The Need for Scientific Experiments: The Experience of Pre-service Science Teachers

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Abstract
The availability of scientific information nowadays necessitates scientifically literate learners and teachers well-versed in both content and nature of science (NOS). Despite a clear description of NOS in the Malaysian Education Blueprint, NOS elements have been sidelined by educational practices in Malaysia. This study illuminates the conceptions of pre-service science teachers in Malaysia about one aspect of NOS—the purpose for scientific experimentation. A phenomenographic approach was used to achieve this aim where 10 pre-service teachers were interviewed. Findings revealed three categories, namely a) Experiments prove, b) Experiments invent, and c) Experiments support ideas. The findings also inferred that there are more ways to conceptualise the purpose of scientific experiments other than what has been previously reported. This paper concludes with suggestions on improving the current practices of experimentation in schools and calls for a rethink on the current teachers’ preparatory course in Malaysia.

Key words: Nature of Science, scientific experimentation, pre-service teachers, Malaysia, scientific literacy

INTRODUCTION
The exponential growth of technologies has fostered dynamism in various walks of life. It has also vastly transformed and continues to transform the education system and at the same time, bring in cohorts of learners who grow up surrounded by digital media. These learners are different as they learn in non-linear ways through a myriad of gadgets, enabling them to communicate with others and gain information virtually (Pedro, 2006). The current information age exposes them to overwhelming scientific and pseudo-scientific information over the net. Consequently, the demand of teachers in
the present century is increasingly changing as they are now required to not only teach science content, but at the same time cultivate scientific literacy among their students.

LITERATURE REVIEW

Literacy in Science

“Scientific literacy” refers to the skills “essential for effective citizenship” (Hurd, 1958, p.13). The need for scientific literacy has evolved over the decades where the mere aim of producing scientists in 1960s has changed into nurturing citizens who can make informed scientific decisions in the 21st century (Kings, 2002). Every individual is expected to be able to make sound decisions in their daily life, considering the impact science and technology have on the society today (DeBoer, 2000). Such heightened need is reflected in numerous 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, science education in Malaysia urges students to be scientifically literate to shoulder the vision laid out by the former Prime Minister, Tun Dr. Mahathir Mohamad. Vision 2020 which envisions the growth of Malaysia as a developed country with a mature economy by the year 2020 lists scientific society as one of the challenges to be met (Department of Information Malaysia, 2012). It 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 all Malaysian citizens to be independent and become sound decision makers of issues pertaining to science.

Corresponding to the importance of being literate in science, academicians and researchers have put forth various ideas in fostering such literacy among learners from a young age. One of the strongly proposed paths is ensuring that learners understand well the nature of scientific knowledge.

Nature of Science

Understanding of scientific content alone is insufficient for an individual to understand and apply science effectively. Various reform documents in science education have regarded the understanding of Nature of Science (henceforth NOS in this paper) as a critical factor in being scientifically literate (NGSS, 2013; AAAS, 1990; NRC, 1996; Chen et al., 2009; Chai et al., 2012). NOS is widely referred in the literature as an epistemology of science or how science is done (Lederman, 1992; Keiser, 2010). It describes how scientific knowledge is developed as a result of human endeavour to
understand the world. Various research and documents have supported the benefits of understanding NOS, which include

- helping learners to understand why certain ideas in science are changeable, thus promoting better science understanding where scientific contents are concerned (Tobias, 1990)
- assisting learners in engaging and solving real life scientific issues (AAAS, 1990; NRC, 1996)
- improving learners’ general understanding in science (Smith, 2010)
- advocating critical thinking and analysis in using science knowledge in daily life (Wheeler-Toppen, 2005).

Other than the students, it is also documented that diverse groups such as practitioners and educators should achieve NOS understanding standard because every group is part of an interconnecting system (NRC, 1996). A successful achievement of NOS hence is dependent on the accomplishment of all respective groups making up the system (NRC, 1996). This includes the need for teachers to have sound NOS understanding so that they will not impart their naive understanding to students.

Despite acknowledging the importance of understanding NOS, disputes among sociologists, historians, scientists and academicians in regard to what constitutes NOS remained unsettled due to the distinctive paradigms adopted by these groups. However, Lederman (1992) argued that there is a set of consensus which is non-controversial and pertinent to be highlighted to K-12 students for the sake of science literacy. Among them are: (i) the tentativeness of scientific knowledge, (ii) the creativity and imagination in science, (iii) the nature of experimentation in science, and (iv) the social and cultural embeddedness of science. In this paper, only the conceptions about the nature of experimentation as part of the research participants’ understanding of NOS are reported.

**NOS in Malaysian Science Education**

Consistent with the global aim of science education, Malaysian science education also highlights similar interest for NOS understanding among science students. The Ministry of Education in Malaysia has enumerated 11 objectives emphasising students’ critical thinking skills with 2 of these objectives focusing on NOS understanding (2006, p. 5). They are:

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.
However, it is common to find a gap between the desired and actual outcome. A close scrutiny on the local science curriculum revealed that the features of NOS are not explicitly highlighted to learners despite the emphasis on inquiry-learning specified in the school’s science curriculum (Ministry of Education, 2005). The only experiment which aims to reflect scientists’endeavour in understanding the world is the “black box” experiment. This experiment constitutes one of the experiments in the Science subject at Form One level, and is the sole experiment which reflects the endeavor of scientists in the five year span of science learning in secondary school.

**Past Research—Global setting**

A prominent study that investigated the understanding of aims and structure of experimentation was conducted by Abd-El-Khalick (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). Abd-El-Khalick revised the VNOS (B) in heeding the need to address the experimental aspect in science. VNOS (B) was improvised to VNOS(C) with the addition of two items to assess the understanding of the aim and structure of science by various groups. It was revealed that most respondents defined experiments as “procedures” or “a sequence of steps” which are used to answer relevant scientific questions. This was consistent with McComas’ descriptions on the common myths held about NOS (1998). Lederman et al. (2002) drew similar claims based on their study. The researchers alleged that their respondents who held sophisticated views on NOS understood that experiments are conducted to validate ideas but the naive ones viewed experiments as activities to “prove” a theory. Lederman et al. further clarified the word “prove” when their respondents explicated their understanding of “prove” as “proven by collecting evidences and doing experiments” (2002, p.510).

The use of the VNOS(C) was also extended to other distinct groups, namely pre-service elementary teachers (Abd-El-Khalick, 2001) as well as pre-service and practising secondary science teachers (Abd-El-Khalick & Lederman, 2000; Lederman, Schwartz, Abd-El-Khalick & Bell, 2001; Schwartz, Lederman, & Crawford, 2004). Although all the aforementioned studies utilised VNOS (C) and reported that their respondents have both “naive” and “informed” views, it was found that the differences were not highlighted despite the large contrast between the two categories. The problem with such dichotomous classification is the lack of details on the exact understanding held by the participants of the studies. An attempt to close this gap was carried out by Keiser (2010) in his doctoral thesis, where he investigated high school chemistry students’ understanding of NOS using an in-depth approach and deriving further categories from raw excerpts. His analyses resulted in three categories namely “Experiment test”, “Experiment prove” and “Experiment discover”.

**Past research—Local setting**
The heightened need for NOS understanding has also prompted several studies to be conducted in the local settings. Most of the studies conducted in Malaysia used Nature
of Science Knowledge Scale (NSKS) developed by Rubba and Anderson (1978) in their research to gauge the understanding of NOS among their subjects of study. The studies were largely similar, where sets of NSKS instrument were used to gauge the NOS understanding of Form Five students (Sivaratnam, 2004), Lower Form Six students (Eng, 2002), and pre-university students (Sathasivam, 2002). All three studies delivered a somewhat average percentage (over 50%) mean score for NOS understanding and concluded that the understanding of their research participants were “satisfactory”. However, an action research investigating the effectiveness of NOS instruction in a local university claimed contrasting findings. Through a pre-test, it was revealed that 94.2% of the pre-service biology teachers felt that theories are the true depiction of the world which provides facts and proof while a substantial 77.8% believed that experiments in science generate proof for theories (Jain, Beh & Abdullah, 2013). Through a two-tiered instrument, the participants of the study provided naive views in almost all the NOS aspects that were investigated which led to the conclusion that there is inadequate understanding of NOS among the participants of the study (Jain et al., 2013).

A justification made for using NSKS as an instrument in the studies was the assumption that the local respondents understood and interpreted the statements in the instrument in the same way as the instrument developers (Sivaratnam, 2004). However, scholars are of the opinion that Malaysia with its different religious denominations and societal values puts it in a unique position when compared with Western countries such as the United States (Sutherland & Dennick, 2002; Karabenick & Moosa, 2005; Chai et al., 2012). Besides that, reports from the local research did not specifically probe on the facet of experimentation. An in-depth study as presented in this paper intends to close this gap by illuminating more details about the conceptions of pre-service science teachers’ understanding.

**The Study**

This paper focuses on the conceptions held by pre-service science teachers in regard to the aim of scientific experimentation. In the effort to probe such conceptions, the following question was posed:

What is the variation in conceptions held by pre-service science teachers about the aim of scientific experimentations based on their experience?

By understanding the variation of the pre-service teachers’ understanding, further initiatives can be taken to specifically target these conceptions during the NOS instruction at the teacher preparatory level.
METHODOLOGY
The data for the present study was collected through a phenomenographic approach where 10 first year pre-service science teachers from a university in Selangor, Malaysia were interviewed. These pre-service teachers are in the first semester of their freshman year, anticipating to graduate from the four-year program and become science educators in Malaysian secondary schools.

Phenomenography is regarded as the best method for this study because it describes a phenomenon as experienced by individuals (Marton & Booth, 1997). Phenomenography adopts a second-order perspective in which it solely describes the conceptions held by the participants without injecting the researcher’s conceptions (Trigwell, 2000). Hence, it provides a holistic way of describing conceptions and allows a wider range of conceptions to be captured (Bruce, 1999).

The interview sessions were guided by a semi-structured interview guide consisting of items adopted from VNOS (C) developed by Lederman and his team (Lederman et al., 2002). The items chosen were intended to probe the participants’ conceptions about the aim of experimentation in science. A panel of five experts who validated the instrument suggested that the participants should draw their mental images of “scientific experiments”. This is to ensure that the participants are inferring to the same meaning of experimentation as perceived by the researchers. A pilot study was then carried out with another two pre-service science teachers who are in their first year, resulting in the revision of items to ensure the interview guide was clarified well. The questions asked during the interviews are as follows:

a) Can you please draw the first image which comes to your mind when I mention “scientific experiment”? [Papers and pen were provided]

b) Why do you think we need to conduct experiment in science? OR What is the purpose of experimentation in science?

Additionally, the quality and rigor of the present study was enhanced through the framework of awareness used at the outset of the study (Sin, 2010). 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). The purpose of such framework is discussed in the next section.

Due to the ontological and epistemological perspectives adopted by phenomenography which is different from other qualitative studies, the validity and reliability of findings are dealt with differently (Morse, Barett, Mavan, Olson & Spiers, 2002). The validity of the analysed data was established using the communicative and pragmatic validity (Sandberg, 2000) while its reliability was established through inter-judge communicability (Saljo, 1988) and interpretive awareness (Sandberg, 1997).
The Framework of Awareness

From the phenomenographic perspective, an individual must be aware of something in order to experience it (Marton & Booth, 1997). As experience is always within the context of a phenomenon, an individual’s experience about a phenomenon depends on how his or her awareness is structured. Marton and Booth (1997, p.87) explained that there are two aspects in which experience can be conceptualised, namely the “referential” and the “structural” aspects. The referential aspect refers to what is experienced, that is, 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 of the myriad phenomena at the same time but not in the same way. There are three levels of awareness namely theme, thematic field and margin (Gurwitsch, 1964). They are elaborated as follows:

- **Theme**: The concepts which are focused 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, initial responses provided by the participants when answering the questions in regard to scientific experimentation (the phenomenon) inferred the attached meaning brought to the fore of their awareness (theme) as they reflect about the phenomenon. Besides that, it was mentioned earlier that the participants were required to draw their first mental image of the word “experiment”. It should be clarified at this juncture that no specific way was used to analyse the drawings. It is regarded sufficient as long as the drawings by the participants inferred the same meaning of experiment as the researcher’s.

**FINDINGS**

The drawings provided by the participants depicted that experiments in science are generally activities carried out in an enclosed laboratory with science apparatuses and chemicals. It was found that all the notions of “scientific experiment” are as intended by the researcher, signalling a unanimous meaning of “scientific experiment” between the researcher and research participants. These images are provided in the appendix.

The findings revealed that the conceptualisation of experiments in the context of Science can be categorised into three groups. The aim of experiments has been associated with proving ideas or theories, for invention and supporting ideas. These three categories refer to the three distinctive ways participants of the present study conceptualise the aim of scientific experiments.

- **a) Category 1: Experiments prove**
  The understanding under this category was inferred by 6 out of 10 participants, implying it as the most typical way participants perceive reasons for experiments
to be conducted. The theme brought to the participants’ awareness in this category emphasised the generation of proofs through scientific experimentation. Proofs generated in the form of experimental data are regarded as the concrete evidences for scientists to claim that theories are true. The following excerpt illustrates such notion:

“There must be experiments behind all theories...so that we have concrete evidences to support that the theories are true. All of the theories I learnt have been experimented before they were derived.” (R9)

Another participant, R10 also echoed similar sentiments.

“...cannot just observe, they have to conduct experiments...they can produce theory [only through that way]. It means that, theory is different [during observations] and they will realize that it is different when they investigate it [further]. Experiment is to confirm the theory. Theory has to go through experiment to know that it is real... to confirm it.” (R10)

The thematic field of this category consisted of the experiences the participants have had in science learning where they articulated examples arising from experiments they have conducted. On the other hand, the margin of their awareness stemmed from the conception that scientific experiments are processes which filter true theories from the “wrong” ones. Hence, scientific knowledge is regarded as an absolute knowledge that has been repeatedly validated to ensure its truth.

b) Category 2: Experiments invent
This category was inferred to by only two participants. The focal of this category viewed experiments in science as a route for discovery and invention of new knowledge. The reasoning given by the participants of this category described experiment as a route towards new invention. The conceptions held were framed on the notion of inventing better technology through scientific experimentation. For example, R2 mentioned

“We want to know how a theory or law...[sic]...works...[through] experiment. For scientists, they are looking for new theories; to do more things, to make life easier.” (R2)

For R2, the purpose of doing experiments is seen from a dualistic perspective. A layperson carries out experiments to learn how a particular science theory works while scientists carry out experiments for invention purposes. R4 too, inferred the same idea. The excerpt provided by R4 is as follows:
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“Investigation done [by] scientists [as they] try to invent new things.” (R4)

The **thematic field** from which such an idea was derived is their daily exposure to various new technologies and knowledge developed from scientific field. The participants described innovations as one of the products endeavoured by scientists in experiments. The **margin** of this category on the other hand, reflected experience of science as a dynamic knowledge. The development of scientific knowledge contributes to the advancement of the world, implying science as a dynamic epistemology but this conception is only peripheral in the participants’ awareness.

c) Category 3: Experiments support ideas
The **theme** brought to the foreground of awareness under this category portrayed experiment as a set of procedures that support claims by comparing experimental outcome with the predicted outcome. The emphasis is more on the believability of scientific ideas or theories, rather than the truth of theories. R8 provided an explanation inferring the focused theme as follows:

“When they conduct experiments, they do observation that they can see. Some people believe what they see. So, when they do experiments, they know what they see, then they believe in that theory.” (R8)

According to R8, experiments provide concrete evidences for them to be believable, further suggesting that theory can be real. R5 who supported the same view commented the following:

“Experiments are important. Other people will claim that it’s crazy to get a theory just by merely thinking about it. Knowledge alone is insufficient; it must be proven by something which showed that the research is true.” (R5)

R9, in a similar vein, went to the extent of believing that experiments help with decision making. He pointed out the following:

“When scientists are doubtful of something and have two options, they conduct experiments to know which is better...there will be evidence in support of a theory. This is because most of the theories that I had learnt have experiments conducted before the emergence of that theory.” (R9)

R9 inferred that experimentation assists in deciding which the better idea is while data obtained from the experiment will serve as evidence for the chosen idea. According to R2, experiments also function as a procedure for revising any existing theory with generated empirical data. This is to ensure that the theory is still useable and acceptable. R2 who reflected this notion, said that:
"If we do experiments, we want to do experiments to test our theory and look for result whether it is same or not with the theory and the law." (R2)

All of the conceptions inferred by the respondents under this category demonstrated that scientific experiments are designed accordingly to produce concrete evidences in order to support the theory or idea they are based on. Other than that, an experiment is also depicted as an endeavour to reconfirm the claims made by other existing theories.

The thematic field refers to the awareness of learners that was not focused upon while discussing the aim of experimentation as experienced by them. When focusing on experiment as a way to substantiate ideas, the participants contemplated on the social interactions among scientists. This includes the validation of findings by other scientists in ensuring the transparency of data reported is as claimed.

Science is perceived as a rigorous knowledge which is constantly revised and rechecked to ensure its believability and credibility. Hence, being aware of the credibility and trustworthiness of theories in science due to its rigour forms the margin of this understanding.

RELATION TO OTHER FINDINGS: A DISCUSSION
The nature of phenomenographic analysis emphasised at a collective level which allows comparison with other studies has been recognised by other phenomenographers (Schmidt & Volke, 2003; Stefani & Tsaparlis, 2009). The findings reported earlier are compared in relation to other studies in this section.

The Experiments prove category found in this study was also reported in another local study by Jain et al. (2013). Their study reported that 77.8% of the pre-service Biology teacher respondents held the notion that experiments in science generate proofs for theories (Jain et al., 2013). Both Jain et al.’s study (2013) and this study describe the contrived ways of conducting experimentation in Science where evidences produced are perceived as confirming theories. This category is also identical with the categorisation carried out by Keiser (2010) based on the responses for conceptions that he gathered from college students. The striking similarities between the category of this study with that of Keiser’s is no surprise as McComas (1998) has reported that perceiving experiments as an act to prove scientific theories is the most prevalent conception held by most individuals. It is also common to hear participants of this present study use the word “proven” while explaining their understanding about theory during the interview sessions. Individuals who indicated such notion about experiments are labelled as having “naïve” views about NOS (Lederman et al., 2002).
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The category *Experiments support ideas* found in this study is similarly reported in other studies, recognised as “informed” view about the process of experiments in science (Lederman *et al.*, 2002). The responses under this category are similar to other studies investigating conceptions among pre-service elementary teachers (Abd-El-Khalick, 2001), seventh grade students (Carey, Evans, Honda, Jav & Unger, 1989) and high school chemistry students (Keiser, 2010). While the two former studies categorised acknowledging responses as “informed” or “naive” views, Keiser (2010) reported that he categorised such views under “Experiment test”. Under this category, he alleged that the respondents were informed about the role of experimentation in testing ideas or hypotheses and not about proving theories. However, it was found that this kind of informed view was not as dominant as compared with the naive ones (Keiser, 2010).

One category revealed by this study which is not clearly reported in the literature is the *Experiments invent* category. The responses under this category claimed that experiments are carried out to invent new things or to find out about something new. Although Keiser (2010) reported “Experiments discover” as a category found in his study, his descriptions of that category was different with that found in this study. He explained that “Experiments discover” characterises experiments as processes that are carried out to discover new information. Such conception does not reflect science as an absolute knowledge. In this study however, the *Experiments invent* category co-existed with the *Experiments prove* category described earlier. The co-existence of both conceptions reflects experiment as a process serving various purposes, ranging from “proving a theory”, “inventing new things” or “to finding out about something new”. The focus of *Experiments invent* in this study however, emphasises on the generation of new inventions such as technology to “make life easier” (R2) or “invent new things” (R4), and not on new pieces of information as highlighted by Keiser (2010).

Experiments with the purpose of inventing was somewhat explicated in a study by Akerson & Hanuscin (2007). Although they did not specifically investigate the aim of experimentations in science, they asserted that the notion of exploratory and discovery are more common among elementary students. Such conceptions then gradually dissipate as individuals experience science learning longer, and eventually adhere to the notion that experiments are conducted to accumulate facts (Driver, Leach, Millar & Scott, 1996; Khishfe, 2008). The participants of this study who are pre-service science teachers indicated that such conception still persist among them, suggesting for more research on this topic to be undertaken before classroom experience can be associated with the development of exploratory notion about science.

**Implications Of Study**
Experts blame science experimentation carried out in contrived ways as causing students to perceive that experiments prove scientific theories (Driver *et al.*, 1996; Rivas, 2003).
A similar notion was inferred by the majority of participants in this study, providing reasons for theories to be true as theories have been tested and proven by scientists. More alarmingly, the participants of this study are pre-service science teachers who are the product of the Malaysian education system and who will be posted into schools to teach science. Instead of encouraging thinking, the nature of experimentation in schools train individuals into carrying out experiments to yield data as described in textbooks. Substantiated by the experience of teaching science in schools, the researcher reckons that such a naive notion about the purpose of experimentation lies in specific words being used loosely. For example, the word “proven” is usually used in laboratory report to conclude whether the experiment’s hypothesis is “proven” or “confirmed”. Although these words are merely used to describe the hypotheses tested, the words entailing truth might cause students to accept an understanding that once the hypothesis is confirmed, then the theory is proven as well. It is lamented that more neutral words such as “support” are not being used as it provides a notion of “strengthening” the understanding and ideas in science, and the premise of “it is now a true idea” is adopted instead. In short, the phrase “hypothesis is supported” reflects a more neutral view compared to “hypothesis is proven”.

The researchers also recognise that learners have a poor understanding of the principle of theory falsification in this regard. Popper (1963) alleged that the generation of predicted empirical data derived from an experiment only supports the theory used to predict such an outcome, convincing us that there is a possibility for the theory to be true. However, that particular theory can be directly falsified when the findings turn out to be the opposite (Kosso, 1997). In a way, experiments are conducted to falsify a theory and not to prove them. The falsification principle should be made clear to students because it is an apt strategy that helps individuals to understand that experiments do not prove theories.

A Consideration for Pedagogical NOS Knowledge
The findings from this study clearly points out that the practice of experimentations has led to various different understandings, which are largely undesired by educators. The use of words in science learning and teaching might be the contributing factor as to why scientific knowledge is conceptualised as an objective among students. Apart from having sound NOS understanding, it is imperative to ensure that future teachers are aware and cautious about their choice of words used in science classrooms as they may impart a different meaning to their students from what they intended. However, it is a challenging task when they are not equipped with proper guidance during their preparatory courses prior to teaching. One major implication arising from the findings of this study is the heightened need to develop the pedagogical content knowledge for pre-service teachers, focusing on NOS (henceforth, pedagogical NOS knowledge). The assumption that teachers’ sound understanding translates directly to their students has been falsified (Lederman, 1986) and this calls for a more scrutinised inspection into teacher education courses. The authors lament that although NOS understanding is an
essential knowledge for teachers, it is insufficient in preparing the teachers to channel their NOS understanding to their students.

Pedagogical NOS knowledge should be weaved into the teachers’ education programmes to equip them with the knowledge of addressing NOS explicitly in their instructions. Such pedagogical courses on NOS should also emphasise how their choice of words influence the way their students interpret meanings. In this regard, teachers should be trained to use the phrase “the hypothesis is supported with the data found”, instead of “the hypothesis is confirmed or proven with the data found”. The naive conceptions uncovered in this study can also guide the development of pedagogical courses that can correct the misaligned NOS understanding of learners. In short, the findings of this study provide information critical to the design and plan of quality teacher education courses.

CONCLUSION
This paper highlights the importance of sound NOS understanding, especially regarding the aim of scientific experimentations. As was pointed out in the introduction of this paper, it is pertinent to mould learners who are literate in science. In pursuing this aim, more changes need to be considered at the outset, specifically at the teacher preparatory level to produce science teachers who are well-versed both in NOS and teaching NOS. Such measures are vital as teachers make up the workforce that will in turn produce science-literate individuals who will shoulder the development of the future.

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APPENDIX
Samples of participants’ drawings depicting “scientific experiments”.

![Diagram of scientific experiments drawings]