Evaluating the effectiveness of teacher preparation courses in raising students' understanding of the nature of science using the SUSSI survey

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This paper reports on an exploratory pilot study conducted to evaluate the effectiveness of various science teacher preparation courses in raising pre-service teachers understanding of the nature of science (NOS). Undergraduate (n1=229, n2=211) and postgraduate (n1=81, n2=53) students in four courses, across five campuses and two universities, were assessed using the Student Understanding of Science and Scientific Inquiry (SUSSI) survey (Liang et al., 2008) both pre- and post- course. Paired samples t-tests on individual items of the SUSSI revealed limited change in the pre-service teachers' understanding of NOS in the various courses examined. In addition to the tightening of methodological controls a more explicit reflective approach will be adopted in the next round of data collection.

Introduction

One of the aims of science teacher preparation courses is to raise pre-service teachers' understanding of the nature of science. The new Australian Curriculum: Science (ACARA, 2012) describes science as...

> ... a dynamic, collaborative and creative human endeavour arising from our desire to make sense of our world through exploring the unknown, investigating universal mysteries, making predictions and solving problems. Science aims to understand a large number of observations in terms of a much smaller number of broad principles. Science knowledge is contestable and is revised, refined and extended as new evidence arises (p. 3).

This view contains much more than the content often associated with science, in particular, one of the three overlapping strands of the Australian Curriculum for Science, 'Science as a Human Endeavour', acknowledges the unique ways of 'knowing and doing' (ACARA, 2012, p. 5) science and the important role of people from different cultures in developing our scientific understanding. The sub-strand 'Nature and development of science': "... develops an appreciation of the unique nature of science and scientific knowledge, including how current knowledge has developed over time through the actions of many people." (ACARA, 2012, p.5). Cakmakci (2012) and the *National Professional Standards for Highly Accomplished Teachers of Science* (ASTA, 2002) also emphasise that an understanding of the nature of science and scientific inquiry is essential for science teachers if they are to model suitable approaches in their classrooms (Lederman, 1998; Murcia & Schibeci, 1999).

Teachers who have a deeper understanding of the nature of science will in turn teach students in a less content-focused and more process-focused manner. This is in line with the nature of science and the goals of science teacher associations (e.g., Australian Science Teachers Association, National Science Teachers Association (US)) and various peak national science organisations (e.g., American Association for the Advancement of Science, Australian Academy of Science, The Royal Institution of Great Britain). As these representative bodies advocate that teachers have a deep understanding of the nature of science it is therefore a priority within our programs that we develop teachers as such.

Literature review

The 'nature of science' (NOS) is defined as the process by which scientific inquiry develops scientific knowledge through a particular set of epistemological and ontological assumptions (Ryan & Aikenhead, 1992). While the finer points are debated (Alters, 1997), some consensus exists on less controversial aspects. Osborne et al. (2003) suggest that teaching 'the nature of science' should focus on scientific methods and critical testing, creativity, historical development of scientific knowledge, science and questioning, diversity of scientific thinking, analysis and interpretation of data, science and certainty, and hypothesis and prediction.

Lederman et al. (2002) defines the nature of science as being empirical in nature, constructed on hypothesises, laws and theories and thus being theory ladened, inherently creative and imaginative, and that the knowledge is socially and culturally embedded. This is a definition that sums up many of the themes raised by Osborne et al. (2003), McComas & Olsen, 1998, a range of theoretical discussions (e.g., Lederman & Lederman, 2004; Reeves, Cressin and Chambless, 2007) and empirical studies (e.g., Abd-El-Khalick, Lederman, 2000; Aikenhead, 1988; Chen, 2006). Liang et al. (2008, p.3-4) summarise the six themes developed by Lederman et al (2002) as: *Tentativeness of Scientific Knowledge*, *Observations and Inferences*, *Subjectivity and Objectivity in Science*, *Creativity and Rationality in Science, Social and Cultural Embeddedness in Science, Scientific Theories and Laws,* and *Scientific Methods.*

The teachers' views of science influence those of their students - which also mean they can pass their own conceptual difficulties to their students. Pre-service teachers, therefore, need a strong, well-elaborated understanding of the nature of science (Cakmakci, 2012). Teachers also need to be able to incorporate this understanding into their classroom practice, and this can be challenging (Akerson, Cullen & Hanson, 2009; Brickhouse, 1990; Abd-El-Khalick, Bell & Lederman, 1997; Hanuscin, Lee & Akerson, 2011). It is therefore imperative that as teacher educators we make explicit for our per-service teachers how this understanding can be incorporated into practice.

A range of quantitative (e.g., 'Test of Understanding Science' by Cooley & Klopfer (1961) and 'Views on Science-Technology-Society' by Aikenhead and Ryan (1992)) qualitative instruments (e.g., 'Views on the Nature of Science' by Lederman et al. (2002)) have been devised over time to measure understanding of the nature of science. The quantitative instruments have used multiple-choice or Likert type scales while the qualitative instruments have used open ended questions and follow up interviews to achieve the same goal. Criticisms of the quantitative instruments centred around the oversimplification of the nature of science (Alters, 1997) while the qualitative studies can be time consuming and analysis of a large number of responses can be prohibitive.

Johnson, Fargo & Kahle (2010), in a longitudinal study of the science achievement of the students of middle years science teachers in a professional development program intended to enhance student understanding of the nature of science (NOS), have shown that such students achieve better on a test of science inquiry skills than students whose teachers are not participating in such professional learning. This study highlights the potential for improved teacher understanding of NOS to impact positively upon student outcomes.

Pre-service teachers have some naive views of NOS (Abd-El-Khalick, 2005; Kucuk, 2008). Explicit reflective approaches have shown some increase in pre-service teachers' understanding of NOS although this was not reflected in their teaching practice. Although some included NOS the majority believed that teaching that included the "messiness of science" would undermine their authority in the classroom, would not interest their students, be too abstract and complicated for students or leave insufficient time for teaching content (Abd- El- Khalick, 2005). Even in Singapore, where students achieve well on international tests, pre-service teachers' views of NOS counteract the inculcation of scientific literacy and an understanding of NOS in their students (Thye & Kwen, 2004).

Hypothesis and Aim

We hypothesise that a greater understanding of NOS will ultimately lead to teachers who teach in a less content-focused manner and in a more process-focused manner, in line with expectations of the Australian Curriculum: Science. As teacher preparation courses are the major source of science education training for these teachers, the current study aims to measure the impact of these courses on pre-service teachers' understanding of NOS. If the science teacher preparation courses being studied have any impact on pre-service teachers' understanding of NOS, then mean cohort scores on the 'agree' statements within the SUSSI should increase pre- to post- course and while scores on 'disagree' statements will decrease pre- to post- course. Course and institution effectiveness will be judged according to the degree of movement in these items as well as the number of items for which there is a measurable change.

Method

The Student Understanding of Science and Scientific Inquiry (SUSSI) (Liang et al., 2008) is a dual-response instrument designed to measure student understanding of the nature of science. It consists of 24 five-point Likert items divided into six themes: observations and inferences, tentative nature of scientific theories, scientific laws versus theories, social and cultural influence on science, imagination and creativity in scientific investigations, and methodology in scientific investigations. Each theme consists of four items. To guard against agreement bias half the items were reversed so 12 items were true (respondents should have agreed with them) and 12 were false (respondents should have disagreed with them). Liang et al (2008) developed the items after extensive consultation of the literature to define the nature of science (e.g., AAAS, 1993; NSTA, 2000; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; McComas, 1998). The reliability for the entire instrument was deemed to be satisfactory (alpha=.69). The individual reliabilities are shown in Appendix 1. For clarity, whenever the individual items are mentioned a plus sign (+) indicates it was a true statement and a minus sign (-) indicates it was a false statement.

A modified version of the SUSSI (Liang et al., 2008) was used in this study. All 24 items measuring student understanding of NOS were retained, along with the 5 point Likert-type scale, but the free response items after each section, where respondents could provide additional information, were removed. This was done for two reasons. Firstly, as an exploratory study, it was done to trial run the deployment of the survey across the various courses. And secondly, as the survey was to be conducted during a tutorial, not to take up too much teaching time. Demographic data was also collected at the beginning of the survey.

Paired sample t-tests were conducted on individual items and these are presented in the results section. Although total of 310 and 264 completed the pre and post course surveys respectively, only 148 responses could be used in the final analysis due to the pairing of pre and post surveys for each student.

Intervention

Griffith University

A total of 239 undergraduate primary science pre-service teachers undertook 3029EDN at Griffith University across the Mt Gravatt, Logan and Gold Coast campuses. This is a third year course and is the second and final science focussed course these students undertake. The 13 week course consisted of 8 two-hour online lectures, 2 face to face lectures employing a flipped classroom model and 7 two-hour tutorials. Four of those tutorials focussed on pedagogy appropriate for the primary science classroom, one tutorial on group presentations and another tutorial on exam revision. The focus in lectures was on content knowledge while the focus in the tutorials was on inquiry-based science and pedagogy relevant to the primary science classroom.

The nature of science was presented to this cohort through a specific four part online lecture series dedicated to this topic, presented in Week One. The 8 two-hour lectures also incorporated philosophies and examples of the nature of science as the course progressed. The content of the dedicated nature of science online lectures were based around 25 true/false items developed by Flamer (n.d.) on the nature of science. As of week 9, the four video? have been viewed 137, 86, 86 and 76 times respectively which is in contrast to the 239 students enrolled in the course. It is acknowledged that this situation may change closer to the exam. At various points within the tutorials relevant aspects of the nature of science were explicitly addressed.

7032EDN is the first science education course undertaken by participants who have science as one of their teaching fields in the one year Graduate Diploma of Secondary Education. Most will proceed to complete one or two (depending on their teaching fields) courses on senior secondary science education. The focus is on teaching science in the junior secondary years of schooling, developing the pedagogical content knowledge (Shulman, 1986) of participants who all have a science undergraduate degree. It also attempts to refresh and extend their science content knowledge in physics, chemistry, biology and earth and space science.

The nature of science is an explicit emphasis of this course, with one lecture devoted to the topic in addition to pervasive references throughout the course. Naive conceptions of the nature of science tend to be held by many participants (confirmed by their responses in the pre-course survey), and are exacerbated rather than ameliorated by much of their undergraduate experience. The course contains lectures, tutorials and a laboratory program involving experiments used in junior secondary science classes.

University of the Sunshine Coast

Students in the Bachelor of Education Primary at University of the Sunshine Coast do two science-teaching courses. In first year 228 students undertook EDU107. This course has ten 2 hour lectures where biological sciences content and curriculum is taught. The course is structured so that each week focuses on a different year level. The ensuing 2-hour tutorial is all inquiry based activities extending on the content and curriculum developed in the lectures. The first five weeks were structured around observing the life cycle of Mealworm (darkling beetles). The nature of science was integrated throughout this course.

The third year course EDU309 included 62 students and consists of 10 one-hour lectures, the first of which was explicitly the nature of science and subsequent lectures teaching the content of physics, chemistry, earth and space science. The 10 three-hour tutorials were scientific investigation experiments focussing on fair tests, the scientific method, presenting data and linking these to theories.

Eight students in the Bachelor of Education/Bachelor of Science undertook a third year senior phase curriculum course EDU330. All B.Ed. students have ten 2 hour lectures on curriculum and then separated into their major teaching areas for ten 2 hour tutorials. These included theoretical and practical teaching activities. The nature of science was presented to this cohort through the same four part online lecture series as the primary pre-service teachers at Griffith University. The online lecture series was shared with the primary per-service teachers at the University of the Sunshine Coast.

Students in both the Graduate of Diploma of Education Primary and students in the Bachelor of Education Early Childhood/ Bachelor of Human Services study EDU652 Curriculum B Primary Years P-7. The course consists of ten 2 hour lectures about writing unit plans and science curriculum and content in the physical sciences. The 10 two-hour tutorials contained inquiry activities. The nature of science was integrated throughout. The pre-service teachers engaged with the NOS concepts that were embedded in the tutorial activities.

Results

Results are only ever shown where there has been a statistically significant change. Table 1 show the groupings of students who responded to both the pre- and post-tests.

Table 1: University and degree level of participants

University	Undergraduate	Postgraduate	total
Griffith	9	20	29
Sunshine Coast	99	20	119

What is the impact on undergraduate students' understanding of NOS, regardless of institution?

Student (n=108) understanding only changed on one item of the twenty-four items, "Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies". There was a statistically significant decrease in mean scores from pre (M=1.56, SD=1.01) to post (M=1.23, SD=1.02), t(108)=2.454, p<.05. the mean decrease in scores was 0.327 with a confidence interval ranging from .063 to .591. The eta squared statistic (.06) indicated a moderate effect size. This is an item where students should have disagreed with the statement post unit as scientific research is influenced by society and culture.

What is the impact on postgraduate students understanding of NOS, regardless of institution?

Student (n=40) understanding changed on two of the twenty-four items. "Scientists may make different interpretations based on the same observations." There was a statistically significant decrease in mean scores from pre (M=3.38, SD=.544) to post (M=3.03, SD=1.04), t(40)=2.214, p<.05. The mean decrease in scores was 0.327 with a confidence interval ranging from .031 to .687. The eta squared statistic (.08) indicated a moderate effect size. This is interesting as students should have agreed with this statement less post unit.

For the statement "scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies" there was a statistically significant decrease in mean scores from pre (M=1.15, SD=.893) to post (M=1.83, SD=1.28), t(40)=-2.798, p<.01. The mean decrease in scores was 0.675 with a confidence interval ranging from -1.163 to -.187. The eta squared statistic (.08) indicated a large effect size. This is an item where it was anticipated that students would have disagreed with the statement post unit as scientific research is influenced by society and culture.

What is the impact of USC science teacher preparation programs on student understanding of NOS?

Student (n=119) understanding changed on four of the twenty-four items shown in Table 2. It is important to note students moved to a more correct position on only two of the items "Scientific theories may be changed because scientists reinterpret existing observations" where it was anticipated that would have agreed more with the statement post course and "Scientific theories based on accurate experimentation will not be changed" where they should have agreed less with the statement post course.

Table 2: Items for which there was a statistically significant change for USC students only

Item	pre mean		post mean		t score	sig	effect size*
	M	SD	M	SD			
Scientists may make different interpretations based on the same observations.+	3.31	.650	3.08	.843	2.406	.018	.05

Scientific theories may be changed because scientists reinterpret existing observations.+	1.39	.890	1.69	1.192	-2.202	.030	.04
Scientists use their imagination and creativity when they analyse and interpret data. +	1.51	.967	1.88	1.235	-2.602	.010	.05
Scientific theories based on accurate experimentation will not be changed.-	2.82	.784	2.54	1.11	2.122	.036	.04

* effect size: .01=small effect; .06=moderate effect, .14=large effect.

What is the impact on undergraduate students understanding of NOS at the USC?

Student understanding changed on one of the twenty-four items; "Scientific theories may be completely replaced by new theories in light of new evidence". There was a statistically significant increase in mean scores from pre (M=2.78, SD=0.726) to post (M=3.02, SD:0.849), t(99)=2.179, p.<.05. The mean increase in scores was .245 with a confidence interval ranging from .468 to .022. The eta squared statistics (.05) indicated a small effect size. It was anticipated that students would have agreed with the statement more post unit.

What is the impact of GU science teacher preparation programs on student understanding of NOS?

Student (n=29) understanding changed on five of the twenty-four items. It is important to note that the intended direction of change was only observed in one of the five items, "Scientists use their imagination and creativity when they collect data" where it was anticipated that students would have agreed more with the statement post course.

Table 3: Items for which there was a statistically significant change for GU students only

Item	pre mean		post mean		t score	sig	effect size*
	M	SD	M	SD			
Scientific theories may be completely replaced by new theories in light of new evidence.+	3.66	.484	3.24	.739	-2.571	.016	.20
Scientific theories may be changed because scientists reinterpret existing observations.+	2.76	.786	1.97	1.21	-2.948	.006	.24
Cultural values and expectations determine what science is conducted and accepted+	2.62	1.083	2.00	.964	-2.389	.024	.17
Scientists use their imagination and creativity when they collect data.+	1.93	1.223	2.69	1.198	2.368	.025	.17
Scientific theories based on accurate experimentation will not be changed.-	1.31	.806	2.28	1.251	3.362	.002	.33

* effect size: .01=small effect; .06=moderate effect, .14=large effect.

SUSSI measures understanding in six themes using a total of 24 items and free response items attached to each theme. Undergraduate understanding across the two universities only changed significantly in terms of one of the 24 items. This was the same for undergraduates at the USC while the sample from the GU was too small to subject to statistical analysis. It was a similar picture with the postgraduate students with there only being a significant difference in two of the items.

When analysed by institution, USC and GU students' understanding of NOS as measured by the SUSSI changed significantly on four and five items respectively. It is interesting to note that while changes in the items for the USC cohort were in the expected direction (i.e., greater agreement post-course with the true statements and greater disagreement post-course with the false statements) for three of the four significant items, it was only in the expected direction of change for one of the five significant items for GU.

It can therefore be concluded that the intervention of the nature of science in the courses examined, as measured by the SUSSI, had little to no impact upon pre-service teachers' understanding of the nature of science.

Discussion and Conclusions

As an exploratory pilot study, many areas to tighten methodological controls were identified, In the next stage, the research team will ensure data is collected as close as possible to the beginning and end of the courses. For example, in the undergraduate primary teacher course at Griffith University the post course data was collected in Week 9, well before many students commenced study for the final exam. It is anticipated that students will more fully engage with the video resources closer to examinations and this might influence the effect size seen. Future site studies will be asked to conduct the survey in the first and last tutorials for the subject to standardise this aspect across the sites.

While the removal of the free response items certainly decreased time requirements for participants to complete the survey and for the analysis of the data, information was lost as a result of this decision. While the 24 Likert type items can identify 'what' students understand to be the nature of science, 'why' they think that way can only be truly explored through the free response items. A better demonstration of their understanding would be ascertained by requiring students to provide explanations or examples.

Another aspect of the survey that needs closer inspection is the wording of the items. This is in line with Liang et al's (2008) suggestion that further work was still required to refine the instrument. For example, for items 4b and 4c (see Table 1), we would suggest to Liang et al (2008) that 'influence' or 'strongly influence' may be an appropriate substitute for 'determine'.

Pre-service teachers understanding of the nature of science did not appear to change as measured by the SUSSI. Work by Abd-El-Khalick and Lederman (2000) hints at a possible explanation. In a comprehensive review they found such efforts were generally not successful in helping teachers develop an understanding of the nature of science. They did note that an explicitly reflective approach to enhancing teachers' conceptions (e.g., Abd-El-Khalick et al., 1997; Akerson et al., 2000; Shapiro, 1996) was more effective than an implicit approach that utilised hands-on or inquiry science activities lacking explicit references to NOS (e.g., Barufaldi et al., 1977; Haukoos and Penick 1983, 1985; Riley 1979). Discussions will be held to explore ways in which a more explicitly reflective approach can be incorporated into our teaching.

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Appendix 1: The items of SUSSI by theme

Item number	Item	True	False
	Observations and inferences (alpha=0.61)		
1a	Scientists observations of the same event may be different because the scientists prior knowledge may affect their observations.	x	
1b	Scientists observations of the same event will be the same because scientists are objective.		x
1c	Scientists observations of the same event will be the same because observations are facts.		x
1d	Scientists may make different interpretations based on the same observations.	x	
	Tentativeness (alpha=0.56)		
2a	Scientific theories are subject to on-going testing and revision.	x	
2b	Scientific theories may be completely replaced by new theories in light of new evidence.	x	
2c	Scientific theories may be changed because scientists reinterpret existing observations.	x	
2d	Scientific theories based on accurate experimentation will not be changed.		x
	Scientific theories and laws (alpha=0.48)		
3a	Scientific theories exist in the natural world and are uncovered through scientific investigations.		x
3b	Unlike theories, scientific laws are not subject to change.		x
3c	Scientific laws are theories that have been proven.		x
3d	Scientific theories explain scientific laws.	x	
	Social and cultural embeddedness (alpha=0.89)		
4a	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.		x
4b	Cultural values and expectations determine what science is conducted and accepted.	x	
4c	Cultural values and expectations determine how science is conducted and accepted.	x	
4d	All cultures conduct scientific research the same way because science is universal and independent of society and culture.		x
	Creativity and Imagination (alpha=0.89)		
5a	Scientists use their imagination and creativity when they collect data.	x	
5b	Scientists use their imagination and creativity when they analyse and interpret data.	x	
5c	Scientists do not use their imagination and creativity because these conflict with their logical reasoning.		x
5d	Scientists do not use their imagination and creativity because these can interfere with objectivity.		x
	Scientific methods (alpha=0.44)		

6a	Scientists use different types of methods to conduct scientific investigations.	x	
6b	Scientists follow the same step-by-step scientific method.		x
6c	When scientists use the scientific method correctly, their results are true and accurate.		x
6d	Experiments are not the only means used in the development of scientific knowledge	x	