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Assessing the Nature of Science Views of Singaporean Pre-service Teachers

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Abstract: Despite the many developments in the teaching of science, an aspect that continues to be neglected appears to be the character and nature of science (NOS). This is becoming especially important in the light of recent developments in pedagogy, as, for example, more teachers adopt constructivist methodologies and computing technology enables simulations that may blur the lines between models and reality. From the literature, it is known that teachers' modern NOS conceptions, though not a sufficient condition for transmission of modern NOS views, is necessary. In this study, pre-service teachers' NOS conceptions are assessed with an adapted Views of the Nature of Science (VNOS) instrument, originally designed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). The modified instrument is an eight-item, open ended questionnaire – designed to elicit descriptive responses to common NOS misconceptions. Responses were analysed into coded categories of 'informed, 'uninformed, and 'ambiguous'. It was found that a significant proportion of teachers possessed uninformed views. Some implications for teaching and teacher education are presented in this paper for discussion.*

Introduction

The nature of science NOS is an aspect of Science education that continues to receive little attention in the enacted curriculum of schools in Singapore. While there has been no detailed investigation into the exact amount of attention paid to NOS issues, related research by Cheung and Toh (1990), Boo (1995), and Boo and Toh (1998) have indicated that the level of NOS understanding exhibited by teachers to be very low. While particularly revealing, the studies conducted were reliant upon questionnaires that were not validated, and hence no firm conclusions as to the exact understanding on the part of the respondents, or otherwise, can be reached. This study, similarly motivated as the previous studies, relies upon an adapted Views of the Nature of Science (VNOS) questionnaire, Form C, which has been validated and developed over two revisions (A and B) by Lederman et al. (2002). These authors also wish to make a case for the more overt inclusion of the Nature and Philosophy of Science in the Science curriculum, in part to assist the aims of facilitating scientific literacy among the general public, and also for the education of an intellectual response toward controversial philosophies, for instance, constructivism.

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What is the Nature of Science?

While it must be stressed that the NOS is not an issue without contentious debates – especially in the esteemed academic circles[1], there still exists a great degree of agreement on some of the more basic tenets. These include, but are not limited to, a summary presented by Bell, Lederman, and Abd-El-Khalick (2000):

- The main purpose of science is to acquire knowledge of the physical world. It has no connection with outcomes, applications, or other uses aside from the generation of new knowledge.
- There is an underlying order in the world which science seeks to describe in a maximally simple and comprehensive manner. The world is orderly, and science seeks to construct theories which describe this order.
- Science is dynamic, changing and tentative. Science is not a static collection of facts. We cannot take current scientific knowledge to be complete and final.
- There is no one, single Scientific Method. The overly simplified hypothetico-deductive method that is frequently given as the only example of scientific methodology in the initial chapters of textbooks is not the only way science progresses.

McComas, Clough and Almazroa (1998) add the following:

- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence.
- Observations are theory-laden.
- The history of science reveals both an evolutionary and revolutionary character.
- Scientific ideas are affected by their social and historical milieu.

Why teach the Nature of Science?

Matthews (1994) explains the liberal tradition in education, which views education, as opposed to schooling or vocational training, as one where "science education is not just an education or training *in* science, although of course, it must be this, but also an education *about* science." He further cites Alfred North Whitehead in the same chapter:

> The antithesis between a technical and liberal education is fallacious. There can be no adequate technical education which is not liberal, and no liberal education which is not technical; that is, no education which does not impart both technique and intellectual vision. (Whitehead 1947, p. 73)

In Singapore, where we have been successful in at least the technical aspect of education, as evidenced by outstanding performances by our students in the International Mathematics and Science studies (Smith, Martin, Mullis and Kelly (2000); Chan (1996)), there is a need to always ask ourselves the question: Now that we have come so far, what next? And, how do we continue to do well in the face of popular culture, for which there is a undercurrent of antiscientific thought? Equally worrying is the rise of pop-science, with many converts to the ideas of crystal healing, ESP, UFOs and other dubious and often poorly substantiated ideas. In these times where almost everyone with access to the Internet can publish authoritative sounding information, what skills do our students have to distinguish between scientific assertions and just plain bad science?

At the same time, we see recent calls in the media for greater participation in the democratic process as signs that an enhanced education, especially in the sciences, is required. Longbottom and Butler (1999), in their paper titled "Why teach science?", develop what may be called the "democratic argument" for science. The authors argue that societies tend toward self-replication; and to improve itself, it must change, and one of the great obstacles to achieving change in society is the ``all-pervasive set of ideas that form the hegemony of the ruling class". Humans, they claim:

> will be able to transcend this ... but to do so will require more than simply a belief in democratic ideals. To make effective use of their democratic ideals, citizens must ask fundamental questions, they must analyse and challenge the accepted norms, and they

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[1] see, for example, Alters (1997), and Elfin, Glennan & Reisch (1999)

must be able to appraise programs, assess policies, and judge suitable means of achieving them.

Science, with its "quintessentially rational view of the world", has a special role in the development of a rational population. If science – the first, if not the only, rational means of thought that a student is exposed to – is taught with a style that does not, for example, emphasise the general tentativeness of scientific ideas and its human and creative aspect, would it be any wonder that generations will be brought up to believe that there is one "right answer", which cannot be questioned, and is always right in all circumstances regardless?

Scientific literacy, the evergreen aim of science education, deserves special mention in this age where the calls are for reengineering the economic machinery for the 'knowledge based economy', and to make use of the science and technology to "pursue knowledge for the prosperity of Singapore" (A*STAR, 2002). Laugksch (2000), cites Thomas (1987), who writes that "as economies become more ``knowledge-based", the quality of human resources is increasingly seen as the most important economic asset of modern societies. Scientifically literate individuals may therefore be in a favourable position to exploit new job opportunities and be able to take advantage of technical developments in the workplace." To develop scientifically literate individuals, it should be recognised that the history and nature of science forms an integral part of science, and that its teaching should be purposefully integrated into the curriculum.

The good news for parties concerned with science performance appears to be that teaching the NOS has a positive effect. McComas et al. (1998), in their summary of research, highlight results from Songer and Linn (1991), where a comparison was made between two courses in thermodynamics. Students taught with a view of science as a dynamic body of knowledge acquired a more integrated understanding as compared to the other group, which held the view that science was a static body of knowledge. This result is by no means unique. Recent evidence for such improvement in science performance can be found in, for example, Rudolph and Stewart (1998), and Lin, Hung, and Hung (2002). Nelson, Nickels, and Beard (1998) also report positive outcomes in integrating NOS with the teaching of biological evolution, a topic that has been receiving much opposition for most of its almost 150 year history.

With such reasons to back an increased emphasis on the Nature of Science as a curriculum objective, perhaps the question we should actually be asking ourselves should be: Why *not* Teach the Nature of Science.

What is needed to teach the Nature of Science?

Lederman (1992), in his well cited review, traces the development of research into teachers' and students' views of the NOS over much of the 20th century. When it was decided that NOS-type objectives were to be included into the curriculum, it was found that the teachers' views were not well-developed, and thus attempts were made to correct this. Much later research found that teachers' informed NOS views, while necessary for teaching, were not sufficient indicators of teachers' abilities to conduct science lessons infused with history and nature of science. Typical of this line of thought were findings from Tobin and McRobbie (1997), Mellado (1997), Bell, Lederman, and Abd-El-Khalick (2000), and Schwartz and Lederman (2002). In this paper, we find that this necessary condition is not even met in our local sample of pre-service teachers.

The research instrument.

Lederman, Wade and Bell (1998), in a review of assessment instruments used to determine NOS conceptions, noted that most of these instruments were of the forced-choice nature (agree/disagree, Likert scale and multiple choice). The authors criticised many of the instruments used over the last forty years. Of the major difficulties encountered, the validity of the instruments were called into question on two accounts. Firstly, the instruments were predicated upon the assumption that the respondent would interpret the instrument items in the same manner as the researchers. Secondly, as they were forced-choice, the instruments tended to reflect the biases of the developers on the respondents.

As a result, researchers began to develop open-ended instruments, with emphasis on descriptive questions, together with interviews that allowed meaningful assessments of the individuals' NOS views. Lederman et al. (2002) developed such a questionnaire, focusing on aspects of the NOS as (a) its empirical nature; (b) the relation between observation, inference and theoretical entities in science; (c) the distinction between theories and laws; (d) the creative and imaginative nature of scientific knowledge; (e) the theory- laden nature of scientific knowledge; (f) the social and cultural embededness of scientific knowledge; (g) the myth of the scientific method; and (h) the tentative nature of scientific knowledge.

After passing through 2 prior versions of the questionnaire (Forms A and B), with VNOS-B being validated by comparison between expert and novice groups, the authors propose VNOS-C. Validity of this latter instrument was tested with undergraduate and graduate college students, pre-service elementary teachers, and pre-service and in-service secondary teachers. By comparing and contrasting NOS profiles of participants produced from separate analyses of the questionnaire and interview transcripts, it was found that "interpretations of participants NOS conceptions as elucidated from the VNOS-C were congruent to those expressed by participants during individual interviews" (p. 511)

The authors stress that the validity of such an instrument is not a final "once-and-for-all" state, and emphasise that the principal source of the instrument's validity evidence stems from the follow-up interviews, where it is possible to check respondents understanding of items. Lederman and co-workers also claim that the questionnaire is developed with an interpretive stance in mind, with aims to elucidate learners' views rather than for labelling their views as inadequate or adequate.

Research Methods

For this study, convenient samples of pre-service teachers undergoing a chemistry pedagogical methods module as part of the Post-Graduate Diploma in Education (PGDE) course were sent an email of the questionnaire, with instructions to fill in their responses, in particular, asking their attention to only state their own opinions and not consult other sources or each other. In accordance with recommendations of Lederman et al. (2002), no time limit was given. Also, participants were reminded that the questionnaire was not a test, and did not constitute any form of assessment in any way. A total number of 125 responses were thus obtained, and this represents approximately 30% of the total cohort of pre-service PGDE science teachers.

Responses were then read and separately rated by both researchers. For each question, a rating was given as either uninformed, informed, or ambiguous. Exemplar statements were derived from Lederman et al. (2002), and also agreed upon by both researchers before rating was done. As strongly cautioned by the authors,

> "the VNOS could be abused if its interpretive stance and qualitative interviewing component were overlooked or undermined. As such, the importance of coupling the use of the VNOS with individual follow-up interviews with all or a reasonable sample of respondents cannot be overemphasised" (p. 517)

Due to time constraints, it was decided that instead of interviewing a significant sample, it would be more efficient to discard responses which could not be clearly interpreted without the respondents' further input. These responses were therefore classified under the "ambiguous" category.

Results and Analysis

Table 1 below shows, by percentage, the assessed responses per question:

Table 1

Response to questions by percentage

Question	1	2	3	4	5	6	7	8
Informed (%)	26	9	60	17	12	46	30	26
Uninformed (%)	40	79	26	46	42	9	24	33
Ambiguous (%)	34	12	14	37	46	45	46	31

As compared to previous local studies that asked up to 4 questions (Cheung and Toh, 1990, Boo 1995, and Boo, 1998), this study reveals a richer set of data about the respondents' NOS views. With at least 8 different aspects of the NOS to examine, it is now possible to see that their responses to some aspects are actually fairly informed, and instead of an overall judgment of the respondents' status, we are now able to identify specific aspects where more work would be required.

The number of ambiguous responses discarded was, on average, 2.2 per respondent, constituting 27.5% of the responses. This only serves to highlight the advice given by the instrument authors, and indicates the relative difficulty in rating such open-ended questionnaires. This state of affairs must be compared however, to an alternative close-ended, forced choice type of questionnaire, where quantitative data may be more easily obtained, but where the pitfalls highlighted by Lederman et al. (1998), as previously mentioned in this paper, would loom large.

In general, we find that for many of the respondents, their standard of the English language, specifically for the terminology of science, was a limiting factor. For a small category of teachers, it was doubtful if they could even string a coherent sentence together, or interpret the question accurately – some of the replies did not even begin to answer the questions asked.

What follows is a question-by-question analysis of the typical responses, and a brief explanation of how the figures in Table 1 came to be what they were. The subsection header will contain a quotation verbatim from the respondents' views.

Question 1: "Science is the study of entities that exist in the universe. Scientific disciplines are more logical than other disciplines and the former provides explanations with facts and proofs."

Many respondents made references to the 'degree of hardness' of the sciences like physics or chemistry in comparison to the 'softer sciences' like the social sciences and philosophy (which gave an impression of intellectual snobbery). Reading the responses, it was apparent that many have not given much thought to the fundamental question of what science really was – many expressed views that were not well elaborated, and thus had to be discarded. In this question, we concur with the findings of the earlier papers, whose instrument involved a similar question.

Question 2: "Yes. To confirm truth and validity of scientific theory and inquiry. Without experimental validity, there is no scientific knowledge. There is only blind faith."

This was the question to which most respondents expressed their uninformed views. We see numerous strong opinions concerning the necessity of experimentation to forward the development of science. This is due in part, to their confusion as to what an experiment is as compared to the empirical nature of scientific evidence; for example, in the above quote, replacing "experimental validity" with "empirical validity" would make for a perfectly sensible statement.

Experiments and demonstrations, which command so much respect in the classroom, may not necessarily be an unmitigated good. As an aspect of science teaching, Rudolph and Stewart (1998), arguing for a deeper inclusion of NOS concepts to teach evolutionary theory in biology, point out that:

> "Students come to view *science* and *experiment* in constant conjunction and fully expect that all assertions in science, if valid, should be capable of unambiguous demonstration. This misconception of science has the potential to become an important stumbling block to effective evolution education."

Indeed, we do observe many cases where respondents make mention to the theory of evolution (in biology) as the prime example of a "scientific theory", which they claim to be "not confirmed", "not a law yet", and state that "there is no proof for evolution".

Question 3: "Scientific theories do change because theories are suggested proofs and are not actual proofs or facts."

As can be seen in Table 1, most respondents managed to reflect the more informed view in Question 3, which asked about the tentative nature of theories. This however, must be seen in context of question 4, which asked the difference between theory and law. A highly significant number of respondents took the uninformed view, in effect falling for the "laws-are-mature-theories-fable" as coined by Rubba, Horner, and Smith (1981), which therefore brings light to the informed response in question 3: due to the respondents' misconception of the concept of a theory, they may have mistakenly answered the question "correctly". One wonders what the response would be like if the question had been phrased with "scientific law" instead.

Question 4: "Scientific theory is a hypothesis that has not been proven yet. e.g. evolutionary theory."

It was not at all surprising that many respondents fell for this 'fable', for it has long been promulgated, even in science textbooks today. This question was the most clear-cut and easiest to categorise into the uninformed and informed classifications, and had the least variance in responses.

Question 5: "Since they can provide the structure of the atom universally in textbooks and reference books, I think that they must be very certain of it. Maybe they look at it at a microscopic view."

Question 5 revealed what the respondents knew about the epistemology of science, especially with respect to models of physical systems. It is clear that this sample of respondents were not aware of the limitations of scientific modelling, and of the testing and hypothesis generation work that proceeds before confidence in the model could be acquired. In some respects, it was quite disappointing that the respondents did not refer to the black box type experiments, this time with the lid permanently sealed shut. What was comforting however, was that most of the respondents were able to recall the content knowledge, with almost all making some mention of the Rutherford alpha scattering experiment.

Question 6: "The same piece of evidence or the same set of data can be subject to multiple interpretations."

Questions 6 and 7 had the highest number of discarded responses, as these questions dealt with aspects of science which were not "in the syllabus". It is for these questions that the advice of the instrument authors to interview the respondents are taken to heart. A significant number of respondents whose answers were not discarded were able to claim that scientists personalities, motivations and beliefs can affect the theories that they generate. On the down side, perhaps, the respondents were assisted in this question by their close association of "theory" with "hypothesis".

Question 7: "Science should be universal and scientific knowledge should be the intellectual property of all mankind / Social and political values are sometimes reflected in interpretation of data. Statistics and data on the causes and effects of ozone depletion and the subsequent warming of the globe may be interpreted differently by different interest groups. Wealthy industrialist economies tend to downplay these effects as they stand to lose most if any curbs on industrial activities were to be implemented."

This question gave the most number of ambiguous responses, as many respondents could only offer either half of the above response (which was judged to be informed). Most of the respondents would state a variant of the first half, explaining that "science was universal", and that the "equations and symbols used are the same throughout the world". This question had the greatest variance in responses, and we hesitated to judge many responses due to their providing only half of the possible response.

Question 8: "Yes, I think they do; especially in the early stage of their investigation when they are trying to frame the problem, and make sense of it. But as they proceed to verify their prediction they employ the objectivity and critical mindset required of them"

Lastly, concerning the creative nature of scientific investigations, most of the respondents did not seem to think that creativity and imagination were required at all steps; a few of them even adamantly stating that "there must not be any interpretation of the facts, they should speak for themselves". This is, of course, at odds with the more informed view for which creativity and imagination are involved at every step of the way. We speculate that the stress on procedure in the typical classroom laboratories and emphasis on "*the*" scientific method that has been expressed in many textbooks to be culprit here. As an exonerating factor, we understand that for the majority of science students, even up to the undergraduate level, investigations are carried out in such a way that very little latitude is given for the student to explore alternatives.

Overall, while we would hesitate to come up with a quantitative figure to describe the status of the NOS views of our respondents, we would still summarise the findings to state that the respondents in our sample still hold generally naïve, uninformed views regarding most aspects of the NOS. While the overall conclusion does not seem different from the prior research in the same context, we hasten to add that this research is the first to utilise a validated instrument, which has also provided a far richer data set for analysis due to the different aspects of NOS covered in the questionnaire.

Implications for education – How did we get here, and where do we go from here?

We see here that for the most part, pre-service teachers NOS views are certainly nowhere near the level of sophistication that would be required for an effective education of NOS and general scientific literacy to their potential charges. Examining their histories, this cohort of pre-service teachers would have been students in high school in the mid-to-late 1990s, when the new educational initiatives were beginning to take some form. The MOE Thinking Programme involved explicit teaching of creativity and thinking skills as well as infusion of these skills across content subjects (Chua and Leong, 1998). While this would not be a suitable venue for the criticism of these initiatives, it is noted that the teachers of this cohort, on the whole, did not make use of the excellent opportunities to achieve synergistic effects of incorporating aspects of the nature, history and philosophy of science into the their teaching repertoire.

To us, it would not be surprising at all to find that the NOS views of these teachers – practicing teachers with at least 10 years of experience – to have poor NOS views. Guided by research, it would also not be surprising that for the few teachers who hold progressive views, the enacted curriculum in their classrooms would not be progressive, but rather, from anecdotal experience, limited by factors such as the 'peer pressure' to complete the curriculum, a reluctance to deviate from the planned syllabus for fear of affecting the educational 'bottom line', and the lack of mental energies left after the implementation of education initiatives 'from above'.

These, however, are mere assertions, and no study has been undertaken so far. While there have been some research in foreign contexts regarding the obstacles, it is our contention that some of these obstacles are context-sensitive, and would require a study to elucidate. What would be interesting too, would be the closer examination of where the modern NOS views of our respondents derive from – whether from their teachers or from the media. Given the amount of scientific and (sometimes) pseudo-scientific programming in the media, it would only be too tempting to attempt an analysis of scientific messages from the media, especially since, with computer assisted scene-rendering, aspects of scientific theories and models could be presented as if they were reality, hiding the amount of work that had to be put in to verify these models.

Conclusions

Science, if understood properly, for and in itself, is a fascinating adventure that can, for many people, become a source for their lifelong thirst for knowledge. In the way that has been taught in so many schools, as simply a vocational training to qualify workers for the technological industries, we find students being shortchanged; and we view the educational initiatives to foster creativity and critical thinking as disappointingly inferior substitutes that distract learners from the true flavour of intellectual curiosity and excitement that is science.

Appendix A

Views of the Nature of Science Questionnaire

1. What, in your view, is science? Are scientific disciplines, such as physics, biology, etc. different from other disciplines of inquiry (e.g. religion, philosophy)? If they are different, what makes science different? If they are the same, explain why.
2. Does the development of scientific knowledge require experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.
3. After scientists have developed a scientific theory (e.g. atomic theory, evolutionary theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answers with examples.
4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
5. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?
6. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
7. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
   - If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
   - If you believe that science is universal, explain why. Defend your answer with examples.
8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
   - If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
   - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

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