Student Understanding of Scientific Inquiry (SUSI): Development and Validation of an Assessment Instrument

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ABSTRACT: This paper presents the development and validation of the *Student Understanding of Scientific Inquiry* (SUSI) instrument based on the data collected from undergraduate students in the USA, China, and Turkey. Built on the existing questionnaires published in the science education literature, including the *Views on Science-Technology-Society* (VOSTS) and the *Views of Nature of Science* (VNOS), SUSI blends Likert-type multiple-choice items and related open-ended questions to assess students' understanding about how scientific knowledge develops. It is suggested that SUSI can be used as either a summative or a formative assessment tool in small or large-scale studies. SUSI will also be most suitable for conducting cross-cultural comparison research because cultural influences may be revealed in the participants' responses to open-ended questions.

National and International Science Education Standards documents identify the development of student understanding of scientific inquiry and the nature of science (NOS) as critical elements for developing scientific literacy of all learners (American Association for the Advancement of Science [AAAS], 1993; National Research Council, 1996; McComas & Olson, 1998; Ministry of Education of the People's Republic of China, 2001). 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, 2000). This has become a serious concern for many science educators, curriculum developers, and science education researchers at both national and international levels. Because of the deficient understanding of what science is about, a valid and meaningful standardized instrument is much needed to track students' growth and promote evidence-based practice in learning and teaching of science (Good, Lederman, Gess-Newsome, McComas, & Cummins, 2000). The purpose of this paper is, therefore, to report the development and validation of an instrument, *Student Understanding of Scientific Inquiry* (SUSI) that can be used for creating a shared context to discuss issues related to NOS and scientific inquiry, both locally and globally.

In the last decades, both quantitative and qualitative questionnaires have been developed and used in conducting NOS related research. Examples of 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 consist of multiple-choice or Likert-type questionnaires and were usually written from perspectives of experts. Jungwirth (1974) and Alters (1997) pointed out that those experts did not adequately represent perspectives of scientists, philosophers, or science educators. Moreover, these instruments often assumed that all scientists had the same view and behaved in the same way. Views of NOS were oversimplified and over generalized.

Another major criticism about the traditional true/false or Likert-type questionnaires is that they often fail to detect either the subjects' perceptions and interpretations of the test items or their underlying reasons for making a choice. The traditional instruments using forced-choice items have generally been used with the 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 (1988) investigated the problem of ambiguity harbored by four different response formats: Likert-type, written paragraph, semi structured interview, and empirically derived multiple-choice items. He found that Likert-type formats had the highest level of ambiguity. Likert-type questionnaires only provided a guess of subjects' beliefs. Although paragraph responses worked better than Likert-type responses, the ambiguity was still high because subjects often lacked the skill to present their thoughts well. Semi-structured interviews offered the most accurate data, but were time-consuming. Finally, it was concluded that empirically derived, multiple-choice responses reduced the ambiguity to a level between 15% and 20%. 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 decide their teaching materials and for researchers to interpret students' beliefs appropriately. However, Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) and Abd-El-Khalick and BouJaoude (1997) pointed out that subjects might have combinations of views that would not be reflected in the multiple-choice format. This problem may be resolved by using the Likert scale and scoring model proposed by Vazquez-Alonso and Manassero-Mas (1999). Moreover, the scale and scoring scheme allow researchers to make maximum use of its 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 tool perhaps is the Views of Nature of Science Questionnaire (VNOS), developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). There are several forms of VNOS (Form A, B, C, D, and E). With certain variations in length and complexity of language used in the questionnaires, all VNOS instruments consist of open- ended questions accompanied follow-up interviews. For instance, the VNOS C is composed of 10 free-response questions and takes 45-60 minutes for students (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 certain items blank. This limits the potential of the VNOS instruments as both accurate and informative classroom assessment 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 students' perceptions over the last decade. 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. This has led to the development of the SUSI instrument, which combines both quantitative and qualitative approaches to assess students' views about how scientific knowledge develops.

Development and Validation of the SUSI Instrument

SUSI blends Likert-type items and related open-ended questions to assess students' understanding about how scientific knowledge develops. It was developed through a three-phase process. During phase one, the National and International Science Education Standards documents and related literature were examined to select target NOS aspects to be included in the instrument. In phase two, a draft form of the SUSI was developed built on existing NOS instruments and was piloted in the USA and China. In the third phase, a modified version of SUSI was produced based on the pilot studies and expert reviews. Nine international experts of science educators and scientists reviewed the items for content validity. Students were also interviewed for content clarification. During the last phase, the SUSI was administered in the USA (English translation), China (Chinese translation), Turkey (Turkish translation), respectively, to further establish the validity and reliability of the instrument.

What NOS Related Content Should Be Taught in School Science?

NOS usually refers to the values and assumptions inherent to science, scientific knowledge and its development (Lederman, 1992). NOS involves a wide variety of topics in history, philosophy, and sociology of science. SUSI focuses on seven aspects of the nature of science and scientific inquiry 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; NRC, 1996; NSTA, 2000; Ministry of Education of the People's Republic of China, 2001):

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. Observation 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. Scientific theories are inferred 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.

Item Development and Pilot Studies

The SUSI 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 the SUSI was developed in May of 2004. Using a format similar to the VOSTS, the SUSI allows participants to rank each item on a five-point scale, i.e., strongly disagree, disagree more than agree, uncertain/not sure, agree more than disagree, strongly agree. The draft form was piloted with 60 Chinese science educators who taught grades 3-16 and 40 American preservice teachers with follow-up interviews between the summer of 2004 and the fall semester of 2004. 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 or laws. Therefore, in the revised version, the term “scientific knowledge” was replaced with “scientific theories” for improved clarity and consistency. In addition, the SUSI was further reviewed for content validity by nine international science educators who are either currently engaged in NOS related research or teaching.

Sample Selection and Data Analysis Procedures

The revised version of the SUSI consists of 10 questions accompanied by a total of 58 Likert items. Each question in the SUSI addresses the aforementioned aspects of the nature of science and scientific inquiry. There are three equivalent forms of the SUSI that is in English, Chinese, and Turkish (see Appendix A for the English translation). During the year of 2005, the revised version was administered to 60 American biology students and pre-service teachers who enrolled in science courses, 60 Chinese preservice physics teachers, and 60 preservice Turkish science teachers, respectively. 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 by the first author based the existing literature and later examined by other co-authors and external reviewers. All 58 Likert items were classified into two groups: positive or negative items. All statements marked as '+' are representing views consistent with the National and International Science Education Reform documents, whereas the items with '-' signs are representing common student understandings of NOS that are not consistent with the Standards documents. The higher the score a student achieves in the SUSI, the higher the consistency between the student's view and the informed view presented in 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 (from 'strongly disagree= 5' to 'strongly agree=1').

A scoring guide for analysis of students' free responses to the open-ended questions in the SUSI was also developed and used to analyze the consistency between the students' responses to the Likert items and their written responses. Each of student responses to the Likert items was rated as "Consistent" (C) or "Not Consistent" (NC) with free responses. A code "NA" was used when the student did not address any content related to the examined Likert item. First, all student responses on at least five surveys were coded by at least two members of the research team, and an average inter-rater reliability of > 80% was achieved. Then one research team member completed the rest of the coding using the rubric. Table 1 summarizes the English version of the written response prompts.

Table 1: Prompts for Written Responses by Question

SUSI Question	Written Response Prompt
1. Do you think scientific knowledge is…?	Please ***explain*** how scientific knowledge is different from knowledge developed in other disciplines such as art, philosophy, or mathematics.
2. Do you think scientists will accept two different theories at the same time, if both theories explain the same event/phenomenon equally well?	Please ***explain*** what you mean by "theory" and how you would judge whether one theory is "better" than another. Use example(s) to illustrate your answer if necessary.
3. Do you think science is influenced by the society and culture in which it is practiced?	Please ***explain*** how society and culture affect science **OR** ***explain*** why science is not affected by society and culture. Use example(s) to illustrate your answer if necessary.
4. Do you think scientists use their imagination and creativity during different phases of their scientific investigations (e.g., planning, hypothesizing, designing experiments, making observations, analyzing data, interpreting findings, reporting results, etc.)?	Please ***explain*** how imagination and creativity affect the work of scientists **OR** ***explain*** why imagination and creativity does not affect the work of scientists. Use example(s) to illustrate your answer if necessary.

5.	Do you think the scientific theories may still change in the future, even when scientists conduct all investigations correctly?	Please ***explain*** why you think scientific theories changes **OR** ***explain*** why they do not change over time. Use example(s) to illustrate your answer if necessary.
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?	Please ***explain*** the difference between discovering scientific theories and inventing scientific theories. If you can, please use an example to illustrate your idea.
7.	Do you think that scientists *discover* scientific laws (e.g., the law of universal gravitation) just like gold miners "discover" gold, or that scientists *invent* scientific theories somewhat like artists "invent" sculptures?	Please ***explain*** the difference between discovering scientific laws and inventing scientific laws. If you can, please use an example to illustrate your idea.
8.	How do you think scientific theories are different from scientific laws?	Please ***explain*** the difference between a scientific theory and a scientific law. If you can, please use an example to illustrate your idea.
9.	Do you think scientists make different observations of the same event/phenomenon because of various background knowledge and personal experience?	Please ***explain*** why scientists' observations are the same **OR** why they may be different. Use example(s) to illustrate your answer if necessary.
10.	Do you think all scientists follow the same fixed, step-by-step "scientific method" when they investigate (i.e., defining the problem, gathering information, forming a hypothesis, collecting data, testing hypothesis, drawing conclusions, reporting results)?	Please ***explain*** why you think there is a single universal step-by-step scientific method OR different scientific methods. Use example(s) to illustrate your answer if necessary.

Results and Discussion

High validity and reliability are two important indicators of any standardized instruments of high quality. However, due to the empirical components involved in the development of the SUSI, 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 stresses the trustworthiness and authenticity of data (Erlandson, Harris, Skipper, & Allen, 1993) rather than the consistency across constructs and measurements. In our study, our first priority is to establish an inherent validity for the SUSI instrument, by analyzing the consistency between students' responses to each Likert items and the written response related to that item. For each item, a percentage of "Consistent" student responses was calculated by dividing the number of "Consistent" codes by the sum of the number of "Consistent" codes plus "Not Consistent" codes and multiplying by 100. The percentage of "Not Addressed" responses was calculated by dividing the number of "Not Addressed" codes by the total number of responses ("C" + "NC" + "NA") and multiplying by 100. The Items that were "Not Addressed" by 70% or more of the respondents were not analyzed for consistency. Then those items with a "NA" of <70% were further classified as

"Consistent" if the percentage of "Consistent" codes achieved 80% or above, "Not Consistent" if the percentage of "Consistent" codes was below 80%. Table 2 presents the results based on the analysis of student responses to all 58 Likert items and 10 open-ended questions, by both topic and country. The detailed item-by-item analysis results are presented in Appendix A.

Table 2. Percentage of Items That Were Scored "Consistent", or "Not Consistent", by Topic Question and by Country

Topic Question	**USA (n=60)**		**China (n=60)**	
	Number of Items "Consistent"	Number of Items "Not Consistent"	Number of Items "Consistent"	Number of Items "Not Consistent"
Q1:Characteristics of Scientific Knowledge (9 items)	2 (22%)* 1F, 1G	2 (22%)** 1A, 1B	0 (0%)	1 (11%) 1A
Q2: Acceptance of Competing Theories (7 items)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Q3: Social and Cultural Influence (7 items)	4 (67%) 3A-D	0 (0%)	1 (17%) 3A	0 (0%)
Q4: Creativity and Imagination (6 items)	1 (17%) 4A	0 (0%)	1 (17%) 4A	0 (0%)
Q5: Tentative Nature of Theories (4 items)	4 (100%) 5A-D	0 (0%)	2 (50%) 5A, 5B	0 (0%)
Q6: Theories: Discovery vs. Invention (5 items)	1 (20%) 6A	4 (80%) 6B-E	3 (60%) 6A, 6B, 6E	2 (40%) 6C, 6D
Q7: Laws: Discovery vs. Invention (5 items)	2 (40%) 7A, 7B	3 (60%) 7C-E	5 (100%) 7A-E	0 (0%)
Q8: Differences between Theories & Laws (5 items)	2 (40%) 8A, 8B	0 (0%)	0 (0%)	0 (0%)
Q9: Nature of Observations (5 items)	2 (40%) 9A, 9C	0 (0%)	2 (40%) 9A, 9C,	0 (0%)
Q10: Scientific Methods (6 items)	3 (50%) 10A, 10C, 10D	0 (0%)	2 (33%) 10A,10C	0 (0%)
Total (58 items)	21 (36%)	9 (16%)	16 (28%)	3 (5%)

Note. * This percentage was calculated by dividing the number of "Consistent" Likert items by the total number of Likert Items under each topic question.

** This percentage was calculated by dividing the number of "Not Consistent" Likert items by the total number of Likert Items under each topic question.

The results presented in Table 2 indicate that the ambiguity level associated with use of SUSI was relatively low: the Likert items labeled as 'Not Consistent' was 16% for the USA sample, 5% for the Chinese sample, respectively. Those items are 1A, 1B, 6B, 6C, 6D, 6E, 7C, 7D, and 7E. Further examination suggested that those items should either be revised or deleted. Item 1F was also excluded for further analysis because the item was initially designed to target the Empirical aspect of science. The following is a list of the items to be removed:

Item 1A: Scientific knowledge is composed of solely facts that are proven to be true.
Item 1B: Scientific knowledge is solely based on direct observation.
Item 6B: Scientists discover theories from experimental facts.
Item 6C: Some scientists may discover theories by chance, but other scientists may invent theories from facts they already know.
Item 6D: Scientific theories were invented by scientists to explain the observed or perceived natural phenomenon.
Item 6E: Scientific theories were invented and tested by scientists.
Item 7C: Some scientists may discover laws by chance, but other scientists may invent laws from facts they already know.
Item 7D: Scientific laws are invented by scientists to describe or interpret the observed or perceived relationships of natural phenomenon.
Item 7E: Scientific laws are invented and tested by scientists.
Item 1F: Scientific knowledge is essentially testable against the natural world.

Table 3 Analysis of Reliability for the Seven Aspects of Nature of Science and Scientific Inquiry by Country

Aspects	**USA (n=60)**	**China (n=60)**	**Turkey (n=60)**
Tentativeness 1E, 1G, 2A, 2G, 5A-D	0.039	0.44	-0.03
Nature of Observations 9A-E	0.43	0.25	0.085
Subjectivity and Objectivity (*) 2A-G	-0.072	0.37	0.17
Creativity/rationality 1I, 4A-F	0.53	0.52	0.72
Social and cultural embeddedness 1 D, 1H, 3A-F	0.86	0.64	0.84
Scientific theories and laws 6A, 7A, 7B, 8A, 8B, 8C, 8D, 8E	0.30	0.34	0.45
Scientific methods 10A-F	0.53	0.62	0.43
Overall (48 items)	0.61	0.68	0.66

Table 3 presents the reliability results (Cronbach Alpha values) by NOS aspect and by country after the item removal. The reliability (Alpha) of Likert items in three NOS aspects (i.e., creativity/rationality, social and cultural embeddedness, & scientific methods) is consistently high across the three samples, which is also consistent with the results from students written responses and selected interviews. In the next section, we will focus on the aspects with a relatively lower reliability for closer examinations.

Tentativeness. The reliability alpha for this aspect is low. This may be due to the scope of content addressed here. For instance, some items discuss the scientific knowledge in general while other items focus on the tentative nature of scientific theories. When considering only the items that discuss whether and /or why theories change (i.e., Items 5A-D), then the reliability alpha increased to 0.32 for Turkey sample and 0.51 for both American and Chinese samples.

Nature of Observations. Students' written responses in this aspect can be classified into two major groups: some stated that scientists' observations of the same events might be different due to various personal knowledge and experience, whereas others believed that scientists' observations are the same because scientists use the same "scientific method" to get results. There were also students who confused "observations" with "interpretations" or "inferences" in their free responses. Therefore, the Likert items in this aspect should be further examined for clarity and readability. Finally, the idea of triangulation (i.e., Scientists' observations are similar because scientists use different methods to verify results, Item 9E) seems vague to students. The Alpha value was improved to 0.4-0.5 for all three samples with the deletion of item 9E.

Subjectivity and Objectivity. It appeared that the majority of students in our samples were not familiar with the NOS content discussed in the Likert statements. Most students stated that scientists would judge theories based on evidence and experimental testing results. Few students seemed to be aware of the convention of knowledge validation in science such as "parsimony" and "paradigms". The average "Not Addressed" rates across the seven items in this aspect were over 90% for both Chinese and American groups. In other words, these items seem to fail to capture students' understandings. Since the subjective/objective nature of science was already presented in both "Nature of Observations" aspect (Item 9A-E) and "Social and Cultural Embeddedness" aspect (Items 3A-F) in SUSI, it is suggested that the Likert items in this aspect either be removed or substantially revised.

Scientific theories and laws. Students demonstrated most mis-understandings and confusions in responding to the Likert items related to this aspect of NOS. Some students interpreted the term "discover" or "invent" differently from what was defined in the topic questions 6 and 7. Some students believed that scientific theories could be both discovered and invented by scientists. For instance, one student selected "agree" or "strongly agree" in all five items under topic question 6, which indicates a combination of both informed and non-informed views. However, what she really believed was that scientists discover certain facts or information that led to the invention or creation of a theory, which was confirmed by the information obtained from a follow-up interview and her written response. She wrote, "Discovering a scientific theory is when a scientist experiments a hypothesis to discover what is going to happen as a result. Scientists can also invent theories from data collected and research done."

This indicates that further refinement of Likert statements in this aspect is needed.

Conclusions and Recommendations

This study collected multiple resources of information such as standards documents, research literatures, numerical and written responses, and interviews to construct the SUSI items. A further revised version of the SUSI has been recommended for future studies and appended in the paper (see Appendix C.). This version includes revisions in the structure of the instrument to improve clarity and to make the instrument more readable. It is suggested that more diverse samples with larger sample size should be used to further validate the instrument.

Students possess diverse perceptions of the nature of science and scientific inquiry. A simple Likert scale instrument or multiple choice tests will not be able to detect students' combined conceptions and/or conflicting views as well as the SUSI did. The SUSI can also be used to effectively assess students' partial understandings of certain NOS issues that involve multiple aspects, such as the both evolution and revolution aspects of the tentative nature of science.

The quantitative and qualitative nature of the SUSI instrument can help teachers and/or researchers to diagnose student understanding of nature of science and scientific inquiry. It also allows the use of inferential statistics to determine effects of any instructional interventions in both small and large-scale studies. In addition, the SUSI will be most suitable for conducting cross-cultural comparison studies because cultural influences may be revealed in the responses to open-ended questions.

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Appendix A. Analysis of Consistency between Student Reponses to Likert Items and Written Responses By Country

Items	USA (n=60)		China (n=60)	
	Consistent Responses (%)	Not Addressed Responses (%)	Consistent Responses (%)	Not Addressed Responses (%)
1A	**78**	55	**55**	67
1B	**42**	60	85	78
1C	80	92	100	95
1D	100	97	100	98
1E	71	72	N/A	100
1F	88	46	60	92
1G	88	60	N/A	100
1H	100	93	N/A	100
1I	100	95	88	87
2A	100	98	86	88
2B	100	97	93	77
2C	50	97	100	97
2D	N/A	100	67	95
2E	43	88	100	98
2F	33	95	100	95
2G	100	85	91	82
3A	94	18	96	55
3B	98	28	100	70
3C	100	50	100	85
3D	86	27	100	95
3E	72	70	100	97
3F	100	90	100	98
4A	100	58	100	65
4B	73	75	100	87
4C	92	78	90	83
4D	93	74	100	88
4E	75	93	100	97
4F	100	98	50	97
5A	98	30	96	22
5B	86	42	81	73
5C	93	53	75	93
5D	100	65	92	58
6A	87	50	85	22
6B	**75**	67	85	57
6C	**62**	43	**73**	32
6D	**79**	45	**79**	28
6E	**75**	67	83	30
7A	94	48	93	28
7B	100	58	92	58

7C	**60**	42	82	37
7D	**79**	45	92	37
7E	**67**	65	89	41
8A	83	30	89	85
8B	89	53	78	85
8C	75	87	83	90
8D	67	90	75	80
8E	56	85	100	85
9A	97	51	98	27
9B	100	93	67	90
9C	82	63	86	63
9D	75	93	100	85
9E	20	91	86	88
10A	87	60	91	63
10B	67	90	71	88
10C	49	22	100	68
10D	69	45	100	80
10E	89	84	90	83
10F	64	81	88	87

Items that were addressed, but have Consistent percentages less than 80% are in bold.

Appendix B. SUSI (English Translation)

ID #__________ **Date _________**

Views about the Nature of Scientific Knowledge (VANSK)

Please indicate the degree to which you agree or disagree with EACH statement below 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

8. Do you think scientific knowledge is …..?					
A. Composed of solely facts that are proven to be true.	SD	D	U	A	SA
B. Solely based on direct observation.	SD	D	U	A	SA
C. A product of the scientific method.	SD	D	U	A	SA
D. A part of social and cultural traditions.	SD	D	U	A	SA
E. Durable, that is, substantially stable over time.	SD	D	U	A	SA
F. Essentially testable against the natural world.	SD	D	U	A	SA
G. Certain or exact.	SD	D	U	A	SA
H. Subject to reviews by peer scientists.	SD	D	U	A	SA
I. Heavily Dependent on logical arguments.	SD	D	U	A	SA
Please ***explain*** how scientific knowledge is different from knowledge developed in other disciplines such as art, philosophy, or mathematics.					

9. Do you think scientists will accept two different theories at the same time, if both theories explain the same event/phenomenon equally well?					
A. Yes, because scientists cannot tell which theory is better, they may consider both useful for the time being.	SD	D	U	A	SA
B. Yes, because scientists interpret evidence differently based on their theories.	SD	D	U	A	SA
C. No, because scientists tend to favor one theory over another.	SD	D	U	A	SA
D. No, because scientists tend to accept the simpler theory.	SD	D	U	A	SA
E. No, because scientists tend to accept the theory that is favored by more expert scientists.	SD	D	U	A	SA
F. No, because scientists tend to reject the theory inconsistent with the presently accepted scientific theories and laws.	SD	D	U	A	SA
G. No, because scientists will accept the true theory only.	SD	D	U	A	SA

Please ***explain*** what you mean by "theory" and how you would judge whether one theory is "better" than another. Use example(s) to illustrate your answer if necessary.					
10. **Do you think science is influenced by the society and culture in which it is practiced?**					
A. Yes, because scientists who conduct scientific research are influenced by their culture and society.	SD	D	U	A	SA
B. Yes, because the values and expectations of the culture determine <u>what</u> science is conducted, interpreted, and accepted.	SD	D	U	A	SA
C. Yes, because the values and expectations of the culture determine <u>how</u> science is conducted, interpreted, and accepted.	SD	D	U	A	SA
D. No, all cultures conduct scientific research the same way because science is universal and independent of culture and society.	SD	D	U	A	SA
E. No, because scientists are trained to conduct "pure", unbiased research.	SD	D	U	A	SA
F. No, because the purpose of scientific research is to find the absolute truth without the influence of the society and culture.	SD	D	U	A	SA
Please ***explain*** how society and culture affect science **OR** ***explain*** why science is not affected by society and culture. Use example(s) to illustrate your answer if necessary.					
11. Do you think scientists use their imagination and creativity during different phases of their scientific investigations (e.g., planning, hypothesizing, designing experiments, making observations, analyzing data, interpreting findings, reporting results, etc.)?					
A. Yes, scientists may use their imagination and creativity during the planning and hypothesizing phase.	SD	D	U	A	SA
B. Yes, scientists may use their imagination and creativity during data collection phase.	SD	D	U	A	SA
C. Yes, scientists may use their imagination and creativity during data analysis phase.	SD	D	U	A	SA
D. Yes, scientists may use their imagination and creativity during interpretation and reporting phase.	SD	D	U	A	SA
E. No, imagination or creativity is in conflict with logical reasoning in science.	SD	D	U	A	SA
F. No, imagination or creativity can interfere with the true facts to be discovered. (This sentence was taken from my students' writing.)	SD	D	U	A	SA

Please ***explain*** how imagination and creativity affect the work of scientists **OR** ***explain*** why imagination and creativity does not affect the work of scientists. Use example(s) to illustrate your answer if necessary.

12. Do you think the scientific theories may still change in the future, even when scientists conduct all investigations correctly?

A. Yes, Scientific theories will be gradually refined or modified as experimental techniques/instruments improve.	SD	D	U	A	SA
B. Yes, old scientific theories maybe abandoned and be replaced with new theories in light of new evidence.	SD	D	U	A	SA
C. Yes, scientific theories changes because new scientists may reinterpret or reconceptualize existing observations.	SD	D	U	A	SA
D. No, correctly done experiments yield unchangeable theories or facts.	SD	D	U	A	SA

Please ***explain*** why you think scientific theories changes **OR** ***explain*** why they do not change over time. Use example(s) to illustrate your answer if necessary.

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 discover theories that are embedded in nature.	SD	D	U	A	SA
B. Scientists discover theories from experimental facts.	SD	D	U	A	SA
C. Some scientists may discover theories by chance, but other scientists may invent theories from facts they already know.	SD	D	U	A	SA
D. Scientific theories were invented by scientists to explain the observed or perceived natural phenomena.	SD	D	U	A	SA
E. Scientific theories were invented and tested by scientists.	SD	D	U	A	SA

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

7. Do you think that scientists *discover* scientific laws (e.g., the law of universal gravitation) just like gold miners "discover" gold, or that scientists *invent* scientific theories somewhat like artists "invent" sculptures?

A. Scientists discover laws that are embedded in nature.	SD	D	U	A	SA
B. Scientists discover laws from experimental facts.	SD	D	U	A	SA
C. Some scientists may discover laws by chance, but other scientists may invent laws from facts they already know.	SD	D	U	A	SA
D. Scientific laws are invented by scientists to describe or interpret the observed or perceived relationships of natural phenomena.	SD	D	U	A	SA
E. Scientific laws are invented and tested by scientists.	SD	D	U	A	SA

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

11. How do you think scientific theories are different from scientific laws?

A. Scientific laws are certain but theories are uncertain.	SD	D	U	A	SA
B. Scientific laws are theories that have been proven.	SD	D	U	A	SA
C. Scientific theories explain scientific laws.	SD	D	U	A	SA
D. A scientific law is a part of a scientific theory.	SD	D	U	A	SA
E. Scientific theories and scientific laws are two different categories of scientific knowledge.	SD	D	U	A	SA

Please ***explain*** the difference between a scientific theory and a scientific law. If you can, please use an example to illustrate your idea.

12. **Do you think scientists make different observations of the same event/phenomenon because of various background knowledge and personal experience?**

A. Scientists' observations may be different because the scientists' prior knowledge affects their observations.	SD	D	U	A	SA
B. Scientists with similar background knowledge are trained to make similar observations.	SD	D	U	A	SA
C. Scientists' observations are the same because scientists are objective.	SD	D	U	A	SA
D. Scientists' observations are the same because observations are true facts.	SD	D	U	A	SA
E. Scientists' observations are similar because scientists use different methods to verify results.	SD	D	U	A	SA

Please ***explain*** why scientists' observations are the same **OR** why they may be different. Use example(s) to illustrate your answer if necessary.

10. Do you think all scientists follow the same fixed, step-by-step "scientific method" when they investigate (i.e., defining the problem, gathering information, forming a hypothesis, collecting data, testing hypothesis, drawing conclusions, reporting results)?

A. Yes, because the scientific method is necessary to generate and validate theories.	SD	D	U	A	SA
B. Yes, when scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
C. No, there is no single universal step-by-step scientific method.	SD	D	U	A	SA
D. No, scientists use any method (including imagination and creativity) that can produce fruitful results.	SD	D	U	A	SA
E. No, scientific findings may be accidental.	SD	D	U	A	SA
F. No, scientists may use different methods to investigate, but all results will eventually be verified or confirmed by using the scientific method.	SD	D	U	A	SA
Please ***explain*** why you think there is a single universal step-by-step scientific method OR different scientific methods. Use example(s) to illustrate your answer if necessary.					

If you have additional thoughts and/or questions about the nature of scientific knowledge, please describe below.

Taxonomy of Views about Nature of Scientific Knowledge (NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002)

Aspect	Explanation/Description	Items
Tentativeness	Scientific knowledge is simultaneously reliable and tentative. 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.	1A(-); 1E (+); 1G(-); 2A (+); 2G(-); 5A (+); 5B (+); 5C(+); 5D (-);
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world. Science aims to be testable.	1B (-); 1F(+),
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.	1 B(-); 9A(+); 9B(+); 9C(-); 9D(-); 9E(+);
Subjectivity/objectivity	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.	2A (+); 2B(+); 2C(+); 2D(+); 2E(+); 2F(+); 2G (-);
Creativity/rationality	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.	1I (+); 4A(+); 4B(+); 4C(+); 4D(+); 4E(-); 4F(-); 10D(+);
Social and cultural embeddedness	Science is part of social and cultural traditions. People from all culture contribute to science. Science requires accurate record keeping and peer review and aims to be replicable. 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.	1D(+); 1H (+); 3A (+); 3B(+); 3C(+); 3D(-); 3E(-); 3F(-);
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 inferred 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.	6A (-); 6B(-); 6C (-); 6D(+); 6E(+); 7A(-); 7B(-); 7C(-); 7D(+); 7E (+); 8A (-); 8B (-); 8C(+); 8D(-); 8E(+)
Multiple methods of scientific investigations	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.	1C(-); 3D(-); 10A(-); 10B (-); 10C(+); 10D(+); 10E(+); 10F(-)

Appendix C. Revised SUSI (English Translation)

ID #__________ **Date _________**

STUDENT UNDERSTANDING OF SCIENTIFIC INQUIRY
July 2005-revision

Please indicate the degree to which you agree or disagree with EACH statement below 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. Characteristics of Scientific Knowledge					
A. Scientific knowledge is a product of the scientific method alone.	SD	D	U	A	SA
B. Scientific knowledge is affected by social and cultural traditions.	SD	D	U	A	SA
C. Scientific knowledge is durable, that is, substantially the same over time.	SD	D	U	A	SA
D. Scientific knowledge is certain or exact.	SD	D	U	A	SA
E. Scientific knowledge is subject to review by other scientists.	SD	D	U	A	SA
F. Scientific knowledge is heavily dependent on logical arguments.	SD	D	U	A	SA

Please ***explain*** how scientific knowledge is different from knowledge developed in other disciplines such as art, philosophy, or mathematics. Use example(s) to illustrate your answer.

2. Acceptance of Theories in Scientific Community					
A. Scientists will accept two different theories at the same time, when both theories explain the same event/phenomenon equally well because if scientists cannot tell which theory is better, they may consider both useful for the time being.	SD	D	U	A	SA
B. Scientists will accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well because scientists interpret evidence differently based on their theories.	SD	D	U	A	SA
C. Scientists will **not** accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well because scientists tend to favor one theory over another.	SD	D	U	A	SA
D. Scientists will **not** accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well, because scientists tend to accept the simpler theory.	SD	D	U	A	SA
E. Scientists will **not** accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well, because scientists tend to accept the theory that is favored by more expert scientists.	SD	D	U	A	SA
F. Scientists will **not** accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well, because scientists tend to reject the theory inconsistent with the presently accepted scientific theories and laws.	SD	D	U	A	SA
G. Scientists will **not** accept two different theories at the same time, even though both theories explain the same event/phenomenon equally well because scientists will accept the true theory only.	SD	D	U	A	SA
Please ***explain*** how you think scientists deal with competing theories when both theories seem to have evidence to support them. Use example(s) to illustrate your answer.					

3. Social and Cultural Influence on Science					
A. Scientists who conduct scientific research are influenced by their culture and society.	SD	D	U	A	SA
B. The values and expectations of the culture determine what science is conducted, interpreted, and accepted.	SD	D	U	A	SA
C. The values and expectations of the culture determine how science is conducted, interpreted, and accepted.	SD	D	U	A	SA
D. All cultures conduct scientific research the same way because science is universal and independent of culture and society.	SD	D	U	A	SA
E. Scientists are trained to conduct "pure," unbiased research, therefore their work is not affected by culture and society.	SD	D	U	A	SA
F. The purpose of scientific research is to find the absolute truth without the influence of the society and culture.	SD	D	U	A	SA
Please ***explain*** how society and culture affect science **OR** ***explain*** why science is not affected by society and culture. Use example(s) to illustrate your answer.					

4. Imagination and Creativity in Scientific Investigations					
A. Scientists use their imagination and creativity during planning and hypothesizing.	SD	D	U	A	SA
B. Scientists use their imagination and creativity during data collection phase.	SD	D	U	A	SA
C. Scientists use their imagination and creativity during data analysis.	SD	D	U	A	SA
D. Scientists use their imagination and creativity during interpretation and reporting.	SD	D	U	A	SA
E. Scientists do **not** use their imagination and creativity because imagination and creativity is in conflict with logical reasoning in science.	SD	D	U	A	SA
F. Scientists do **not** use their imagination and creativity because imagination and creativity can interfere with the true facts to be discovered.	SD	D	U	A	SA
Please ***explain*** how imagination and creativity affect the work of scientists **OR *explain*** why imagination and creativity does not affect the work of scientists. Use example(s) to illustrate your answer.					

5. **Nature of Scientific Theories**					
A. Scientific theories will be gradually refined or modified as experimental techniques/instruments improve.	SD	D	U	A	SA
B. Old scientific theories may be abandoned and be replaced with new theories in light of new evidence.	SD	D	U	A	SA
C. Scientific theories change because new scientists may reinterpret or reconceptualize existing observations.	SD	D	U	A	SA
D. Scientific theories that are built on correctly done experiments will not change.	SD	D	U	A	SA
Please ***explain*** why you think scientific theories change **OR** ***explain*** why they do not change over time. Use example(s) to illustrate your answer.					

6. Scientific Laws vs. Theories					
A. Scientists <u>discover</u> (or find) **theories** that have been existing in the natural world.	SD	D	U	A	SA
B. Scientists <u>discover</u> (or find) **laws** that have been existing in the natural world.	SD	D	U	A	SA
C. Scientists <u>discover</u> (or find) information to create scientific **laws.**	SD	D	U	A	SA
D. Scientific laws are certain but theories are uncertain.					
E. Scientific laws are theories that have been proven.	SD	D	U	A	SA
F. Scientific theories explain scientific laws.	SD	D	U	A	SA
G. Scientific theories do not become scientific laws because theories and laws are two different categories of scientific knowledge.	SD	D	U	A	SA
Please ***explain*** the difference between a scientific theory and a scientific law. Use example(s) to illustrate your answer.					

7. Nature of Observations					
A. Scientists' observations of the same events may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B. Scientists with similar background knowledge are trained to make similar observations of the same events.	SD	D	U	A	SA
C. All scientists' observations of the same events must be the same because scientists are objective.	SD	D	U	A	SA
D. All scientists' observations of the same events are the same because observations are true facts.	SD	D	U	A	SA
E. All scientists' observations of the same events are similar because scientists use a variety of methods to verify results.	SD	D	U	A	SA
Please ***explain*** why scientists' observations are the same **OR** why they may be different. Use example(s) to illustrate your answer.					

8. Processes of Science					
A. In order to generate and validate theories, scientists must use the universal step-by-step scientific method.	SD	D	U	A	SA
B. When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
C. There is no single, universal step-by-step scientific method.	SD	D	U	A	SA
D. Scientific findings may be accidental.	SD	D	U	A	SA
E. Scientists use a variety of methods that can produce fruitful results.	SD	D	U	A	SA
F. Scientists may use different methods to investigate, but all results will eventually be verified or confirmed by using the scientific method.	SD	D	U	A	SA
Please ***explain*** why you think there is a single, universal step-by-step scientific method that is always used by scientists **OR** why you think that scientists may different methods in science. Use example(s) to illustrate your answer.					

Taxonomy of Views about Nature of Scientific Knowledge (NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) Revised July 2005

Aspect	Explanation/Description	Items
Tentativeness	Scientific knowledge is simultaneously reliable and tentative. 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.	1C (+); 2A (+); 2G(-); 5A (+); 5B (+); 5C(+); 5D (-)
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.	7A (+); 7B (+); 7C (-); 7D (-); 7E (+)
Subjectivity/objectivity	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.	2A (+); 2B(+); 2C(+); 2D(+); 2E(+); 2F(+); 2G (-)
Creativity/rationality	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.	1G (+); 4A (+); 4B (+); 4C (+); 4D (+); 4E (-); 4F (-);
Social and cultural embeddedness	Science is part of social and cultural traditions. People from all culture contribute to science. Science requires accurate record keeping and peer review and aims to be replicable. 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.	1B (+); 1F (+); 3A (+); 3B(+); 3C(+); 3D(-); 3E(-); 3F(-)
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 inferred 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.	6A (-); 6B (-); 6C (+); 6D (-); 6E(-); 6F(+); 6G(+)
Multiple methods of scientific investigations	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.	1A (-); 3D (-); 8A (-); 8B (-); 8C (+); 8D (+); 8E (+); 8F (-)