can complete the SUSSI instrument in about 30 minutes. The presence of the Likert statements and associated writing prompts help students to construct more focused responses related to the target SUSSI aspects. 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. Finally, SUSSI is most suitable for conducting cross-cultural comparison studies, because it has been tested in three different cultures: Western (USA), Eastern (China), and a blend of Eastern and Western (Turkey). The combined quantitative and qualitative methods enhance the sensitivity of the instrument for detecting cultural influences.

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.

References

Abd-El-Khalick, F., & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. Journal of Research in Science Teaching, 34, 673-699.

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

Abd-El-Khalick, F., & Lederman, N. (2000b). The influence of the history of science courses on students' views of the nature of science. Journal of Research in Science Teaching, 37, 1057-1095.

Aikenhead, G. S. (1987). High-school graduates' beliefs about Science-Technology-Society: Methods and issues in monitoring student views. Science Education, 71, 145-61.

Aikenhead, G. S. (1988). An analysis of four ways of assessing student beliefs about STS topics. Journal of Research in Science Teaching, 25, 607-29.

Aikenhead, G. S., Fleming, R. W., & Ryan, A. G. (1987). High-school graduates' beliefs about science-technology-society. I. Methods and issues in monitoring student views. Science Education, 71, 145-61.

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: “Views on science-technology-society” (VOSTS). Science Education, 76, 477-491.

Alters, B. J. (1997). Whose nature of science? Journal of Research in Science Teaching, 34, 39-55.

American Association for the Advancement of Science. (1990). Science for all Americans. New and Science Teaching Conference, England.

American Association for the Advancement of Science. (1993). Benchmarks for science literacy: Project 2061. New York: Oxford University Press.

Author (2005, July). Paper presented at Eighth International History, Philosophy, Sociology & Science Teaching Conference, University of Leeds, London, United Kingdom.

Central Association of Science and Mathematics Teachers. (1907). A consideration of the principles that should determine the courses in biology in the secondary schools. School Science and Mathematics, 7, 241-247.

Chen, S. (in press). Development of an instrument to assess views on nature of science and attitudes toward teaching science. Science Education.

Cooley, W.W., & Klopfer, L.E. (1961). Manual for the test on understanding science. Princeton, NJ: Education Testing Service.

Cooley, W.W., & Klopfer, L.E. (1963). The Evaluation of specific education innovations. Journal of Research in Science Teaching 1, 73-80.

Erlandson, D. A., Harris, E. L., Skipper, B. L., & Allen, S. D. (1993). Doing naturalistic inquiry: A guide to methods. Newbury Park, CA: Sage.

Jungwirth, E. (1974). Testing for understanding of the nature of science. Journal of College Science Teaching, 3, 206-210.

Kimball, M. E. (1967). Understanding the nature of science: A comparison of scientists and science teachers. Journal of Research in Science Teaching, 5, 110-120.

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. (1998). The state of science education: Subject matter without content. Electronic Journal of Science Education, 3, 1-12.

Lederman, N. G. (2004). Syntax of nature of science within inquiry and science instruction. In L. B. Flick and N. G. Lederman (Eds.), Scientific inquiry and nature of science (pp. 301-317). Dordrecht, 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'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. Science Education, 74, 225-239.

McComas, W. (1998). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), The nature of science in science education: rationales and strategies (pp. 53-70). Dordrecht, The Netherlands: Kluwer Academic Publishers.

McComas, W., & Olson, J. (1998). The nature of science in international science education standards documents. In W. F. McComas (Ed.), The nature of science in science education: Rationales and strategies (pp. 41-52). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Meichtry, Y.J. (1992). Influencing student understanding of the nature of science: Data from a case of curriculum development. Journal of Research in Science Teaching, 29, 389-407.

Ministry of Education. (2003). Curricula guidelines for elementary and junior high schools. Taipei, Taiwan.

Ministry of Education of the People's Republic of China. (2001). Science education standards (7-9). Beijing: Beijing Normal University.

National Research Council (1996). National science education standards. Washington, DC: National Research Council.

National Research Council. (1999). How people learn: Brain, mind, experience, and school. Washington, DC: The National Academies Press.

National Research Council. (2001). Knowing what students know: The science and design of educational assessment. Committee on the Foundations of Assessment. Pelligrino, J., Chuodowsky, N., and Glaser, R., editors. Board on Testing and Assessment, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

National Research Council. (2005). How students learn: History, mathematics, and science in the classroom. Committee on How People Learn, A Targeted Report for Teachers, M.S. Donovan, & J. D. Bransford (Eds.). Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Science Teachers Association (2000). NSTA position statement: The nature of science. Arlington, VA: National Science Teachers Association Press.

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

Rubba, P. A. (1977). The development, field testing and validation of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. Unpublished doctoral dissertation, Indiana University, Indiana.

Rubba, P.A. & Andersen H.O. (1978). Development of an instrument to assess secondary students' understanding of the nature of scientific knowledge. Science Education, 62, 449-458.

Rubba, P. A., Schoneweg Bradford, C., & Harkness, W. J. (1996). A new scoring procedure for the views on science-technology-society instrument. International Journal of Science Education, 18, 387-400.

Turkish Ministry of National Education (2005). New curriculum of science and technology education. Retrieved December 24, 2005, from Turkey's National Board of Education Web site: http://ttkb.meb.gov.tr/ogretmen/

Vazquez-Alonso, A., & Manassero-Mas, M.-A. (1999). Response and scoring models for the 'views on science-technology-society' instrument. International Journal of Science Education, 21, 231-247.

Welch, W. W. (1966). Welch science process inventory, Form D. Minneapolis: University of Minnesota.

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).

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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 what science is conducted and accepted.	SD	D	U	A	SA
C. Cultural values and expectations determine how science is conducted and accepted.	SD	D	U	A	SA
D. All cultures conduct scientific research the same way because science is universal and independent of society and culture.	SD	D	U	A	SA

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.	SD	D	U	A	SA

[Suggested revision: Scientists use different types of methods to conduct scientific investigations.]

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 removal.

Appendix B

Taxonomy of Views about Nature of Science and Scientific Inquiry

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 (+)

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Table 1

Sample SUSSI Scoring Guide for Evaluation of Constructed Responses

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

Not Classifiable	Naïve View (1)	Transitional View (2)	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 scientists observes or interprets because scientists are objective or because observations are facts. **OR** The response includes contradictions of basic assumptions concerning the nature of science or self-contradicting statements.	Scientists' observations **OR** interpretations may be different because of their prior knowledge, personal perspective, or beliefs. **OR** The observations **AND/OR** interpretations may be different, but give no reason or an unrelated reason.	Scientists' observations **AND** interpretations may be different because of their prior knowledge, personal perspective, or beliefs.

Table 2

Illustrative Examples of Student Responses to the Open-Ended Questions by Theme and by Country (Part-I)

Target Aspect	More Naïve Views			More Informed Views		
	USA	China	Turkey	USA	China	Turkey
Observations and Inferences 1. With examples, explain why you think scientists' observations and interpretations are the same OR different.	The same, because there is usually a control and very specific "specifications." For each experiment that cannot be interpreted in many different ways. (Subject #: U21)	Facts do not change. In addition, scientists are trained to think in similar ways. Therefore, scientists may obtain the same observational results. (Subject #: C6)	To me, different scientists should have the same observations and interpretations for the same phenomena because they are looking for the truth embedded in the nature. (Subject #: T50)	Scientists' observations and interpretations are different because each scientist's knowledge and outlook on an experiment or object varies. For example, a teacher's interpretation of something would be completely different from a student's interpretation due to the lack of experience and knowledge compared to the teacher. (Subject #: U32)	Different. When two observers observe the same person, one may get the front view while the other may get the side view. Different inferences or interpretations may be made because both observers see things from their own perspective. (Subject #: C85)	Everyone has different prior knowledge, thinking and belief system and culture. Such differences will result in differences in scientists' observations and interpretations of the same event. (Subject #: T17)
Tentativeness 2. With examples, explain why you think scientific theories change OR do not change over time.	I don't think scientist will change their mind because I think that is something they every time observed & will not change. (Subject #: U25)	Scientific theories are facts embedded in nature, they may or may not be discovered by scientists. (Subject #: C23)	Only theories that are proven through experimental research by different scientists will become laws. These kinds of sound theories will not be changed because they are certain. Other theories can be changed. (Subject #: T26)	Scientific theories change over time because we are constantly coming across new, more accurate data, observations, and facts. New perspective arise over time that replace old ones. World experiences change thoughts on theories. (Subject #: U12)	I think that scientific theories can change. During different historical periods, people may study the same objects in different depth. A theory may be tentatively consistent with certain phenomena, but it is possible that something more fundamental is to be discovered, and therefore previous theories may be corrected afterwards. (Subject #: C88)	In light of new or different evidence, scientific theories are completely changed or partially modified. These new evidences are based on not only the technological development but also reconsidering existing knowledge. For example, after almost 30 years of arguing that a black hole swallows up everything that falls into it, Stephen Hawking changed his mind about his black hole theory. I am sure that he re-conceptualized his previous ideas and evidence more than using a new technology. (Subject #: T22)

Table 2

Illustrative Examples of Student Responses to the Open-Ended Questions by Theme and by Country (Part-II)

Target Aspect	More Naïve Views			More Informed Views		
	USA	China	Turkey	USA	China	Turkey
Scientific theories and laws 3. With examples, explain the difference between scientific theories and scientific laws.	Scientific theories are "guesses" that lack enough proof that makes it a theory. A theory is an educated claim but can change. A scientific law always remains the same. There is 100% of the evidence to back up laws. (Subject#: U8)	Scientific laws are facts embedded in nature, while theories are descriptions of natural phenomena using certain language. (Subject #: C56)	Theories are similar to hypotheses that is the first step toward scientific laws. Theories are open to discussion, but laws can not be changed or even discussed. (Subject #: T48)	N/A. [Note: No constructed responses received a score of "3" or qualified as informed views.]	N/A. [Note: No constructed responses received a score of "3" or qualified as informed views.]	N/A. [Note: No constructed responses received a score of "3" or qualified as informed views.]
Social and cultural embeddedness 4. With examples, explain how society and culture affect OR do not affect scientific research.	I do not really believe that culture affects scientific research because research is based on facts and proving things, not what is going on inside different cultures. (Subject#: U9)	Scientific research such as cloning will not be stopped by some people. Scientific research is not influenced by society and culture. (Subject #: C46)	If you are a scientist, you should put aside all of your feelings, cultural and religious beliefs during scientific research because scientific results are true and certain. (Subject #: T33)	Certain societies and cultures value specific sciences. They choose to study and examine different categories of science and in different methods or manners. (Subject#: U19)	Culture and society influence the content and methods of scientific research. (Subject #: C18)	Scientists are also human beings who live in a society. Therefore, they have their own social and cultural values. And these values certainly affect not only what kinds of research they can do but also how to do it. … (Subject # T12)

Table 2

Illustrative Examples of Student Responses to the Open-Ended Questions by Theme and by Country (Part-III)

Target Aspect	More Naïve Views			More Informed Views		
	USA	China	Turkey	USA	China	Turkey
Creativity and Imagination 5. With examples, explain why scientists use OR do not use imagination and creativity.	No, I don't think scientists use their imaginations because imaginary things aren't facts. (Subject #: U40)	No. scientific research seeks for facts. Scientific knowledge can not be a product of creativity and imagination. (Subject #: C68)	Doing scientific inquiry definitely requires being objective. And science consists of logical reasoning, not imagination and creativity. (Subject #: T51)	I definitely think scientists use their imagination and creativity when collecting and interpreting data. Without our imagination everything is too black and white. We need to think outside of the box. (Subject #: U12)	Yes. The structure of DNA was created from imagination and then tested. (Subject #: C66) [Note: No constructed responses received a score of "3" or qualified as informed views.]	In my opinion, the most important difference between scientists and us is that they are always using their creativity and imagination from the beginning to the end of their research. Using creativity and imagination is necessary to see nuance or important points in scientific research. I believe that developments of many theories (e.g., molecular kinetic theory) are based on the capacity of scientists' creativity and imagination. (Subject #: T13)
Scientific methods 6. With examples, explain whether scientists follow a single, universal scientific method OR use different methods.	I think there is a universal scientific method because there would be complications if the methods vary. (Subject#: U41)	Same method or procedure, i.e., from making observation => proposing hypothesis => conducting experiments=>interpreting results. (Subject #: C70)	Scientists certainly use a universal step-by-step method because they need to get proof for their research from other scientists. Scientific journals also show that they are using the same way to do scientific research. For example, each article consists of similar headings such as research questions, hypothesis, research design and procedure, data collection, results and discussions. Moreover, we are also using the same method in our laboratory courses. (Subject #: T60)	I think they use different methods depending on what type of study they are conducting. (Subject#: U29)	Scientists use multiple methods, such as observing, experimenting, and hypothesizing. (Subject #: C77)	The way how scientists do investigations is based on the nature of problems or questions that are related to the structure of field. Furthermore, scientists use different ways even for the same problem in the same field. Otherwise, science will be very mechanical. But, I believe that scientists should be very creative. It means that they need to use different ways such as performing lab experiments and observations to study the nature. (Subject #: T36)

Notes: Codes are used to identify individual participants. Each code comprises a numerical number and one letter, which indicates the country in which the participant belongs. The letters "U," "C" and "T," refer to the USA, China, and Turkey, respectively

Table 3

Comparison of Student Responses to the Likert Items and Open-Ended Questions by Theme and by Country

Target Aspect	Naïve Views						Informed Views					
	USA		China		Turkey		USA		China		Turkey	
	LR*	CR**	LR	CR	LR	CR	LR	CR	LR	CR	LR	CR
Observations and Inferences [1A-D]	2%	3%	0%	2%	8%	9%	35%	35%	27%	22%	45%	35%
Tentativeness [2A-D]	0%	3%	0%	2%	0%	5%	40%	5%	50%	2%	52%	15%
Scientific theories and laws [3A-C]	90%	98%	36%	49%	70%	82%	0%	0%	0%	0%	0%	0%
Social and cultural embeddedness [4A-D]	5%	8%	2%	7%	25%	19%	21%	7%	18%	2%	12%	10%
Creativity and Imagination [5A-D]	48%	42%	2%	3%	13%	19%	15%	10%	27%	0%	37%	26%
Scientific methods [6B-C]	30%	33%	8%	3%	32%	35%	13%	14%	65%	50%	28%	18%

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 per country.

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 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.

Table 4

Reliability (Cronbach's Alpha) of the SUSSI Instrument by Country

SUSSI	USA (n=209)	China (n=212)	Turkey (n=219)
Current version: all 24 items	0.67	0.61	0.67
Suggested revised version 1: 21 items after removal of 3D, 6A, & 6D	0.69	0.62	0.69
Suggested revised version 2: 18 items after removal of 3A-D, 6A, & 6D	0.72	0.69	0.69