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## Pre-service teachers' views about the nature of science and scientific inquiry: The South African case

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The convenience sample used in the study reported on here consisted of 91 students enrolled in the primary and middle school Postgraduate Certificate in Education course for 2 consecutive years at a South African university. We used the Student Understanding of Science and Science Inquiry instrument to answer questions about these students' knowledge of the nature of science and scientific inquiry compared to that published for pre-service primary and middle school teachers from China, Turkey, and the United States of America (USA), whether the changes proposed for the instrument enhanced its reliability, and whether any correlation could be found to these students' age and educational factors. The findings show that these South African student teachers shared similar levels of knowledge of the nature of science and scientific inquiry to their counterparts from Turkey and the USA, all of which were less sophisticated than that of the Chinese students. The test was found to have a high degree of reliability in the South African context, with the proposed changes to the instrument doing little to enhance this. The older students and those who did not study any tertiary science or mathematics courses scored statistically significantly higher. We suggest that the confirmatory nature of tertiary practical science work and exposure to the complexity of science in postgraduate work or employment in industry could explain these findings.

**Keywords:** international comparison; nature of science knowledge; pre-service teachers; scientific inquiry

### Introduction

Knowledge about the nature of science (NOS) refers to “the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge” (Abd-El-Khalick, Bell & Lederman, 1998:418). This is related to knowledge about science inquiry (SI), which refers to “the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge” (Lederman, JS, Lederman, Bartos, Bartels, Meyer & Schwartz, 2014:65). While acknowledging a lack of consensus, in some spheres, as to what a desirable NOS knowledge entails, NG Lederman (2007:833) argues that at the level relevant to school science education, “little disagreement exists among philosophers, historians, and science educators,” namely that this involves a view that scientific knowledge is “tentative ... empirically based ... subjective ... necessarily involves human inference, imagination and creativity ... and is socially and culturally embedded.” Similarly, JS Lederman et al. (2014:68) acknowledge multiple views on what a desirable understanding of SI involves, after which they propose a list, which encapsulates commonalities in the literature: “scientific investigations all begin with a question ... there is no single set of steps followed in all investigations ... inquiry procedures are guided by the questions asked ... inquiry procedures can influence results ... conclusions must be consistent with the data collected ... scientific data are not the same as scientific evidence ... explanations are developed from a combination of collected data and what is already known.” These descriptions of desirable knowledge of the nature of science and SI can together be termed a sophisticated knowledge of science and scientific inquiry (KNOSSI).

The extent of sophistication of a student's KNOSSI has been shown to impact the depth to which he/she learns science and appreciates and uses science in decision-making regarding socio-scientific issues (Deng, Chen, Tsai & Chai, 2011). Teachers with more sophisticated KNOSSI are more likely to engage deeply with the subject and teach in an inquiry-oriented manner (Abd-El-Khalick, 2013), which is more likely to promote the development of critical thinking and deep learning of science (Hattingh & Killen, 2003; Stott, 2008). Therefore, unsurprisingly, there has been an international thrust to promote KNOSSI development at all levels of education. South Africa's alignment with such views is evidenced in the current Curriculum and Assessment Policy Statement (CAPS) where Specific Aim 1 focuses on investigations and Specific Aim 3 on the use of the context of science and society to illustrate the tentative, social, and contested natures of science (Department of Basic Education [DBE], Republic of South Africa, 2011).

### Problem Statement

This South African curricular emphasis has likely contributed to various positive aspects related to KNOSSI in the South African context. These include: Gaigher, Lederman and Lederman's (2014) measurement of relatively high prevalence of informed views among South African learners for certain aspects of SI; Ibrahim, Buffler and Lubben's (2009)'s findings of high levels of NOS sophistication among students in a first-year physics course; positive beliefs towards inquiry-based teaching, even among physical sciences teachers teaching in rural parts of South Africa (Ramnarain & Hlatswayo, 2018). However, as illustrated in Ramnarain and Hlatswayo's (2018)

study, which found limited enactment of inquiry-based teaching, promotion of KNOSSI has fallen far short of curricular ideals, particularly in low-quintile (poor) schools. Reasons for a mismatch between curricular emphasis and beliefs, and actual practises include low emphasis of KNOSSI in science textbooks (Ramnarain & Chanetsa, 2016; Ramnarain & Padayachee, 2015), naïve KNOSSI conceptions held by physical sciences teachers (Dudu, 2014), and physical sciences teachers' pedagogical orientations. In a survey conducted by Ramnarain and Schuster (2014), teachers from higher-quintile (richer) schools indicated alignment to guided inquiry shown to be potentially effective in improving learner NOS sophistication (Bell & Linn, 2002), but those from lower-quintile schools preferred the greater control provided by direct instruction, which they considered necessary for their teaching context.

Ramnarain and Schuster's (2014) largely quantitative study deviated from the small-sample, qualitative case studies which form the bulk of the South African literature on KNOSSI. Against the general trend of focussing on KNOSSI teaching and learning in upper secondary, or higher education, JS Lederman, Lederman, Bartels, Jimenez, Akubo, Aly, Bao, Blanquet, Blonder, De Andrade, Bunting, Cakir, EL-Deghaidy, ElZorkani, Gaigher, Guo, Hakanen, Hamed Al-Lal, Han-Tosunoglu, Hattingh, Hume, Irez, Kay, Dogan, Kremer, Kuo, Lavonen, Lin, Liu, Liu, Liu, Lv, Mamlok-Naaman, McDonald, Neumann, Pan, Picholle, Rivero García, Rundgren, Santibáñez-Gómez, Saunders, Schwartz, Voitle, Von Gyllenpalm, Wei, Wishart, Wu, Xiao, Yakaki and Zhou (2019), performed a study across 18 countries with 2,364 upper primary school learners, which included South Africa. The aim of their study was to gain information on what, if anything, learners have learnt about SI during their primary school years and what their beginning knowledge was as they started high school. The KNOSSI of the teachers who taught at primary and middle school level was relevant to address the high prevalence of naïve conceptions which they found at this level across the different countries. JS Lederman et al. (2019) assert that much like research on understandings of NOS, neither learners nor teachers typically hold informed views of SI. Although JS Lederman et al. (2019) refrained from performing inter-country comparisons in their study on learners, benchmarking South African teachers' KNOSSI against that of teachers in other countries is of obvious interest and is lacking from the existing literature.

In order to perform this benchmarking, an existing, validated KNOSSI test, which has been administered to primary and middle school teachers in other countries, is needed. This is provided by the Student Understanding of Science and Scientific Inquiry (SUSSI) instrument, which has been developed, validated, and used to collect data from primary and middle school student teachers in China,

Turkey, and the USA (Liang, Chen, Chen, Kaya, Adams, Macklin & Ebenezer, 2005, 2006, 2009). Use of this test enables one to respond to Liang et al.'s (2009) call for study into the applicability of SUSSI in other countries and whether proposed modifications, to form SUSSI-3, enhance the reliability of the instrument.

This research is therefore guided by the following questions: (1) How does the sampled South African pre-service teachers' knowledge of the nature of science and scientific inquiry (KNOSSI) compare to that published for pre-service elementary and middle school teachers from China, Turkey, and the USA? (2) Do the changes proposed for SUSSI-3 enhance the reliability of the instrument? and (3) How have age and educational factors affected the KNOSSI knowledge of the sampled South African pre-service teachers? The answer to the first research question is of particular interest to South African scholars, whereas the answers to the other two research questions are applicable to the broader community of researchers and practitioners in science education.

#### Literature Review

A number of KNOSSI tests have been developed over the last decades. These are of three main kinds: argumentative-resource, unidimensional, and multidimensional frameworks. Employment of an argumentative-resource framework requires observation of the participants as they engage in argumentative discourse, which was not feasible in this study. The outcome of a unidimensional framework is categorisation of each participant along a continuum from empiricist to constructivist perspectives. However, since people tend to hold a mixture of KNOSSI views (Dudu, 2014), a multidimensional framework, which is better suited to capturing the complexity of the situation, was considered more appropriate for this study.

Early KNOSSI tests consisted of researcher-determined items that suffered from high degrees of participant misunderstanding (Lederman, NG & O'Malley, 1990). To increase validity, Aikenhead and Ryan (1992) developed the Views on Science-Technology-Society (VOSTS) test by extracting items from participant responses. VOSTS was developed and validated over several years and provided a substantial improvement in NOS-test validity. However, it requires significant amounts of time to complete, and some items appear to be redundant (Liang et al., 2006). The Views of Nature of Science (VNOS) questionnaire, developed by NG Lederman, Abd-El-Khalick, Bell and Schwartz (2002), followed as the most influential NOS tool. Schwartz, Lederman and Lederman (2008) expanded KNOSSI testing to include a focus on knowledge of scientific investigation by developing the Views of Scientific Inquiry (VOSI) instrument. This was expanded and revised by JS Lederman et al. (2014) into the Views about Scientific Inquiry (VASI) instrument.

The instrument used in this study, SUSI, was modified from NOS frameworks, including the VOSTS and VNOS. It measures views of the NOS dimensions, common to NOS tests (Lederman, N, Wade & Bell, 1998), listed in Liang et al. (2009:989, 991, 994): (1) "Observations and inferences": scientists' perspectives influence both what they observe and the inferences they make from these observations; (2) "Tentativeness of scientific knowledge": scientific knowledge is both durable due to its rigorous origin and tentative due to the possibility of its revision in light of new evidence or reconceptualization; (3) "Scientific theories and laws": laws describe and theories explain generalised relationships; (4) "Social and cultural embeddedness in science": the values and expectations of the society and culture in which science is practised influence what and how science is conducted, interpreted, and accepted; (5) "Creativity and rationality in science": scientists apply creativity and logical reasoning to their observations and inferences throughout their scientific investigations; (6) "Scientific methods": there is no single universal step-by-step method that all scientists follow.

Since SUSI claims to measure knowledge of SI as well as knowledge of the NOS, a brief comparison between SUSI and VASI is considered valuable. VASI (Lederman, JS et al., 2014) is built on eight essential aspects of knowledge about scientific inquiry. One of these ("There is no single set and sequence of steps followed in all investigations") corresponds directly with one of the SUSI dimensions, "Scientific methods." Another ("Scientific data are not the same as scientific evidence") appears to be a paraphrase of the SUSI dimension, "Observations and inferences." Two of the VASI aspects describe the tentativeness of scientific knowledge, suggesting influence by society, culture, and prior knowledge, and the remaining four items describe the rationality of science. Therefore, SUSI can be seen to incorporate the aspects of scientific inquiry tested by VASI within its six dimensions, lending support to its claim that it also measures knowledge of scientific inquiry, rather than only knowledge of the NOS.

The modifications made by the SUSI developers, from previous tests that influenced its creation, were intended to increase ease of large-scale implementation within the time frame of a typical instructional contact session (Liang et al., 2006). To accomplish these goals, a Likert-scale format is primarily used, although validity and reliability are enhanced by requiring participants to answer a constructed response for each of the six dimensions measured (Deng et al., 2011). Common naive views of NOS, as informed by literature (such as McComas, 1996), were incorporated into the test. After development and trialling, SUSI was validated (Liang et al., 2006) and implemented in an international comparative study (Liang et al., 2009).

## Methodology

### Research Design

In terms of Plowright's (2011) pragmatic framework for integrated methodology (FraIM), we used a survey-experiment approach to data management. To answer the first research question, we compared scores obtained from the SUSI survey for preservice teachers from three countries, drawn from Liang et al.'s (2009) international comparative study with that which we collected from South African preservice teachers. To answer the second research question, we compared Cronbach's alpha scores published by Liang et al. (2009) for the SUSI-2 survey Likert questions with those we obtained for the South African group's SUSI-2 Likert questions and SUSI-3 Likert questions, which was a subset of those for SUSI-2. Additionally, we compared the correspondence between Likert and constructed response results and gave qualitative descriptions of our findings, for the SUSI-3 constructed questions, which differed slightly from those of SUSI-2, as suggested by Liang et al. (2009). To answer the third research question, we compared the SUSI-2 Likert scores for age and educational factor groupings within the South African data.

### Sample

In an attempt to be as consistent with Liang et al.'s (2009) sampling procedure as was feasible, our South African sample consisted of pre-service elementary and middle-school teachers. For logistical reasons, the participants from the four countries reported in Liang et al., as well as the South African participants, were conveniently sampled according to the researchers' access to them. Given the differences in course structure and enrolment numbers for the South African university at which the research was conducted and those in Liang et al.'s sample, the latter consisted of undergraduates who were all enrolled to major in subjects other than the sciences from China ( $n = 212$ ), Turkey ( $n = 219$ ), and the United States ( $n = 209$ ), whereas the South African sample ( $n = 91$ ) consisted of postgraduate students, nine of whom had majored in a sciences subject. These students were enrolled in the Postgraduate Certificate in Education (PGCE) primary and middle-school courses at a research-intensive university in South Africa. The majority of participants (80) were female. The average age of these students was 25, with a range from 20 to 45. Eight of these students matriculated outside South Africa. Although most (81) studied life sciences at school level, only 49 took physical sciences (PS) up to Grade 12 level. Most (67) had had some postgraduate mathematics or science education, with the most common area of study being life sciences (58), in which eight had majored, four continued to honours level and one to master's level. Only 18 had studied either physics or chemistry at tertiary level, with only one majoring in either of these. This student held an honours degree

in physics. The South African data reported in this study were collected from students who had given informed consent for this research. Individual students' achievements are protected through anonymous reporting.

#### Data Collection Instruments and Procedures

At the start of the PGCE course, 91 South African students completed the SUSI questionnaire as well as a survey about their educational background and other biographical information. They answered the same 24, 5-point Likert items that the Chinese, Turkish, and US respondents had answered. These consisted of two sophisticated NOS statements, termed positive items, and two negative items for each of the six dimensions tested. Each dimension was also tested with a constructed response question. For two of these constructed response questions, slight modifications were made from the test answered by the US, Turkish, and Chinese respondents, as proposed by Liang et al. (2006) for SUSI-

3 (see Table 1). The rubrics and guidelines for scoring and analysing both the Likert and constructed response sections, given by Liang et al. (2006), were used. Participants could respond to each Likert item by selecting one of five options: 5) *strongly agree* (SA), 4) *agree more than disagree* (A), 3) *undecided* (U), 2) *disagree more than agree* (D), and 1) *strongly disagree* (SD). These values were assigned to the positive items, and the scoring was reversed for the negative items. Respondents were categorised as having a naïve view of a particular dimension if he/she scored below 3 for each of the four Likert items for that dimension, as having an informed view for above 3 for each of the items, and otherwise as having a transitional view of the particular dimension. The rubric for scoring the six constructed responses describes the components of each response, which would qualify the response as being *not classifiable* or displaying a *naïve view* (awarded 1 point), a *transitional view* (awarded 2 points) or an *informed view* (awarded 3 points).

**Table 1** Comparisons between versions of the instrument

Version/study	SUSI-2 used in Liang et al. (2006)	SUSI-3 proposed by Liang et al. (2006)	This study
Likert items	24 items: four for each of the six dimensions.	Version 1: 21 items: 3D, 6A & 6D removed Version 2: 18 items: 3A-D, 6A & 6D removed. Dimension 3: Scientific theories and laws. Dimension 6: Scientific methods.	24-item items answered and analysed; analysis repeated with deletions according to SUSI-3 Versions 1 and 2 respectively.
Open items	6 items: 1 for each of the 6 dimensions.		
Tentativeness – open-item wording	“With examples, explain why you think scientific theories change OR do not change over time.”	“With examples, explain why you think scientific theories do change OR how (in what ways) scientific theories may be changed.”	“With examples, explain why you think scientific theories do change OR how (in what ways) scientific theories may be changed.”
Scientific theories and laws – open-item wording	“With examples, explain the difference between scientific theories and scientific laws.”	“With examples, explain the nature of and difference between scientific theories and scientific laws.”	“With examples, explain the nature of and difference between scientific theories and scientific laws.”

#### Data Analysis

Given the lack of raw data from Liang et al.'s (2009) study, analysis for the inter-country comparison – to answer the first research question – was restricted to descriptive statistics. This was: means and standard deviations for each KNOSSI dimension, as determined from the Likert responses (see Table 2); percentages of naïve and informed views, as determined from the constructed responses, per dimension, (see Table 3). When comparing this data across countries, the subjectivity involved in applying the rubric to score these responses should be borne in mind, as well as the fact that the wording for two of the constructed items was changed slightly for the SUSI-3 version, answered by the South African sample.

The differences between the SUSI-2 (used in Liang et al., 2006) and the SUSI-3 versions that they proposed, and what was done in this study, are

summarised in Table 1. In addition to the modifications to the wording of some of the questions for the constructed responses, Liang et al. (2006) suggested deletion of some Likert items for SUSI-3. The South African participants answered all the original Likert items to ensure that the Cronbach's alpha values could be compared when the relevant items were included or excluded, and that a comparison could be made with the corresponding Cronbach's alpha data reported in Liang et al. (2006). This contributed to our answer to the second research question, as did analysis of correspondence between the ratings obtained for the constructed and the Likert responses for the two changed items relative to Liang et al.'s (2006) findings for the original wording.

To answer the final research question, the data was combed for relationships between the overall and individual SUSI scores obtained and the following two variables – age and whether the student

had studied mathematics, physical sciences or life sciences at or after school. The statistical significance was determined by a  $p$  value  $< 0,05$  using a  $t$ -test.

#### Validity and Reliability

Two aspects related to validity and reliability were relevant, namely that of the SUSI instrument and that of the research method employed in this particular study.

#### The SUSI Instrument

Liang et al. (2006) explain the validation process that they followed to arrive at SUSI-2. This involved a literature search, an expert review process, data analysis, and interviews with respondents for three iterations of the tool, namely a pilot survey, SUSI-1 and SUSI-2, conducted in three countries (USA, China and Turkey). SUSI-1 consisted of 58 Likert items and 10 constructed responses. The responses elicited by each of these Likert items were analysed for consistency with the constructed responses, with less consistent items being dropped to enhance reliability, resulting in creation of SUSI-2, consisting of only 24 Likert items and six constructed response questions. Liang et al. (2009) presented the data that they obtained for SUSI-2, which was used in this study, and speculated that the changes they had suggested for SUSI-3 would further enhance the validity and reliability of the instrument. They also speculated on the validity and reliability of the instrument in other cultural contexts. Research question two addresses these speculations through evaluating the consistency of the answers obtained for the Likert and constructed responses, per item, for SUSI-3, as well as the Chronbach's alpha scores obtained for the Likert items, for the South African sample for SUSI-2 and two proposed versions for SUSI-3.

#### Method

The procedures stipulated in Liang et al. (2009) were applied for conducting and analysing the SUSI survey data for the South African sample in order to enhance validity. Both authors used the rubric to score the constructed responses independently, after which scores were discussed and adjustments negotiated where different scores had been assigned per

response. An inter-rater agreement of over 80% was attained for the initial independent scoring and the discussion process was effective in clarifying the guidelines for scoring of the rubrics and their application to specific responses. Access to Liang et al.'s (2009) raw data would have further enhanced validity by enabling a more detailed statistical analysis, but in the absence of this possibility care was taken not to make claims beyond the limitations imposed by a restriction to descriptive data. This is consistent with Plowright's (2011) view of validity and reliability as being equated to warrantability of the research. In other words, the claims made should be consistent with the data applicable to the research questions and should acknowledge the possibility of alternative explanations. In light of the limitations imposed by the use of convenience samples in all four countries, particular care was taken to draw attention to patterns of potential interest without overstating unwarrantable claims.

#### Results

##### Inter-Country Comparison

Table 2 shows the responses to the Likert-type questions by the respondents from the four countries. The average scores are given for each dimension of SUSI, as well as the performance sequence between the four countries, with statistical significance indicated by less than signs ( $<$ ). The South African respondents did not outperform the other countries' respondents in any of the dimensions, retaining Liang et al.'s (2009) findings that the US respondents scored highest for the *Observations and inferences* dimension, while the Chinese respondents outperformed the other countries' respondents for every other dimension. The South African respondents' best performance, relative to that of the other countries, was in the dimension of *Scientific theories and laws*. The South African respondents scored the lowest on the dimension of *Creativity and imagination*, where they achieved similar scores to the USA respondents, as well as *Scientific methods*, where their performance was similar to that of the respondents from Turkey and the USA. The overall mean scores for the South African, Turkish, and USA respondents were similar, with the Chinese respondents clearly outperforming the respondents from the other countries.

**Table 2** Average scores for Likert type responses per dimension

Dimension (maximum <i>M</i> for each = 4 x 5 = 20)	Data from Liang et al. (2009:996)								Performance sequence
	Turkey ( <i>n</i> = 219)		China ( <i>n</i> = 211)		USA ( <i>n</i> = 210)		South Africa ( <i>n</i> = 91)		
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Observations and inferences	14.49	3.47	14.69	2.68	15.98	2.41	14.63	2.51	Turkey, South Africa, China < USA
Tentativeness	15.59	2.26	17.10	2.59	15.81	2.27	15.69	1.78	Turkey, South Africa, USA < China
Scientific theories and laws	9.28	1.85	11.25	2.32	9.75	1.99	10.24	1.69	Turkey < USA < South Africa < China
Social and cultural embeddedness	10.71	3.38	14.64	2.32	14.40	2.64	13.56	3.03	Turkey < South Africa < USA, China
Creativity and imagination	14.41	2.96	15.38	2.94	11.59	3.69	11.45	3.78	South Africa, USA < Turkey < China
Scientific methods	14.24	2.17	15.90	2.43	13.90	1.93	13.53	2.13	South Africa, USA, Turkey < China
Overall	13.12	2.68	14.83	2.55	13.57	2.49	13.18	2.49	Turkey, South Africa, USA < China

Table 3 shows the prevalence of naïve and informed views for each country according to the constructed responses. The resulting inter-country comparisons for naïve view prevalence are consistent with the overall rankings deduced from the analysis of the Likert responses. Chinese respondents have the lowest naïve view prevalence. Respondents from South Africa, Turkey, and the USA have roughly similar prevalence except for the *Scientific theories and laws* item, where South Africa performed similarly to China, and the *Creativity and imagination* item, where the USA respondents had a noticeably higher prevalence of naïve views.

Correspondence between the Likert-score rankings and that obtained from the constructed responses was poor for the prevalence of informed views. According to the constructed response scores the Turkish respondents outperformed all the others, particularly regarding *Creativity and imagination*. The South African respondents displayed similar informed-view prevalence to respondents from the US for all dimensions, and to respondents from China on average, clearly outperforming them on *Creativity and imagination* and being outperformed on *Scientific methods*.

**Table 3** Prevalence of naïve and informed views from the constructed responses

SUSI dimension	Naïve views (%)				Informed views (%)			
	Liang et al. (2009:997)				Liang et al. (2009:997)			
	USA	China	Turkey	South Africa	USA	China	Turkey	South Africa
Observations and inferences	3	2	9	11	35	22	35	19
Tentativeness*	3	2	5	4	5	2	15	9
Scientific theories and laws*	98	49	82	52	0	0	0	8
Social and cultural embeddedness	8	7	19	15	7	2	10	10
Creativity and imagination	42	3	19	21	10	0	26	14
Scientific methods	33	3	35	12	14	50	18	16
Overall <i>M</i>	31.17	11.00	28.17	19.17	11.83	12.67	17.33	12.67

Note. \*Wording was altered slightly between SUSI-2 and SUSI-3 versions. Only the South African respondents answered the SUSI-3 version.

#### Test Changes and Reliability

Liang et al.'s (2006) suggested changes to SUSI-3, as summarised in Table 1, include slight changes to the constructed responses for *Tentativeness* and *Scientific theories and laws*. Additionally, Liang et al. (2006) suggested removal of some or all of the Likert items for the *Scientific theories and laws* and *Scientific methods* dimensions. The consequences of each of these changes are discussed below.

#### *Tentativeness*

We implemented the change in wording that Liang et al. (2006) suggested to address their finding that participants performed worse on the constructed responses than the Likert responses for the dimension of *Tentativeness*. However, this modified version suffered the same problem as the original, with the question requiring explanation only of either why or how scientific theories may be changed, whereas the

marking guideline stipulated that *informed* status should only be assigned if the respondents referred to both of these. Therefore, it was not surprising that we found a similar mismatch between the respondents' scores for the constructed responses (only 9% informed) relative to the Likert responses (36% informed) for this dimension. The reliability of the constructed rating for this dimension could possibly be improved by replacing "or" with "and" in the relevant question.

#### *Scientific theories and laws*

Liang et al. (2006) suggested removal of Likert item 3D since responses to this item tended to be inconsistent with associated constructed responses, suggesting that respondents tended to misunderstand this question. In the South African data, removal of item 3D increased the fraction of respondents classified as having a naïve view for this dimension from 23% to 70% for the Likert-type responses. However, a large discrepancy still existed between the classification yielded by the Likert and constructed responses (52%), and general poor performance of the participants for the *Scientific theories and laws* dimension, lending support to Liang et al.'s (2005) suggestion that this entire dimension should be eliminated from the test when used with pre-service elementary teachers. As shown in Table 4, removal of this dimension (3A-3D) improved the reliability of the test slightly, as shown by a rise in the Cronbach's alpha value from 0.79 to 0.81.

For cases in which retention of the *Scientific theories and laws* dimension was advisable, Liang et al. (2006) suggested modification of the constructed

response question, as indicated in Table 1. They hypothesised that this modification would improve the correspondence between the Likert and constructed response classifications. This modification was implemented with the South African respondents. This may account for the non-zero (i.e. 8%) informed view classification in the constructed responses (see Table 3), whereas no respondents from the other three countries were classified as having an informed view for this dimension for the constructed responses. However, since none of the South African respondents were classified as having an informed view for this dimension for the Likert responses, it was not possible to claim that this change improves the correspondence between the Likert and constructed responses, and therefore the reliability of the test.

Table 4 shows the Cronbach's alpha values for the Likert-type items, calculated for the South African data and reported in Liang et al. (2006). These values are reported for the SUSSI-2 version (referred to as all 24 items), as well as for two sets of item removals, suggested for SUSSI-3. Liang et al. (2006) suggested that SUSSI-3, revised version 2, be used when the subjects have had limited prior exposure to science, as is the case for all four samples reported on here.

Even higher Cronbach's alpha values were found for the South African data than those reported in Liang et al. (2006). This suggests a high degree of reliability for the population of South African students sampled here. The Cronbach's alpha value increased marginally with the item deletions proposed for SUSSI-3.

**Table 4** Cronbach's alpha values for the instrument per country

SUSSI	Liang et al. (2006:20)			
	South Africa (n = 90)	USA (n = 209)	China (n = 212)	Turkey (n = 219)
All 24 items	.78	.67	.61	.67
SUSSI-3 revised version 1: 21 items after removal of 3D, 6A & 6D	.79	.69	.62	.69
SUSSI-3 revised version 2: 18 items after removal of 3A-3D, 6A & 6D	.81	.72	.69	.69

#### Age and Educational Factors

Table 5 summarises those findings regarding relationships between age and educational factors and KNOSSI. The average total score for all 24 items of the Likert-type questions is given here. Additionally, the differences between the groups were ana-

lysed for each individual SUSSI dimension. The groups for whom higher mean scores were calculated are highlighted in bold in the table, as are the two factors and *p*-values that yielded statistical significance. These are age and whether any science or mathematics courses were studied after school level.

**Table 5** Comparisons of total scores for all 24 Likert-type items according to age and educational factor groupings, with higher achieving groups and statistical significance highlighted

Factor	Group	<i>M</i> (/120)	<i>SD</i>	<i>t</i> -test
<b>Age</b>	20–23 ( <i>n</i> = 49)	77.43	8.56	<i>t</i> = -1.94
	<b>24–45</b> ( <i>n</i> = 42)	<b>81.05</b>	9.08	<b><i>p</i> = 0.03</b>
Physical science at school	<b>No</b> ( <i>n</i> = 42)	<b>80.14</b>	8.46	<i>t</i> = 1.02
	Yes ( <i>n</i> = 49)	78.21	9.41	<i>p</i> = 0.15
Physical science after school	<b>No</b> ( <i>n</i> = 73)	<b>79.14</b>	8.77	<i>t</i> = 1.02
	Yes ( <i>n</i> = 18)	78.94	9.60	<i>p</i> = 0.15
Life science after school	<b>No</b> ( <i>n</i> = 33)	<b>79.82</b>	9.79	<i>t</i> = 0.57
	Yes ( <i>n</i> = 58)	78.69	8.39	<i>p</i> = 0.28
<b>Any science or mathematics courses after school</b>	<b>No</b> ( <i>n</i> = 24)	<b>81.50</b>	8.89	<i>t</i> = 1.63
	Yes ( <i>n</i> = 67)	78.24	8.81	<b><i>p</i> = 0.05</b>

### Age

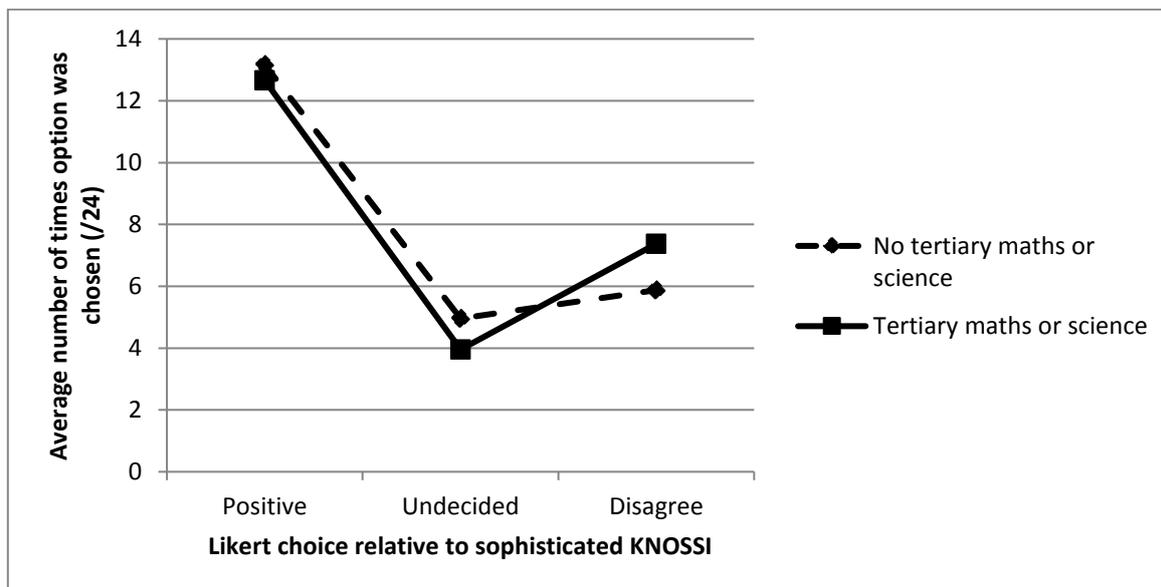
The age division was made at 23 since this divides participants according to their likelihood of having had additional post-school experiences other than undergraduate university study. These experiences included postgraduate study (12% i.e. 4/42), employment in industry (19% i.e. 8/42) and some teaching experience as tutors or assistants (21% i.e. 21/42). The older group (24–45, *n* = 42) ( $M = 81.05$ ,  $SD = 9.08$ ) was found to have a significantly higher mean score than the younger group (20–23, *n* = 49) ( $M = 77.43$ ,  $SD = 8.56$ ),  $t(1) = -1.94$ ,  $p < 0.05$ .

### Science instruction and KNOSSI

As shown in Table 5, for all the education categories studied, the group who had less formal exposure to the sciences achieved the higher mean score. For one such category, whether the student had studied any tertiary mathematics or science courses, the group for which this was not true (*n* = 24) scored signifi-

cantly higher ( $M = 81.50$ ,  $SD = 8.89$ ) than the group who had studied such a course ( $M = 78.24$ ,  $SD = 8.81$ ),  $t(1) = 1.63$ ,  $p < 0.05$ .

Figure 1 represents the average number of counts of the Likert choices for the group who did not do any tertiary maths or sciences courses compared to the group who did. The average number of times a choice was made favouring the sophisticated KNOSSI view was not statistically significant between the groups,  $M = 13.17$ ,  $SD = 4.75$ ,  $M = 12.66$ ,  $SD = 4.15$ ,  $t(1) = -0.49$ ,  $p > 0.05$ . However, the misconception prevalence was statistically higher for the group with tertiary mathematics or science,  $M = 7.37$ ,  $SD = 3.40$ , than for those who had studied no tertiary mathematics or science,  $M = 15.77$ ,  $SD = 3.89$ ,  $t(1) = -1.76$ ,  $p < 0.05$ . This suggests that the apparently lower KNOSSI of the more scientifically educated students is a result of them having greater confidence in KNOSSI misconceptions, possibly because these were explicitly or implicitly taught.

**Figure 1** Likert choices for groups with or without some tertiary maths or science education

A similar analysis was performed for each of the six Sussi dimensions. For two of the dimensions, *Observations and inferences* and *Laws and*

*theories*, statistically significant trends similar to those for the overall score, discussed above, were found (see Table 6).

Although the South African respondents performed relatively high on the *Laws and theories* dimension in the inter-country comparison (see Table 2), the absolute scores for this dimension were the lowest of the six dimensions for both Likert and constructed responses (Tables 2 and 3), with the majority of the responses in favour of the misconception that theories become laws with increased evidence, rather than that the two are qualitatively different

(Table 6). The following quote from a student with a relatively extensive background in tertiary science education was typical of many of the more articulate responses:

*Scientific laws are proven and have facts which defend them, for example, the law of gravity has been proven and is fact based. However scientific theories have limited evidence which support the theories and there is room for them to be disproved or proved.*

**Table 6** Likert item choices for two of the dimensions for respondents with or without tertiary mathematics or science education, with higher achieving groups and statistical significance highlighted

Dimension	Group	n	Likert choice relative to sophisticated KNOSSI			M (/20)	SD
			Positive (/8)	Undecided (/4)	Negative (/8)		
Observations and inferences	No tertiary maths or science	24	<b>2.92</b>	<b>0.75</b>	0.33	<b>15.21</b>	1.91
	Tertiary maths or science	67	2.81	0.36	<b>0.84</b>	14.41	2.67
	<i>t</i> -test		<i>t</i> (1) = 0.39, <i>p</i> = 0.35	<i>t</i> (1) = 2.34, <i>p</i> = <b>0.01</b>	<i>t</i> (1) = -2.17, <i>p</i> = <b>0.02</b>		
Laws and theories	No tertiary maths or science	24	<b>0.96</b>	<b>1.08</b>	1.96	<b>10.71</b>	1.51
	Tertiary maths or science	67	0.94	0.70	<b>2.34</b>	10.12	1.71
	<i>t</i> -test		<i>t</i> (1) = 0.11, <i>p</i> = 0.46	<i>t</i> (1) = 1.63, <i>p</i> = <b>0.05</b>	<i>t</i> (1) = -1.95, <i>p</i> = <b>0.03</b>		

**Discussion**

Inter-country Comparison

The inter-country comparison for the SUSSEI data suggests that the South African respondents possessed similar levels of KNOSSI sophistication to their Turkish and US counterparts, all of whom were outshone by the performance of the Chinese respondents. Perhaps ironically, Liang et al. (2009) suggest that the Chinese respondents' lead can be attributed to the greater degree of lecture-type, exam-driven teaching style used in China, compared to the greater degree of hands-on experiential science thrust of the USA, since explicit teaching develops KNOSSI more effectively than implicit, experiential exposure to science activity (Akerson, Abd-El-Khalick & Lederman, 2000). Eighty six of the 91 respondents in the South African sample had attended high-quintile schools, increasing the likelihood that they had been exposed to guided inquiry (Ramarain & Schuster, 2014). Furthermore, 62 of the sample had been schooled during the enforcement of the South African National Curriculum Statement (NCS) which was particularly supportive of KNOSSI and which reduced the emphasis on a final, high-stakes examination, relative to other South African curricula. While these facts, coupled with this group's reduced performance relative to the Chinese sample, do not refute Liang et al.'s speculations, they can also not be seen as supporting these. Nor would testing these speculations be an easy matter in a South African context, since the higher focus on lecture-teaching in lower-quintile schools, and the greater emphasis placed on examination perfor-

mance in curricula such as stipulated in CAPS, tend to be accompanied by a decreased likelihood for teaching KNOSSI (Ramarain & Hlatswayo, 2018).

Test Changes and Reliability

The SUSSEI test was found to have a high degree of reliability among the South African students studied. Liang et al.'s (2009) suggested exclusion of some of the SUSSEI-2 Likert-scale items in SUSSEI-3 does seem to improve reliability marginally, although their suggested changes for the constructed response questions were not found to improve reliability, suffering from the same problems as their original forms.

Age and Educational Factors

The finding that the older group in the South African sample had a significantly higher mean score than the younger group was consistent with Tschannen-Moran's (2008) finding that besides other forms of prior formal tertiary education, the skills, knowledge, and experiences gained within and beyond education were highly beneficial for mature students studying as prospective teachers. It should be pointed out that the older students had not experienced the inquiry-infused, lecture- and examination- de-emphasised NCS curriculum during their school-going years, although, again, it is not valid to claim that this necessarily supports Liang et al.'s (2009) ironic speculation that such approaches to teaching KNOSSI yielded superior results.

The finding that the means for the group with less formal exposure to the sciences was higher than

for those who were more educated in the sciences was surprising and inconsistent with the general understanding that academic background is not related to knowledge about the NOS (Lederman, N et al., 1998). This finding suggests that naïve views of the NOSSI may possibly be taught in South African science courses at tertiary undergraduate level. This is certainly conceivable, given the prevalence, in science instruction and support material elsewhere, of views such as the existence of a single scientific method (Tang, Coffey, Elby & Levin, 2010) and hypotheses progressing to theory and then law status (McComas, 1996). Similarly, Liang et al. (2009) suggest that the reason that the Turkish and US respondents performed slightly worse in the SUSSI test than the Chinese respondents was that supporting material that promoted NOSSI misconceptions was prevalent in Turkey and the US.

It is not surprising that the misconception related to the difference between scientific laws and theories is so strongly held internationally, given the common meanings ascribed to the terms “theory” and “laws.” However, this does not explain the finding that those respondents with some tertiary mathematics or science education held this misconception more strongly than those who had not taken any tertiary mathematics or science. It is possible that the respondents were taught the misconception explicitly or that they derived the view implicitly, for example, from the confirmatory nature of the practical work that they engaged in. The latter explanation seems to be the most likely to be applicable for the similar finding for the *Observations and inferences* dimension.

The shortcomings, regarding KNOSSI development, of standard courses and the measures, atypical of standard courses, needed to develop favourable KNOSSI, are well illustrated in a South African study performed at the same university where this research was conducted. Ibrahim et al. (2009) report that a major revision was needed to the first-year physics laboratory course they offered in order to effectively develop students’ KNOSSI. For example, they found that there was a need to expose students to a scenario wherein two groups of scientists draw different conclusions from the same data due to the application of different theories, and provide students with opportunities to choose between two competing theories using their own experimental data. It is a fair assumption that if the standard introductory tertiary physics course, i.e. the course before these major revisions were made, did not attend satisfactorily to domains in NOS, standard secondary school science instruction is even less likely to do so.

#### Limitations and Implications

The institution where this study was conducted tends to draw students from higher socio-economic backgrounds than most South African universities.

Therefore, our sample did not represent the lower achieving end of South African students where the development of KNOSSI envisioned by the curriculum creators has largely not been realised (Clark, Case, Davies, Sheridan & Toerien, 2011). The advantage of the features of the sample used is that it has given us an indication of the KNOSSI of South African students in cases where the necessary supportive elements are likely to have been present. However, the associated limitation is that the sample used was not representative of South African pre-service primary and middle school teachers. This is particularly important since socio-economic status is known to influence KNOSSI (Gaigher et al., 2014).

Another possible limitation of this study is the relatively small sample (91), which is less than half the size of each country’s sample used by Liang et al. (2009). However, Liang et al. (2005:1) state that SUSSI “can be used as either a summative or a formative assessment tool in small or large scale studies.” The small size of our sample also reduced the effectiveness of our search for biographical and educational relationships to KNOSSI. Another discrepancy was that the South African sample consisted only of postgraduates, whereas those from the other countries consisted of only undergraduates. Given our finding that KNOSSI seems to become more sophisticated with maturity, this difference seems to have advantaged the South African sample. On the other hand, our finding that enrolment in any mathematics or science course after school resulted in a significant decline in the KNOSSI score registered by SUSSI, ironically suggests disadvantage for the 67 (out of 91) South African respondents for whom this was relevant. It should also be pointed out that the validity of the international comparison rests on the assumptions of equidistance between the items and comparable averaged individual subjectivity between the degrees of agreement or disagreement for the various cultures assessed. It may also be problematic that a choice of *undecided* was assigned a score of 3 out of 5, since respondents’ lack of an opinion regarding an issue is qualitatively very different from an average of 3 out of 5 which could also have resulted from as much agreement as disagreement, on average. Nevertheless, for the purpose of the international comparison, it was necessary to perform the same analysis, with its associated assumptions, as performed by Liang et al. (2009).

This study has contributed to our understanding of the KNOSSI of a group of prospective South African primary and middle school teachers, factors contributing to this KNOSSI, and the applicability of a tool for measuring KNOSSI. The insight gained is valuable, given the worldwide thrust in school science education that aims to develop students’ scientific literacy and to develop of an appropriate KNOSSI.

## Conclusion

According to the SUSSI instrument, the South African sample of pre-service primary and middle school teachers used here possessed, on average, similar levels of KNOSSI sophistication to their Turkish and US counterparts, although these were less sophisticated than that of the Chinese respondents. The SUSSI instrument showed a high level of reliability in the South African context, although the changes proposed by Liang et al. (2006) were not found to enhance reliability of the instrument significantly. KNOSSI was found to improve, significantly, with age and, perhaps surprisingly, to be hampered by enrolment in science or mathematics courses, particularly at tertiary level. We suggest the following explanations for the latter finding: the confirmatory nature of practical work, particularly that done in tertiary science courses, encourages a simplistic, unproblematic, empiric view of science; direct teaching of misconceptions; and intuitive understanding of terms such as “laws” and “theories.”

## Authors' Contributions

Both authors conceptualised the research and collected the data. Angela Stott analysed the data in consultation with Annemarie Hattingh. A first draft was composed by Angela Stott. Both authors refined the manuscript to its final form.

## Notes

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