Pre Service Science Teachers' Conceptions on the Scientific Theory-Law Relationship: A Phenomenographic Study

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Abstract

This study was grounded on the ultimate goal of science education in Malaysia, which is to produce individuals who are scientifically literate. The study specifically aimed to probe how research participants conceptualize the relationship between scientific theory and law. Guided by the phenomenographic structure of awareness as the methodological framework, this study involved interviewing 10 first-year pre service science teachers. Differing from the literature reviewed, the findings revealed that there were unique ways in which the scientific theory-law relationship is conceptualized by the interviewees in the study, namely "Scientific laws are superior to theory" and "Scientific theories are different from law". The findings inferred the interviewees' understanding of nature of science as absolute and objective. To summarize, it is pertinent to further probe and rectify incorrect, alternative understanding about science knowledge among pre-service science teachers to ensure only scientific conceptions will be disseminated to their future students.

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Keywords: Science literacy, Nature of Science, Phenomenography

Introduction

Scientific literacy requires a person to possess the "knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22). In cultivating such literacy, understanding Nature of Science (NOS) is an indispensible and essential facet in producing science literate individuals, consistent with the aim of science education, both globally (AAAS, 1990) and locally (Ministry of Education, 2006).

Nature of Science

NOS is defined by Lederman, Abd-El-Khalick, Bell & Schwartz (2002) as an epistemology of science or how science is done. Currently, there is consensus on the need for leaners to understand both NOS aspects and science contents to be science literate learners. According to Lederman et al. (2002), there are seven aspects of NOS believed to be neutral and should be taught to science learners for the sake of science literacy. The aspects are:

- Tentativeness of scientific knowledge

- Empirical nature of science
- The creative and imaginative nature of science
- Theory-laden nature of science
- The relationship between scientific theories and laws
- The social and cultural embeddedness of science
- The scientific method (p. 500-502)

Wheeler-Toppen (2005) contended that understanding the aspects of NOS enable individuals to establish internal links between science ideas learned, resulting in critical and analytical thinkers. Corresponding to that, the studies on the conceptions held by students in relevance to constructivist's framework in science have been an on-going effort in ensuring that learners can make informed judgment about scientific issues in their life. This is because individuals who do not understand science or the nature of it can hardly participate or contribute to the betterment of the knowledge.

Consistent with that, research has been conducted to examine the conceptions held by learners at various levels (Akerson Buzzelli & Eastwood, 2011; Keiser, 2010) and even the conceptions held by teachers (Buaraphan, 2010; Jones, 2010). Albeit the importance of understanding NOS, a review on the past studies suggested that the pre-service and in-service science teachers held naïve views about the nature of science (Abd-El-Khalick & BouJaoude, 1997). Similar attempts to probe the NOS conceptions among pre-service science teachers in Malaysia were also found. A study by Low (2000) using Process Oriented Towards Science Scale (POTSS) reported that the percent mean score for the overall understanding of NOS was 58.8%. Another study conducted among pre-service Biology teachers, reported that 94.2% of the pre-service teachers think experiments generate evidences which prove that theories are true (Jain, Beh & Nabilah Abdullah, 2013).

Theories and laws

This paper focuses on only one NOS aspect: the need to understand the difference between theories and laws in science (Lederman et al., 2002). The aspect "Scientific theory-law relationship" presents only a fraction of a larger in-progress work which looked at more NOS aspects across ages. According to the American Science Position Statement, "laws are generalizations or universal relationships...[which] behaves under certain conditions" (NSTA, 2000, para. 9). Simply, laws in science are descriptive statements about the discerned patterns of world phenomena that allow human to understand better about these phenomena. On the other hand, scientific theories are well-founded and inferred explanations of those phenomena (Abd-El-Khalick & BouJaoude, 1997). Theories and laws in science from the perspective of scientists are two different constructs playing distinctive roles in science knowledge.

Contrasting with what have been scientist's understanding, previous studies had reported that pre-service and in-service teachers commonly believed that theory and law possess somewhat hierarchical structure, where theory can develop into law with enough evidences (Dogan & Abd-El-Khalick, 2008; Tan & Boo, 2003). Such belief in a hierarchical structure led teachers to perceive theories as less credible knowledge compared to law. Following such findings, it is deemed important to first diagnose and correct these inadequate understandings of NOS among the pre-service teachers before they are posted to teach in schools. This is because it has been reported that teachers' images of science heavily influence not only the nature of their science pedagogy, but also their students' views of science (Park & Yong, 2009). Although science learning in schools involved the usage of terms "theories" and

"laws", teachers' understanding of the relationship between theories and laws as conceptualized by them has been scarce, especially in the local setting. As such, this study aimed to probe in-depth the conceptions held by Malaysian pre-service science teachers regarding the relationship between scientific theories and laws.

Method

This is a qualitative study where data were collected through phenomenographic approach. Phenomenography can be defined as "a description of the limited number of qualitatively different conceptions people may hold of a given phenomenon" (Marton, 1981, p.13). Phenomenography adopts a non-dualistic view which believes that "internal" (thinking) and the "external" (world) are not isolated entities (Saljo, 1997, p. 173). Hence, the meaning an individual gives to a certain phenomenon stems from the relationship that exists between the individual (subject) with the phenomenon (object). The purpose of this study in probing the meaning of NOS as experienced by the pre-service teachers made phenomenography an ideal methodological framework. However, the findings deriving from this work are limited in terms of generalizability due to its small sample size.

Participants

In the effort to gain data, 10 first-year pre-service science teachers of a Malaysian university were interviewed to investigate the different ways they perceived the theory-law relationship in science. All participants were post matriculation graduates from science streams where they had never undergone explicit instruction on NOS. This inclusion criterion ensured that they were having similar experiences in studying science.

Data Collection

The interview sessions were guided with the questions adopted from VNOS(C) (Lederman et al, 2002). Instances showing the examples of theories and laws in science were given (Hewson & Hewson, 1989) to ensure that "shared definition" (Bowden, 2000, p.58) of the terms "theory" and "law" were achieved. Interview took place in August 2012 where the interview session with every participant lasted for about 40-55 minutes. All the interviews were recorded both visually and verbally. These raw data were then transcribed, labelled and prepared for data analysis.

Data Analysis

At the earliest phase of data analysis, the researcher immersed herself by recursive reading of the transcripts (Bowden, 2000). The similar meaning was highlighted with colours to ease the process of rechecking. Towards the end of this process, the relevant parts of transcripts which have been identified were analysed for "pools of meaning" (Marton, 1982, p.43) with excerpts illustrating the same pool. One of the pool that were identified was "Law is more believable compared to theories". This was also the preliminary category which was then further analysed with regards to "awareness" to ensure that the variation of participants' experiences is captured (Marton, 1981). In the phenomenographic perspective, an individual must be aware of something in order to experience it (Marton & Booth, 1997). As experiences are always in the context of a phenomenon, an individual experience about a phenomenon depends on how his or her awareness is structured. Structure of awareness (Marton, 1997) is commonly used to guide both the validity and reliability of phenomenographic study. Cope (2002) also asserted that internal consistency can be reached by fundamentally basing data collection method, nature of interview and data analysis on the structure of awareness. Such structure also shifts the focus off the researchers from interpreting the data using their prior knowledge (Cope, 2002).

In the effort to achieve rigor of research through its internal consistency (Spencer et al., 2003), the analysis of data are highly centred on identifying the structure of awareness of each response received. Generally, the responses gained were identified into three different levels of awareness, namely theme, thematic field and margin.

- Theme: the meaning attached to the phenomenon when respondent articulates their thoughts on scientific theory and law.
- Thematic field: what is directly relevant with the theme but was not focused upon by the respondent during the articulation of thoughts
- Margin: the horizon that a respondent is aware of but did not bring to the fore of awareness when reflecting about a particular phenomenon.

By identifying the structure of awareness, it was found that the preliminary category identified earlier can be better defined as "Law is superior to theory" and "law is different to theory" as the thematic field associated to the theme were explained differently by the respective participants. Figure 1 illustrates three-tiered structure of awareness. The validation of the findings was also carried out with the help of three other experts.

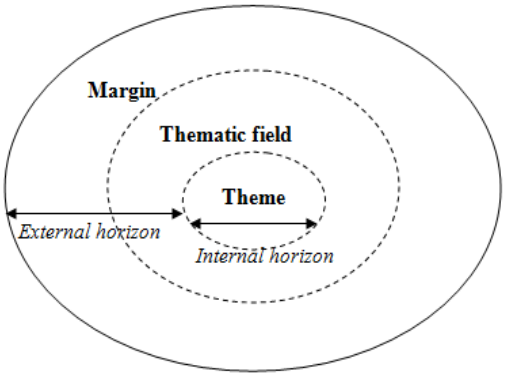

Figure 1: Structure of Awareness

For example, when asked about what a research participant thinks about the relationship between scientific theory and law, the following response was given.

> *I think law is more real compared to theory because theory follows logic and most probably it will change. Law is something which is fixed, therefore it is more believable…as long as there is no further investigation and discovery that can change that theory, maybe it can become law. This is because theories change when there is further discovery. (Participant 6)*

In the example above, the theme identified to be the focus of the Participant 6's explanation is the superiority of law. This is because it was the first notion that Participant 6 associated with, inferring that it was the theme of the phenomena as he is aware of. This notion was derived from his experience and knowledge about scientific theory and law which were used to support his idea about the superiority of law and hence, the thematic field is

based on the knowledge of theory and law. The margin of such conception which was subtly articulated by him is the conception that science is an objective knowledge.

Findings

Analysis using the analytical framework of awareness (Cope, 2004) resulted in two major categories, namely Law is superior to theory (Category A) and Law is different from theory (Category B) as described in the subsequent subheadings. The analysis also resulted in two elements found under the theme of Category A. Elements in a phenomenographic study are an extended variation found within a category that further enhanced the way a phenomenon can be uniquely experienced.

Category A: Law is superior to theory

Theme

When contemplating the scientific theory- law relationship, the respondents brought to the fore of their awareness that "law is superior to theory" (Figure 2). The higher status of law was emphasized by the respondents when they inferred the meanings they attached to the relationship between theories and laws in science.

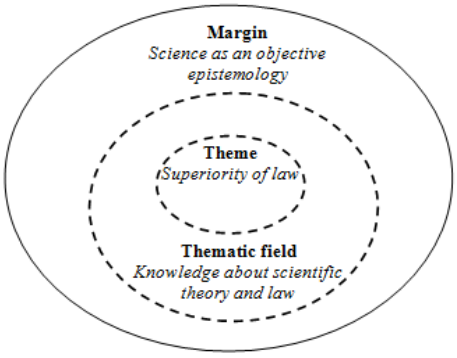

Figure 2: Structure of Awareness for Category A: Law is superior to theory

Elements are different in meaning but they described the parent category similarly for them to be members of the same parent category. There are two different elements constituting this category. The two different elements found under the same parental Category A are "Hierarchical" and "Branched".

Element 1: Hierarchical

The first element that was found under the conception "law is superior to theory" is "hierarchical". "Hierarchical" describes a one-to-one progression of theory into law where the responses inferred scientific theories as changeable, but laws as proven and fixed. Scientific laws were regarded as the final product of science, developed from theories which were well-proven and exhaustively tested during experiments. The following excerpts inferred such conceptions.

> "*A theory is like the initial part of a law*." (Participant 1)

> "*As long as there is no further investigation and discovery that can change that theory, maybe it can become law. This is because theories change when there is further discovery*." (Participant 6)

"*Law I think is something like theory, but a law is more establish and proven compared to theories. Maybe one day when theories are proven, it becomes law."* (Participant 8)

The above responses generally undermined theory as an unreliable knowledge that requires more evidences to be believable. Laws on the other hand, are at a stage of confirmed theories. Laws were regarded as superior compared to theories.

Element 2: Branched

Another less frequent, but existing way of conceptualizing laws as superior to theories is through the 'branched' element. Respondents experienced law as being made up of myriad scientific theories. It depicted scientific knowledge as having orderly structure where a scientific law can be made up of multiple science theories. Only one respondent was found to hold this conception.

"*Law is…law is fixed. For me it is the end. Maybe combination of theory and theory, then it becomes law, or form new law*"(Participant 2)

Thematic field & margin of Category A

When reflecting about the relationship between theory and law, the field in which the theme was derived from was associated with the learners' knowledge about theory and law through their experiences. For example, law was referred to as rules readily made and obeyed, akin to a country's law.

"*Laws are like...[paused]...rules which cannot be changed*." (Participant 5)

Science was perceived as true knowledge in the margin of participants' awareness. This was because laws in science were referred as entity containing truth, refined and developed further from theories. Science knowledge is perceived as objective in this sense.

Both Element 1(Hierarchical) and Element 2 (Branched) extended the variation of how respondents perceived the superiority of law when compared with theory, offering more complicated and naïve understanding about the relationship between scientific theory and law among the respondents.

Category B: Law is different from theory

Theme

Another way of conceptualizing scientific theories and laws reflected theories and laws as two different entities. Different from the previous category, the respondents brought about the differences in theory and law to the focal of their awareness. However, both theory and law are seen as different merely because they encountered the terms used in different settings. The respondents were referring to law as something fixed and will never change. Figure 3 details the structure of awareness for Category B.

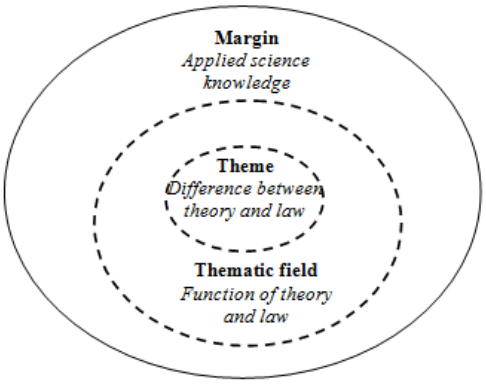

Figure 3: Structure of Awareness for Category B: Law is different from theory

For example, Participant 5 referred laws as different because laws are used as formula in calculations.

> *Law, to me, is more to the principles of something...the technological advancement will cause the theory to change and when it changes, it is not fix. So it cannot become law. Law is something which is fix and never change.* (Participant 4)

> *Laws are like...[paused]...rules which cannot be changed. Take for instance the Newton's first law associated with inertia. The law is real and we cannot change it because even if we investigate the law, it will still be the same- the heavier the object, the harder we are to move it. The law is correct.* (Participant 5)

> *A theory is a statement…and theory works because there is law. When we have rules for a theory to work, it becomes valid as it follows law. They have different purpose in science.* (Participant 9)

> *Theory is an explanation and can change because many people can talk about it while law is something which has been determined by scientists. For now, law is fix but in the future it may change because technology changes. For example, now we learnt about gravity, law of gravity. Gravity has existed for so long and it does not change…but I am not sure if there will be any technology in the future that can make it change. Then, law change.* (Participant 10)

The varied of ways the respondents in Category B experienced science learning made them think that scientific law and theory are two very different entities in science, but law is fixed and theory was portrayed as not.

Thematic field & margin

While contemplating about the theory-law relationship in science, a theme that was related but not focused upon was the function of theory and law as they experience science learning. The experience of learning science provided them with knowledge about the roles that is undertaken by both theory and law in explaining phenomena.

The margin of the theme brought to awareness while contemplating about the relationship of theory and law was their knowledge obtained from their experience during scientific

problem solving. The previous problem solving activities in science which used the formula derived from laws were placed at the peripheral of their awareness. This experience surfaced as the interviewees reflected on their experiences with scientific laws, but did not explicitly mention about such experience. Hence, experiences of encountering laws in science were only in their margin of awareness. Although law was explained as "something fixed", the objectivity is not made the margin of awareness in this category because law was said to be "fixed" and no indication of it entailing "truth".

Discussion and conclusion

In this study, the relationship between theory-law in science was conceptualized differently by the pre-service teachers based on their experiences. The category "Law is more superior to theories" with the "hierarchical" element was similar with what McComas (1998) has reported as one of the most pervasive misalignment among the learners' and scientists' understanding in NOS.

Unique to this study, was the finding that there were other ways of understanding the relationship between scientific theories and laws in science by the pre-service science teacher other than the one reported in the literature. The categories "Law is different from theory" and that law is "Branched" element under the "Law is more superior to theory" category were not explicitly found to be reported previously. These were the unique conceptions adapted by the respondents in understanding what they have learnt and experienced from their surroundings. McComas who earlier reported on the pervasive misalignment in scientist-learner conceptions (McComas, 1998) later on reviewed 15 textbooks in the United States suggested that the textbooks used maybe the contributing factor leading to the understanding that theories develops into laws (McComas, 2004). His analysis deduced that none of the 15 textbooks accurately portrayed precise elaborations, explanations or definitions in regards to theories and laws. A quick survey by the researcher of the local science textbooks also found that there is no clear elaboration about the meaning of scientific theory and law in any of the local textbook. The findings of this study suggested that an effective course should be tailored to diagnose the existing conceptions held by the pre-service science teachers. With inadequate definitions of scientific theories and laws in science textbooks, it is deemed that the teachers need to be the ones who disseminate robust understanding to their students. Hence, the understanding of scientific theory-law relationship among the pre-service teachers should be first identified and corrected so that they, as future teachers, can help promote more holistic understanding of NOS in school. This, in turn, will produce science learners who are more literate in science, in line with the global objective of science education.

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