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Pre-service teachers’ conceptions of the Nature of Science

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Abstract

Learning science without having the correct conceptions of the Nature of science (NOS) is a flaw in science education which warrants attention. This concern extends to the science educators as they are the front-line advocates in parting the right conceptions of NOS. This is a much larger issue as these teachers might induce misconceptions in NOS to the science students under their care at the receiving end, either direct or indirectly. This paper shares the findings of an entrance survey of the course SCE500-Nature of Science on eighteen science education undergraduate students, majoring in biology. The survey was based on the eight common misconceptions of science students as reported in the various recent researches. The purpose of identifying the misconceptions in the entrance study is because the instructional method is based on the paradigm of constructivism. The constructivist paradigm demands that the classroom instruction needs to be guided by students’ preconception of the content area especially the misconceptions and teach them accordingly as suggested by Ausubel, Driver, Cosgrove and Osborne, to name a few among the pioneers in the science constructivist movement. One of the many findings from this entrance study is these eighteen students are very much realists; they perceived science as about truth and scientific ideas are proven facts with certainty. This paper also highlights the innovative design of the course materials which is termed ‘set inductions’. The material targets at explicitly addressing the misconceptions of these students regarding NOS.

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1. Introduction

Constructivists believe that human learning is self-constructed where learners build new knowledge upon the foundation of previous learning. Research in this paradigm revealed that ideas students form in the science classroom often referred to as ‘misconceptions’, ‘alternative frameworks’, or ‘naïve ideas’ often are not the ones intended by the instructors. These ideas which are tenacious to change tend to pose great challenges for teachers when designing effective instruction that will facilitate students’ learning. According to Ausubel (1968), an essential element that science teachers need to address is to identify the nature and source of the misconceptions harboured by the students, and teach them accordingly.

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To ensure students’ engagement in science lessons, reformation in the Malaysian Science curriculum has included constructivism as a suggested pedagogical design (Ministry of Education Malaysia, 2006). Among the fore-mentioned constructivists’ attributes in the reform included:

- taking into account students' prior knowledge, scientific as well as the naïve;
- assisting students to engage in deep learning via restructuring their cognitive web and relating new ideas to existing ones; and
- making certain that instructions accommodate opportunities to cooperate, sharing of ideas and experiences, and reflecting on their learning.

The inclusion of above attributes put emphasis on learners’ understanding of the correct scientific concepts, with the hope that learners will be literate in science. Current science education reform defined science literacy as knowing about science, and how it is acquired (Enger & Yager, 1998). One suggested way to encourage scientific literacy is to make students comprehend the nature of science (NOS) (Parker, Krockover, Lashertrapp & Eichinger, 2008).

2. The Nature of Science

NOS illuminates the development of scientific knowledge and the roles scientists have played during such a process are deemed necessary for students to know. Philosophers have taken several stands in viewing NOS, namely realist, instrumentalist, constructivist, and empiricist (Kosso, 1992). The realists see science as a process of discovery in search for the truth; the empiricists look at it as an epistemology that provides them with useful data; the instrumentalists see science as a tool substantiating the creation of new technologies due to its predictive power while the constructivists see science as another knowledge of human construct where scientific theories help human in comprehending the world. Despite several conflicting views, the scholars had agreed upon few scientific enterprises which are relevant to be introduced in science education (American Association for the Advancement of Science, 1990) for the sake of science literate society. The consensuses reached are:

- Scientific knowledge is both tentative and durable. Scientific knowledge is reliable; however.
- Both observations and inferences are guided by scientists’ prior knowledge and perspectives of current science.
- Science aims to be objective and precise, but subjectivity in science is unavoidable.
- Scientists investigate research questions with prior knowledge, perseverance, and creativity.
- Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Theories are well-substantiated explanations of some aspect of the natural world. Theories explain laws.
- Although processes in science include analysis, speculation, library investigation and experimentation there is no single universal step-by-step scientific method that all scientists follow.
- Scientists investigate research questions with prior knowledge, perseverance, and creativity.
- Scientific knowledge is constructed and developed in a variety of ways including observation.

3. Misconceptions in the Nature of Science

The past decennium has seen many reports on students’ misconceptions in NOS as reported by Bell et al. (2001). All of their findings revealed common misconceptions which include:

- Experiments in science confirm scientific ideas;
- Under determination as one of science's virtues clarifies that a theory can be disproven but cannot be proven. Scientific experiments, therefore, merely provide evidences for theories to be tested but the evidences obtained
cannot be taken as truth. However, experimentation in science is empowered to falsify a theory as the essential feature in the process of science (Low, 2000). Experiments in science do not confirm scientific ideas.

- Scientists use their imagination at the early stage of investigation only;

Science is a blend of logic and imagination as imagination and thought are used to come up with theories while creative insight is required to recognize the meaning of unexpected in data analysis. Hence scientists use their imagination throughout the whole process of investigation.

- Science provides explanations with fact and proof;

The power of science anchors on its ability to provide explanations to natural phenomena. The theories used in explanations make the natural world sensible to us as they answer human curiosity. But the evidences are often indirect in nature as the explanations involve unobservable entities. Hence, the evidences are both tentative but durable.

- Whatever contents in science text are fact with certainty;

Science text only offer the accepted view of the current understanding. The view will change in future when new observations are made. Hence knowledge in science is a dynamic one.

- Theory becomes law with sufficient evidences;

Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; theories explain laws.

- Hypothesis-experiment-conclusion is The Scientific Method used by all scientists;

Although fundamentally, various scientific disciplines tend to rely on evidence, there is no single universal step-by-step scientific method that all scientists follow. The mode of investigation is defined by the phenomena and the context it is being investigated. Hence a variety of methods can be possibly used, such as historical data, experimental, qualitative, and quantitative (AAAS, 1990).

- Same piece of evidence or data cannot be subjected to multiple interpretation;

Science is subjective where a claim is made only when it can be substantiated by many evidences. However, there is no one single answer that indicates truth to any theory. Due to this subjectivity facet in science, a same piece of data can be interpreted differently by scientist from different background, interest or even just another individual scientist. For example, the duality theory of light produces similar data.

- Scientists are people with not ‘normal’ human behaviour as portrayed in most movies.

Movie tends to portrayed scientists with peculiar bizarre behaviours such as in “Back to the Future”, “Honey, I shrunk the kids”, and “Spiderman”. Scientists are normal human in reality with higher intellect and great passion towards their academic pursue. They generally uphold the ethical norms of science (AAAS, 1990) such as being honest, acceptance of critics from peers, respecting life and environment, and being both competitive and co-operative.

To the best of the researchers’ knowledge, local studies on pre-service teachers’ understanding on NOS were limited. One study conducted by Low (2000), found that the percentage mean for the overall understanding of NOS among the teacher trainees in Peninsular Malaysia was 58.8%. Process Oriented towards Science Scale (POTSS) was used as the instrument in measuring NOS understanding of his respondents. With the scarce of research in Malaysia regarding teacher trainees’ conceptions on NOS, this study provides insights on the ways they perceive NOS through the reasons they provided. The different instrument was used to disclose other aspects of NOS which have not been studied by using other instruments. Therefore, the variation of conceptions among the teacher trainees’ can be identified, lest misconceptions of NOS become worse.

4. Methodology

The study reported herein is part of a bigger research examining learners’ views on NOS. In line with the nationwide school-based reforms in science education, the inclusion of SCE500 Nature of Science as a core subject in the curriculum for science teachers’ preparatory programs is believed to be appropriate and timely. The
instructional design for NOS has included, among others, a strategy which explicitly addresses common misconception of NOS. Attending to future science teachers’ misconceptions relating to NOS is crucial as it allows future teachers to have sound understanding to guide their students later. Specifically, the present study aims to examine undergraduate students’ misconception of NOS prior to their attending and completing the SCE500 course.

Eighteen biology education students who took SCE500 in the first semester of 2010 participated in this study. Data were gathered using the NOS inventory, consisting of eight statements. However, only three out of the eight statements are discussed in this paper due to the limited space. Each statement is two-tiered; participants have to indicate their agreement (based on 5 point Likert scale) with the question in the first part followed by justification for their response in the second part. NOS misconceptions were included as constructs in the inventory. The inventory was administrated at the beginning of the very first lesson. To establish face validity of the instrument, a panel of five science teachers and lecturers reviewed the draft of the inventory, and necessary improvements were made prior to actual administration. For each statement, students’ responses in the first part were divided into two – “strongly agree/agree” and “disagree/strongly disagree” – categories. Justifications in the second part of the instrument serve to substantiate the responses given in the first part.

5. Findings

As indicated earlier, only three out of eight statements are included in this paper. The responses provided by the participants of this study are reported and discussed according to the three statements from the inventory.

5.1. Statement 1 (Experiments in science confirm science ideas)

The first section of the instruments requires students to indicate their agreement with the above statement. A vast majority (77.8%) of respondents believed that experiments serve to confirm the truth of scientific ideas. Some justifications of perceiving science as “data-producing endeavor to confirm theories” were inferred by the respondents as followed:

"By conducting the experiments, the scientific ideas can be determined its truth with the outcome produce"

"Certain ideas or theory comes out through thinking or imagination. These theories or ideas is not 100% true and they can only be proven when tested with experiment"

“Observation during experiment gives proof and ideas to the scientists"
"By doing the experiments, we can know the result whether it suits the scientific ideas or not"
Explanations provided by those indicating “agree/strongly agree” centered around the notion of experiment being "truth seeking", "for proving theory or fact", "for certainty" and "repeating results leads to confirmation". One student stated that experiments are conducted to see whether "it suits the scientific idea", where "suit" denotes the notion of support. Students who held these enterprises of idea envisaged that experiments provide them the data to show that theories are true. The experiences of conducting experiments in schools while learning certain theories, and the gain of promising findings as stated in their books inevitably gave them an idea that the theories are proven true. After all, to the students, if the theories are not true, why then do data turn out just as the scientists have anticipated? The hypothetico-deductive (HD) model explained that getting predicted results from an experiment testing a particular theory does not confirm the truth of the theory. It only indicates that the theory has the probability being true while enhances our confidence of it.

11.1% of the students were uncertain and a similar proportion was in disagreement with the statement. Those who disagreed gave the following account:

"Because usually the results for the experiment with the theory are different. The errors still happen. Still cannot confirm as scientific"

These respondents’ notion of opposing the statement was largely due to inaccuracy of data resulted from scientific experiments. Although experimental error can be one of the factors in rejecting a theory, the justifications given were different from Popper’s HD model of confirmation. Popper’s paradigm in falsifying a theory included other significant factors as well, such as viewing conditions during experimentation, auxiliary theories and unnoticed interferences in experiments. The responses however, failed to project any sound understanding of NOS where the data gained can be interpreted by multiple theories (Kosso, 1992).

5.2. Statement 2 (Scientists use their imagination at the early stage of investigation only)

Science is a blend of logic and imagination as these are required to recognize the meaning of unexpected in data analysis. As pointed out by Johnson-Laird (1998), visualization aids in linking the conceptual and the subconceptual, resulting in a model that represents fresh models as scientific investigations happen. Hence it is obvious that imagination is used throughout the whole process of investigation. However, the findings revealed that 55.6% respondents agreed that imagination is only required at the early stage of imagination, a substantial 38.9% did not think so, and a total of 5.6% was unsure.

The responses provided by those in favor of the statement related imagination as a way of looking for ideas to the possible solution. To these respondents, imagination somewhat serves like a hypothesis, which may or may not be accepted before the experiment is carried out. Imagination is needed only in the early stage of getting initial idea; what follows are investigation and proving process - a truth seeking ones as highlighted in the following responses:

"Early imagination needs to get an idea to investigate something. The end stage cannot use imagination but need to [be] proven by a reason and prove"

"Because the next stage require proves and evidence through experiments"

"In my opinion, I agree because like [Newton saw] when the apple fall[s] down he starts thinking how it could be. Then, he proceeds with scientific investigation. Not only imagination anymore. He wants to find the truth, how it [is]"
Others who disagreed with the statement rationalized that imagination is needed throughout the experiments; imagination allows for manipulation of findings and for better explanations for a particular theory, one that is coherent with the data gained. These conceptions are reflected in the responses below:

"Investigation may...result in respect of certain aspect of manipulation. Based on the result scientists can imagine or make hypothesis if other aspect is being manipulated and guess the outcome of the experiment"

"Scientist did not use their imagination only at the early stage. They use their critical thinking to support every idea[s] that they have in mind. They conduct an experiment to find explanation and not only use imagination to solve problem"

"Scientists need to use imagination in every stage of investigation so that they can compare their imagination with the experiments they have done and get useful result"

However, two students provided interesting observations. One quoted:

"This is because at the early stage of investigation occur when the thing happen and not scientist imagination"

This first student seemed to think that the early stage of investigation only involves observation without any imagination, a description of inductive reasoning where observation leads to theorizing. But this idea contradicts the theory ladenness of science, in which the theories perceived by any random person actually determines what he or she is observing, and in a way constrained the observation conducted. The second student meanwhile gave the following explanation as justification for his response:

“I agree because almost all scientists imagine first a thing that they want to discover. After that, they will conduct experiment to know the actual result and design explanation behind the result"
This student apparently does not see that producing explanation needs creativity and imagination, possibly due to the fact that he sees explanation as truth and experiments are mistakenly viewed as truth-seeking activities. Integrating imagination indicates scientists’ biasness in coming out with the explanation, and cannot represent truth.

5.3 Statement 3 (Science provides explanations with fact and proof)

For this section, none of the respondents disagreed with the above statement. A whopping 94.2% respondent agreed with the notion that science explains by giving facts and proofs while 5.5% others unsure. This entrenchment of misconception among the students is coherent with a bigger number of students saying that the purpose of experiment in science is to provide proofs and test theories. The issue of science in producing truth was clearly documented by AAAS whereby according to them, "Although scientists reject the notion of attaining absolute truth and accept some uncertainty as part of nature, most scientific knowledge is durable." (AAAS, 1990, p.3) Students who agreed seemed to stem from the experimental nature of science and the observation made in science.

The following are selected explanations given by those who chose “agree/strongly agree” with the statement:

"Because nobody will believes the sciences if there is no fact and proof"

"If a theory is to be proven true, it needs fact and proof. [This] means that facts and proof must support the theory to be proven true. Hence, science explain the theory based on supported facts and proof"

"Without fact and proof in what happen in science, the explanation and the understanding in science cannot happen"

"Yes for me science already provides all the explanation with fact and proof. So that, we as a human can think rationally upon what totally happen surround us”

"Yes, because most of scientific law or theory is created based on strong fact and proof or otherwise it is not considered as law, and it will be rejected"

"Fact in science is made up from proven experiment"

From the responses, it is clear that the students associated science with truth, its predictive power, and the gratifying explanations science is able to provide to help them understand the world around them. They felt that data from experiments serves as evidences which made them convince of the veracity of science.

6. Conclusion

Table 1 shows the mean scores for all the eight questions. The items discussed were the first three as included in the table. The scores offer an estimate view only of the overall misconceptions since the Likert Scale used in the questions is of ordinance scale.
Table 1: Mean score for responses to the eight statements

| Statements                                                                 | Mean score |
|---------------------------------------------------------------------------|------------|
| Experiments in science confirms scientific ideas                         | 2.1        |
| Scientists use their imagination at the early stage of investigation only | 2.7        |
| Science provides explanations with fact and proof                         | 1.8        |
| Whatever contents in science text are fact with certainty                 | 2.8        |
| Theory becomes law with sufficient evidences                              | 1.9        |
| Hypothesis-experiment-conclusion is the scientific method used by all scientists | 1.8        |
| Same piece of evidence or data cannot be subjected to multiple interpretation | 3.2        |
| Scientists are people with not ‘normal’ human behaviour as portrayed in most movies | 3.9        |

Responses from both part one (Likert scale) and part two (justification for answers) revealed that students generally possessed partial understanding on NOS. The information on misconceptions as presented in this study is able to serve as guidelines in teaching the NOS course to the students. The aspects of NOS, as suggested by Quigley, Pongsanon & Akerson (2011) are best taught through explicit reflective instructions. The course introduced to these pre-service teachers in their NOS course integrated this strategy by projecting various instructional materials (such as optical illusions, the history of science, instances on law and theory), followed by questions and discussions during the set induction of every class. To conclude, it is of paramount importance to diagnose and address pre service teachers’ conceptions in understanding NOS. If the misconceptions are not corrected at the grass-root level, it is envisaged that these teachers-to-be will impose their beliefs about science to their students, without them realizing it (Sajin Chun, 2000). This will then, results in crippling the effort of building science literate society among the students, and in Malaysia as a whole.

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