The Tentativeness of Scientific Theories: Conceptions of Pre-Service Science Teachers

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ABSTRACT

The recognition of sound understanding of Nature of Science (NOS) in promoting scientific literacy among individuals has heightened the need to probe NOS conceptions among various groups. However, the nature of quantitative studies in gauging NOS understanding has left the understanding on few NOS aspects insufficiently informed. This paper aimed to probe the understanding on one of these underexplored aspects, namely the tentativeness of scientific theory. Phenomenographic data collect was used to infer the understanding of ten pre-service science teachers on the tentativeness of scientific theories. Results showed that the participants held two differing conceptions about the scientific theories in this regard, namely 1) Theories are changeable with future occurrences and 2) Theories are changeable opinions. Implications suggest that other than educating the future teachers about NOS, the pedagogical NOS knowledge should be equally emphasized so that they are able to include NOS in their instructions explicitly.

Keywords:

INTRODUCTION

Rapid development of the world has resulted in various transformations in life of people compared to the previous centuries. The increasing reliance to electronic gadgets and the heightened need to access the internet exposes individuals nowadays to various information, products and knowledge. For this reason, there is a need to produce individuals who are able to discern science and pseudoscience, so that they are capable of making informed decisions in their daily life issues related to Science. This paper is written in the effort to meet such aims.

Science Literacy

The term "scientific literacy" was first coined by Paul Hurd (1958), referring it as a skill "essential for effective citizenship" (p.13). The notion of science literacy in the 21st century went beyond what have been perceived as science literacy in the early 1960s (Kings, 2002). The major purpose of producing science literate students back in the 1960s was to create and nurture the younger generation to be scientists (DeBoer, 2000). However, this notion of science literacy in the 21st century has deliberately focuses on producing citizens who are sound in decision making and involve actively in the currently advance scientific and technological world. The need for individuals to equip themselves with science literacy has been reported in various reform documents, and has been made the primary objective of science education worldwide (AAAS, 1990; NRC, 1996; Chen, Shi & Xu, 2009; Chai, Deng & Tsai, 2012).

Similarly in Malaysia, the urge for students to achieve literacy in science surfaced with the unveiling of Vision 2020, aiming to grow towards becoming a developed country with mature economy by the year 2020 (Department of Information Malaysia, 2012). The sixth challenge to be achieved is detailed as follows.

The sixth is the challenge of establishing a scientific and progressive society, a society that is innovative and forward-looking, one that is not only a consumer of technology but also a contributor to the scientific and technological civilisation of the future (para. 12).

The challenge details the need for NOS to be well understood by all citizens so that they can become independent and sound decision makers of issues pertaining to science. National Economic Policy (NEP) outlined in 1976 is one of the evidences which place science and technology as one of the prerequisites for economy development in Malaysia. Such emphasis on science is in line with the New Integrated Curriculum for Secondary Schools (KBSM), introduced in 1980.

Various ways which foster science literacy among science learners have been put forth by academician and researchers in order to inculcate such literacy from young age. One of the strongly proposed paths is by ensuring that learners are equipped with sound Nature of Science understanding.

Nature of Science

Nature of Science has been defined widely in the literature as an "epistemology of science or how science is done" (Lederman, 1992). The essence of NOS describes scientific knowledge as human endeavour. It has been widely reported and documented that the ideas on the scientific knowledge development should be illuminated to learners in order to assist them in engaging and solving real life scientific issues (AAAS, 1990; NRC, 1996). NOS has been recognised to help by exposing learners in understanding why certain ideas in science are changeable, and thus promote better science understanding where scientific contents are concerned (Tobias, 1990; Smith, 2010). Wheeler-Toppen (2004) in support of a similar conception, listed three benefits of weaving NOS into science education which include improving learners' general understanding in science, advocating critical thinking and analysis in using science knowledge in their daily life, and establishing the position of science as a valid knowledge in society. Among the aspects which are non-controversial in NOS are the tentativeness of science knowledge, the creativity and imagination in science, the empirical nature of science, and the social and cultural embeddedness of science (Lederman, 1992).

Malaysian Science Education has also highlighted similar interest in understanding science among the science students. Eleven objectives with emphasis on inculcating thinking skills were enumerated to be met by science learners in the effort to achieve such aim (Ministry of Education, 2006). Two out of the eleven objectives emphasized on NOS, as follow.

Second objective: Understand the developments in the field of science and technology.

Tenth objective: Realise that scientific discoveries are the result of human endeavour to the best of his or her intellectual and mental capabilities to understand natural phenomena for the betterment of mankind. (p.5).

Other than the students' NOS understanding, it is also documented that standards for NOS understanding need to be met by diverse groups such as practitioners and educators as it is believed that every group forms an interconnecting system (NRC, 1996). Therefore, a successful achievement in meeting the standard of a group is dependent on the accomplishment of the whole system in meeting the standards set by all the respective groups making up the system (NRC, 1996). This includes teachers' to have sound understanding of NOS in order to teach science so that they do not impart their naive conceptions to their students.

NOS research

Since the importance of NOS in fostering science literate learners has been acknowledged, there is an increasing large volume of research focusing on various facets of NOS understanding. Among them are a) students' and teachers' conceptions of NOS (Buaraphan & Sung-Ong, 2009), b) the curriculum which places emphasis on NOS (Chen et al., 2009) and c) ways on improving teachers' and students' conceptions (Friedman, 2006). For these reasons, over 20 instruments were developed to measure the understanding of various NOS aspects among various groups or to study the effectiveness of certain interventions on their participants' NOS conceptions (Talbot, 2010; Keiser, 2010; Smith, 2010; Jones, 2010; Sarkar & Gomes, 2010; Dogan & Abd-El-Khalick, 2008; Tan & Boo, 2003; Lederman et al., 2002).

Research on the NOS understanding is extensive, generally investigating the various groups' understanding on numerous aspects of NOS. There is an extensive literature conducted to view the understanding of NOS, mostly using the quantitative approach (Lederman et al., 2002; Khishfe, 2008; Karakas, 2006; Schwartz & Lederman, 2008). All of these studies grouped responses into "naive" and "informed" based on their participants' responses. For example, Lederman et al. (2002) who studied on pre-service teachers' understanding identified "experts" (informed views) and "novice" (naive views) among his research participants. About 71% of the "novice" group indicated that "If you get the same result over and over and over, then you become sure that your theory is a proven law, a fact". The naive understanding stemmed from the belief that science is an absolute and static knowledge. Although the findings from the study were derived from large numbers of research samples, the study did not articulate the common reason for variation in understanding the tentativeness of scientific theories. Providing the categories on the range of notions held by the subjects of study can offer better insights on the reasoning made by them. Such initiative was undertaken by

Keiser (2010) in which he attempted to categorize the conceptions held by high school chemistry students about the tentative nature of scientific knowledge. His analyses resulted in two dichotomous categories, which were "theories change" and "theories do not change". However, as his study utilized free-response instrument, many of the respondents did not provide detailed reasons to why they think theories change or do not change. Common responses only indicate that scientists are not sure about the structure of an atom, or simply implied that theories are not real. The review of literature at large also shows that qualitative research on the understanding of NOS is scant.

In Malaysia, the research on teacher trainees' NOS understanding are limited. One of such studies was carried out by Low (2000) who studied the NOS understanding of 80 teacher trainees from four teacher training colleges in Peninsular Malaysia. He utilised the Process Oriented towards Science Scale or its acronym POTSS to collect his data (Scharmann, Harty & Holland, 1986). Arising from his findings, he reported that the percent mean score for the overall understanding of NOS among the participants of his study was 58.8%, which was rather satisfactory. On the contrary, a small scale study using two-tiered free response instruments inferred a different finding about the NOS understanding among local pre-service teachers (Jain et al., 2012). An action research investigating the effectiveness of NOS instruction in a local university found through the pre-test, that 94.2% of the pre-service biology teachers felt that theories are the true depiction of the world which provide facts and proof whereas a substantial 77.8% believed that experiments in science generate proof for theories. Through a two-tiered instrument, the participants of the study provided naive views in almost all NOS aspects investigated which led to the conclusion that there is inadequate understanding of NOS among the participants of the study.

The Study

The present study will focus on the understanding of pre-service science teachers, specifically on the tentative nature of scientific theories. This paper seeks to address the following question.

What is the variation in conceptions held by pre service science teachers about the tentative nature of scientific theories?

The study used phenomenographic approach, guided by the framework of awareness to ensure the rigor and quality of the study (Sin, 2010). The focus of phenomenographic study is to describe a phenomenon as experienced by individuals (Marton & Booth, 1997). A phenomenographic study pinned to the structure of awareness is regarded as integrated and internally consistent, making it defensible (Cope, 2004; Smith, 2010; Sin, 2010). A total of 10 pre-service science teachers who are in their first year participated in this study, where they were interviewed for their notions about NOS. A semi-structured interview guide which was adopted from VNOS (C) developed by Lederman et al. (2002) was used. The questions included in the interview guide are:

a) Can you please tell me what do you understand about the term theory?

b) After scientists have developed a scientific theory (eg: atomic theory, kinetic theory), does the theory ever change?

The interview protocol was pilot tested prior to actual data collection, resulting in the usage of instances (Gilbert et al., 1985) for the clarification of responses. The questions were also modified to allow more follow up questions by the researcher, enabling the discernment of respondents' structure of awareness.

The interview data was then transcribed and analysed, guided by the framework of awareness to shift the focus off the researcher from interpreting the data using their prior knowledge (Cope, 2002). Due to the ontological and epistemological perspectives adopted by phenomenography that makes it different from other qualitative studies, the validity and reliability of findings are dealt with differently (Morse et al., 2002). Validity of the analyzed data was established using the communicative validity and pragmatic validity (Sandberg, 2000) while its reliability was established through inter-judge communicability (Saljo, 1988) and interpretive awareness (Sandberg, 1997).

Structure of awareness

In the phenomenographic perspective, an individual must be aware of something in order to experience it (Marton & Booth, 1997). As experiences are always in a context of phenomenon, an individual experience about a phenomenon depends on how his or her awareness is structured. Marton and Booth (1997, p.87) detail that there are two aspects in which experience can be conceptualized, namely the 'referential' and the 'structural' aspects. Referential aspect refers to what is experienced i.e. the meaning of the phenomenon as experienced, while the structural aspect focuses on how an individual thinks about the phenomenon through his or her experiences. However, individuals can be aware about myriad phenomena at a same time but not in the same way. There are three levels of awareness which are theme, thematic field and margin (Gurwitsch, 1964).

Theme: The concept which are focus upon when contemplating about a phenomenon.

Thematic field: Other conceptions which exist but are not focused upon.

Margin: The field where the themes are derived from.

In the present study, the initial response provided by the interviewees when answering the questions in regard to NOS (the phenomenon) infers the attached meaning brought to the fore of their awareness (theme) as they reflect about the phenomenon.

FINDINGS

There are two different ways in which the tentative nature of scientific theories are conceptualized by the participants of this study. The categories are a) Theories are changeable with future occurrences and b) Theories are changeable opinions.

a) Theories are changeable with future occurrences

This is the category of understanding inferred by most of the respondents. A total of 9 pre-service teachers recognised that theories can change, but imposed conditions for them to change. The conditions are elaborated as follow.

i) Environmental changes

Three out of nine respondents indicated that changes to theories happened with the change of the environment in the future. As theories are recognised as explanations of the phenomena, theories are required to adapt to the changes too to further explain the phenomena well. The respondents regarded the effects of global warming, fluctuations of temperature and absence of water in the future to cause such changes in the future. The responses provided by the participants constituting such understanding are illustrated in the excerpts.

"The change of the world. For example, there is no more liquid in the future, and then other scientists conduct a new research and got a new theory. For example, a new theory with a new name."(R5)

"Science is associated with environment. So if the environment changes, the theory in the future will change as well...it depends on the current situation, for example, technologies...technologies can change...Because technologies becomes more advanced, automatically it will disrupt the weather patterns...for instance, global warming. Often there also will be science meetings, thorough investigations right? With more research, theories will change." (R6)

"I think the possibility to change is very small…unless the factor is the world itself. I feel that everything in our planet can change. As with the weather, from years before until now, the temperature, environments, technology are all different." (R7)

The way scientific theories conceptualized here are seen as developing, in which theories are susceptible to any changes that may occur in the future.

ii) Knowledge and technological change

Another way of conceptualizing the tentative nature of scientific knowledge put forward technology and knowledge advancements as reasons to why theories change. R2, for example, indicated such conception.

"Theory [can] change as now we have many technologies that change, and more knowledge with additional information. So the theory change with time, and renew into other theory."(R2)

Other participants inferred that technologies as the enabler for changes to happen. For example, experiments can be carried out with more sophisticated technologies, enabling better observations to be feasible. R8, inferred such conception through his response.

"All technologies like computers, were absent before this. Now it has become more advance and technologies has [developed]. When we conduct experiment, it is like we can carry out experiments because we have the technology, then we can prove them." (R8)

Similarly, R9 also contributed responses indicating that technology causes change to scientific knowledge.

"Can change because what the scientists found now is not similar with what will be found by other scientists in the future. So I think theories change…look at the advance technology that we have now too, it help theory change." (R9)

b) Theories are changeable opinions

The notion of theory change in relation to scientists' opinions was indicated by only one participant interviewed. Her idea of theory change is illustrated by the excerpt as follows.

"Changeable. The theory might not be wrong but maybe there are different facets of it which scientist A might not discover, but it's discovered by other scientists. It doesn't mean that scientist A is wrong but it's just that they have different opinions." (R10)

The meaning attached to the change of theory in the response describes an understanding that theories are ideas postulated by scientists in the effort to understand the world. Hence, these ideas are subjected to change, opened to be challenged by other scientists' ideas. It demonstrated an understanding that science is a knowledge constructed through human endeavour.

DISCUSSION OF FINDINGS

Due to the nature of phenomenographic analysis which is emphasized at a collective level, comparison with other studies is permissible and has been recognised by other phenomenographers (Schmidt & Volke, 2003; Stefani & Tsaparlis, 2009).

A review of the literature on the general understanding of NOS indicated that pre-service teachers who have never undergone explicit learning of NOS hold naïve understanding about scientific knowledge, where scientific theories are regarded as static (Khishfe & Abd-El-Khalick, 2002; Wahbeh, 2009; Talbot, 2010). Contrary to expectation, the pre service science teachers in this study did not demonstrate such stagnant understanding about the development of scientific theories. Surprisingly however, they indicated that scientific theories are dynamic and able to change, but to some extend is still absolute. Science knowledge is regarded as objective by the participants as they associated their experiences that can be well explained by science. Such inductivist's view of science has been reported by Driver (1983) to be promoted by the traditional synthesis of understanding science concepts and ability to undertake inquiries in science education.

One reason that was brought to the fore of their awareness infers that new empirical data can be resulted from drastic *environmental changes*. When conception such as this was probed further, it was found that the change that was regarded by the participants is not the change of knowledge but change in the phenomena of science itself. The physical changes in the future articulated by the participants, such as global warming (R6), change of temperature (R7) and absence of liquid (R5) are the observable variables. These variables are experienced by the participants or made aware to them as environmental science issues. The fluctuations of world temperature cause by global warming as indicated by one of the participants (R7) inferred that this way of conceptualization might perceive the change on the temperature only and not the change of the scientific knowledge itself. From scientists' view however, the weather change or fluctuations in temperature cause by global warming for instance, does not alter the theory of greenhouse effect.

Apart from that, the physical and environmental changes found in this study are similar to the "new empirical evidences" as reported in studies carried out by Keiser (2010). However, his analyses grouped such responses differently, characterizing them as conceptions which are in line with the holistic understanding of science epistemology. It was even reported by Keiser (2010) that some of the responses he obtained were not specific about the reasons to such change. This study on the contrary, has contributed to a clearer picture that the learners' conceptions of dynamism in scientific knowledge does not necessarily entails the subjectivity of the knowledge itself.

Another element under the category "Theories are changeable with future occurrences" is the "Knowledge and technology advancement". When analyzed in scrutiny, the notion of technology can be conceptualized by respondents in two different ways.

- Technology as agent indicating change

The technology advancement experienced by the participants in their daily life has been an agent indicating that change can happen to theory, hence making science dynamic (for example, excerpts by R8). These changes can lead to the idea that better theory has developed in aiding better technologies to be created, and hence the availability of more sophisticated technologies. However, the theory that contributed to such advancement has never changed; the outdated mobile phone and the most sophisticated phone today are built and created based on the same Electro-Magnetic theory. Therefore, the changes in the application of science ideas are not caused by similar changes in scientific knowledge. However, participants might conceptualize that such technological advancement are the products of theory change.

- Technology as agent assisting change

Contemplating from the notion inferred by the participants, technology is believed to be held responsible for change in scientific knowledge to happen. In this regard, more products generated from advance technology such as better viewing aids and equipments are perceived as able to provide more and better opportunities for scientists to carry out investigations. Hence, technology advancement in this way reflects science as an endeavour of human in the pursuit of inquiry. While it is undeniable that technology has greatly improved the scientific inquiries, the development of scientific knowledge reflected by the respondents' thinking is only the change of theories within the same paradigm. Theories in science or scientific knowledge in general are regarded as dynamic due to the agile progress of experimentations involving only revision, improvisation or alterations of theories in science. These changes are an example of limited understanding that science development can only evolves.

One major implication arising from the findings of this study is the unsatisfactory understanding about NOS, depicting the heightened need to focus more on enhancing pre-service teachers understanding about NOS.

CONCLUSION

This paper which reports the in-depth understanding demonstrated the more complex way of understanding NOS among pre-service teachers that may not be diagnosed by use of quantitative or free response instruments. In a different note, the assumption that teachers' sound understanding translates directly to their students has been falsified (Lederman, 1986) and calls for a more scrutinized inspection into developing the pedagogical content knowledge for the pre service teachers, focusing on NOS (henceforth, pedagogical NOS knowledge). It is lamented that explicit NOS teaching is essential for teachers, but it is insufficient in preparing them to channel their understanding to their students. It is contended that more deliberate research assessing the current NOS teaching is pertinent to perpetuate science literate individuals shouldering the development in the future.

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