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Examining Secondary School Pupils' Understanding of the Nature of Science and its Implication

Shafiah Abdul Rashid, Zanaton H. Iksan, Khadijah Abdul Razak
Faculty of Education, Universiti Kebangsaan Malaysia
Email: shafiaharashid@yahoo.com, zanaton.iksan @ukm.edu.my, Khadijah.razak@ukm.edu.my

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Abstract
Studies had shown that interest in science subject among secondary school pupils in Malaysia is low and seems to be decreasing. Researchers have posed various potential reasons for this apparent lack of interest in science such as pupils' opinion that science in school is boring and not relevant to their lives. This is due to many science classes are taught as rote classes and science are presented as a pile of facts and lack of humanity aspects associated with the scientific process. Similar trend were also reported in other countries worldwide. The hypothesis put forth by researchers is that pupils need to observe models of how science is done, namely the nature of science (NOS) so that they will be able to connect with the human enterprise of science and thereby able use their knowledge to solve problems surrounding their lives. Therefore the purpose of this study is to investigate the level of NOS among secondary school pupils. This descriptive quantitative study had been administered to 70 Form Four pupils in a district in Malaysia, chosen by basic random sampling method. The result revealed that their NOS level were most likely to be at low level. This implies that pupils do not get adequate exposure on how scientific processes were done, thereby they do not place any interest to the science subject which do not seem to be connected with their lives.
Keywords: Nature of Science, Epistemology of Science, Scientific Literacy, Interest in Science, Scientific Process.

Introduction

Science is a key of transformation that can bring about changes and sustainable solutions for the physical, social and economic development of a country. The study of science offers to children the opportunity to reflect in an operational way and to understand the phenomena that are part of everyone's daily life. Science does not limit itself to describing the effects, but aims to find explanations, to make predictions and to plan interventions with the aim. Realizing the importance of science, the government has allocated a huge amount of budget to improve pupils' ability in science field. However, research reports showed that the government's target is still a long way to go. For instance, the PISA (Programme for International Student Assessment) and achievement report in 2009 till 2015, showed the failure of Malaysian pupils ability in applying scientific concepts into real-life situations (Ismail & Salleh, 2017). The PISA 2018 international assessment body organized by the Organization for Economic Cooperation and Development (OECD) has assessed the scientific literacy ability of Malaysian pupils and found that the country's achievement is at 438 points, much lower than the OECD average of 489 points. Similarly, Jajuri et al. (2019) found that pupils of science, technology, engineering, and mathematics streams were lack in analytical, critical, and creative skills in solving problems.

The Nature of Science (NOS)

Allchin (2015) argued that the above problem arises due to the lack of pupils' exposure to the nature of science (NOS). The phrase NOS refers to the epistemology of science, that is science as a way to acquire knowledge, or values and beliefs that underlie in the development of scientific knowledge (Lederman et al., 2013). NOS is defined as the nature of knowledge which is a complex concept involving philosophy, sociology, and historical knowledge. NOS refers to the main principles and ideas that provide a description of science as a way of knowing, as well as the characteristics of scientific knowledge. It is usually refers to "the values and assumptions that are inherent in science, scientific knowledge, and / or the development of scientific knowledge" (Lederman et al., 2013). The NOS is a part that deals with the understanding of the nature of scientific science as a whole. According to Lederman et al (2002), this understanding includes the empirical nature of science, creative and imaginative nature, instilling social and culture, observation, inference, tentative nature and knowing the difference between theory and law.

NOS is often neglected during science classes, yet it provides a vital background for students to know how science and scientists work and how scientific knowledge is created, validated, and influenced [12]. The nature of science is a part of science that must be taught by the teacher but often neglected or lacking attention. NOS can provide an important background for students about how science and scientists work and how scientific knowledge is created, validated, and influenced. According to Samsudin et al (2017), if pupils are allowed to explore science, technology, mathematics, and engineering (STEM) as the experience of a scientist, they will show a high interest in science as an authentic field of study. This claim is verified by van Griethuijsen et al (2015) who conducted a comparative study on the views and interests of 10 to 14-year-old pupils towards science in the UK, Netherlands, Turkey, Lebanon, India, and Malaysia. As expected he revealed that pupils in Malaysia do not like science in the classroom. Nevertheles, they showed interest in jobs related to science (Refer to Figure 1). Van Griethuijsen et al (2015) argued that this is due to the lack of exposure to NOS not only in Malaysia but also in the United States and countries that use the US education system as its model.

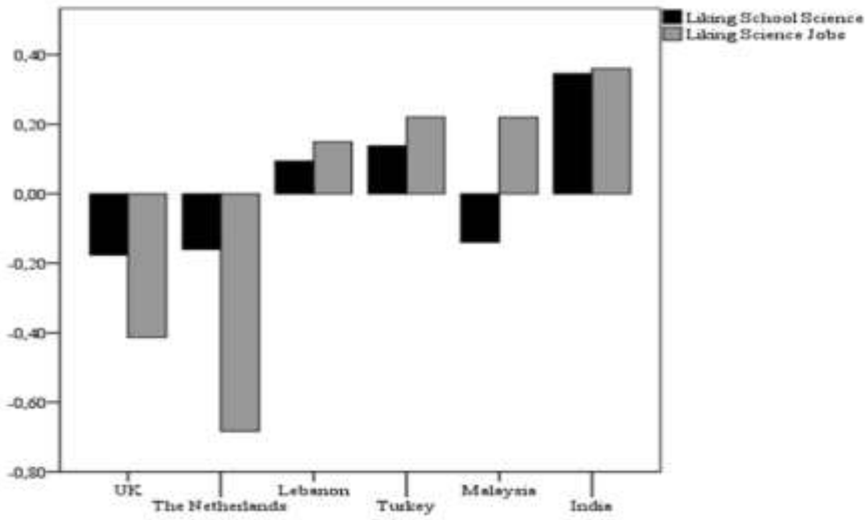

Figure 1: Interest in school science and a career in science (Griethuijsen et al., 2015)

Similar finding is shown in the international study of the Relevance of Science Education (ROSE) which found that 15-year-old students in developed countries find many of the themes and questions posed by science interesting and important (Jidesjo¨, Oscarsson, Karlsson and Stro¨mdahl 2009), but at the same time many students fail to see school science as meaningful for their future careers and consequently reject science and technology as their main field of study (Oscarsson et al., 2009). The traditional, passive and teacher-oriented methods of teaching science are still being widely used and this has led to the deterioration of students' interest in science.

Researchers revealed that the lack of exposure to the NOS concept is the cause of the rote recall of information practise among pupils in schools (Lederman et al., 2013). Traditional direct instruction in school science generally focuses on memorizing content with less focus on the development of scientific skills and attitudes; students become passive receivers while the teacher the dispenser. In most schools, teachers are burdened with academic extra classes in pursuit of the schools' successes; striving to gain as many A's as possible. This scenario does not help students learn in a meaningful manner. It had stunted pupils' ability to build their own knowledge of science, causing the erosion of interest in the subject. Rote learning eliminates pupils' skills to think creatively and critically to solve problems they face in daily lives (Bowman, 2012).

NOS in Malaysia

Given the importance of understanding the nature of science, it is thus crucial for science education stakeholders to access current data that able to show the level of understanding of NOS by students in schools through standard measurement instruments. Students' level of NOS must be tracked from time to time during their learning process, providing teachers with the data needed to inform their instructional practices so that they can help their students build scientific content and epistemic knowledge (National Research Council, 2012).

Rahman and Phang (2016) had conducted a study of the physics NOS level among students and teachers in Malaysia. They found that NOS studies in the field of science education in Malaysia are seldom explored due to the perception that NOS are too fundamental compared to applied and pure sciences. This distorted perception must be avoided because information on NOS are crucial in helping stakeholders to formulate strategies to improve the quality of science education. Exposure to NOS will help pupils to understand how scientific knowledge is formed (Rahman, 2013). It will also able to increase science learning motivation (Habsah et al., 2013), academic achievement (Barvarz et al., 2014), scientific inquiry (Lederman et al., 2013) and pupils' ability to make reasoning in solving socioscientific problems (Cian 2019; Kutluca & Aydın, 2018; Koenig et al., 2012; Acar et al., 2015).

Therefore it is imperative for stakeholders in this country to understand what NOS is and what is the importance of NOS understanding to school children. This study is thus designed to explain NOS and to determine the level of NOS understanding among secondary school pupils in a district in Malaysia.

Research Methodology

This study involved 70 Form Four pupils aged 16 years old from six national secondary schools in a district in Malaysia. The data were collected quantitatively via ten open response items based on the View of Nature of Science (VNOS) instrument proposed by (Lederman et al., 2002). The VNOS instrument is considered suitable to be used in this study as it had been widely used on similar aged-school pupils around the world. It focused on seven dimensions of NOS namely the (1) empirical nature of the scientific knowledge, (2) observation, inference and theoretical entities in science, (3) differences between the theory and the laws of science, (4) the creative and imaginative elements in science, (5) the existence of subjective and theory-laden elements in science, (6) the existence of social and cultural influences in science, and (7) the uncertainty of science (science is tentative). The seven dimensions are implicitly included in the ten items constructed by Lederman et al (2002) as summarized in Table 1.

Table 1
Dimensions tested for each item in the VNOS Instrument

Item no.	**Dimension**
1 and 2	Introduction (no NOS dimension is tested)
3	Tentative nature of science
4(a)	Observation, inferece
4(b)	Tentative, inference
4(c)	Inference, subjectivity
4(d)	The empirical basis of science
5	Tentative, observation, inference
6	Observation, inference
7	Creativity and imagination
8	Differences between theory and law
9	Tentative
10	Social and culture

VNOS Scoring Rubric

The responses presented by the pupils were then compared to the VNOS scoring rubric provided by Lederman et al (2002) to determine pupils' VNOS level (see Table 2).

Table 2
Three levels of NOS

NOS Level	Meaning
Informed	Pupil's response is consistent and addresses ALL part of NOS aspect
Transitional	Pupil's response is consistent with some but not all parts of NOS aspect
Naive	Pupil's response is not consistent with any part of NOS aspect

According to rubric in Table 2, NOS would be categorized into three levels namely Informed NOS, Transitional NOS, and Naïve NOS based on pupils' response to parts of NOS aspects in each items as discussed below;

i. *Item 1: What is science?*

This is merely introductory question. Not evaluated.

ii. *Item 2: What makes science different from other disciplines?*

This is merely introductory question. Not evaluated.

iii. *Item 3: Scientists produce scientific knowledge. Do you think this knowledge can change in the future?*

The truth of science is in fact never fixed or absolute. Facts, theories, and laws in science are tentative in nature that are subject to change in the future as a result of the existence of new evidence, new discoveries, or new methods of interpretation. Facts that are accepted as true today may be rejected in the future due to the rapid development of science and technology.

iv. *Item 4a: In your opinion how do scientists know that the dinosaur really existed?*

Pupils should be able to distinguish between observation and inference. Pupils' ability to distinguish between observations and inferences will place them into the Informed NOS category. 'Observation' is a descriptive statement about a natural phenomenon that can be observed by the five senses. Whereas, 'inference' is an explanation of a natural phenomenon that cannot be directly accessed by the senses. Inferences are made only through the manifestations or assumptions of a scientist. Thus an assumption is unlikely to be absolutely true because it is always prone to error.

v. *Item 4b: To what extent are scientists really sure about the appearance of dinosaurs? How do scientists determine it?*

Pupils' responses to these items will reveal their level of NOS in the tentative and inferential domains, that is science is subjected to change and the facts presented by scientists are mere inferences prone to error as a human being.

vi. *Item 4c: Scientists agree that 65 million years ago all dinosaur species became extinct. But scientists disagree on what caused the dinosaur to become extinct. The two most popular hypotheses suggest the occurrence of meteorite impacts and the occurrence of large volcanic eruptions."*

Why do scientists disagree in putting forward hypotheses even though they refer to the same information?"

vii. *Item 4d: If a scientist wants to convince other scientists of their hypothesis on the issue of dinosaur death, what should they do?*

Science, whether in part or whole, lives on an empirical basis, that is, through observation of natural phenomena. However, scientists have made inferences from their observational data. Consequently, empirical data has gone through a process of filtering through the perceptions and assumptions of scientists' thinking. Thus, it threatens the absoluteness of science knowledge received by pupils and the general public.

viii. *Item 5: In making weather forecasts, meteorologists collect various types of information. This information is then translated by a computer system to produce graph patterns and weather forecast diagrams that vary depending on the type of software used.*

Do meteorologists feel certain (no doubt) about the patterns of graphs and diagrams produced by the computer software they use?

In answering this item, respondents should be aware that the opinions of meteorologists are tentative in nature. Although they take the data empirically at the stage of data analysis there is a process of inference, in which the data is interpreted by meteorologists according to their thinking perspectives which is not necessarily accurate.

ix. *Item 6: Earth model taught in school shows the earth is made up of layers of crust, mantle, and core. In your opinion, do the facts presented truly correspond to the actual state of the earth's crust?*

This item evaluates the Observations and Inferences. Refer to item 4 (a) guideline.

x. *Item 7: Scientists try to find solutions to their problems by conducting investigations/experiments. In your opinion, do scientists also use their imagination and creativity in conducting the investigation/experiment?*

Science is empirical in nature, that is, science is built as a result of observation of natural phenomena. Nonetheless, there is an element of creativity and human imagination in explaining such natural phenomena. In other words, the theories of science presented by scientists are not entirely derived from empirical data, instead, they are processed based on the imagination and creativity of scientists.

xi. *Item 8: Is there a difference between THEORY (such as Black Hole theory and Big Bang Theory) and LAW (such as The Law of Gravity and Boyle's Law of Pressure)?*

Typically pupils have a simplistic belief that a theory will reach a hierarchy of law when there is sufficient evidence to support it. The fact is that theory and law are in different categories of knowledge, not in the same hierarchical column. Law is a description or formula that shows the relationship between several natural phenomena. Instead, a theory is an inference made by a scientist to explain a phenomenon.

xii. *Item 9: Once a scientist puts forward his theory, is there a possibility that the theory will change in the future?*

Tentative domain evaluation. Refer to items 3, 4b, and 5.

xiii. *Item 10: Is there a connection between science, society, and cultural values?*

Today's science has been practiced in a variety of life contexts and successfully crosses the boundaries of diverse cultures and backgrounds. Inevitably, science has assimilated with the social and cultural life of society. Therefore, the scientific knowledge presented by scientists is not neutral in nature but will undergo a process of interpretation that is influenced by social and cultural factors that surround the life of the scientist.

Research Findings

In order to analyse the data, pupils' responses were compared to the VNOS scoring rubric provided by Lederman et al (2002) to categorize their NOS levels. The results are summarized in Table 4;

Table 4

NOS Summary of Form Four secondary school pupils in a district in Malaysia

Item No.	**Item**	**High-Level NOS** (Number of pupils and percentage)	**Moderate NOS** (Number of pupils and percentage)	**Low-Level NOS** (Number of pupils and percentage)	**Mean (and standard deviation)**
1,2	**Introductory question:** What is science? Why is it different from other fields of knowledge?	-	-	-	-
3.	**Tentative**: Scientists produce scientific knowledge. Could this knowledge change in the future?	60 85.72%	1 1.43%	9 12.85%	2.84 (0.404)
4.(a)	**Observation and inference**: How do scientists know that dinosaurs truly exist?	1 1.43%	4 5.71%	65 92.86%	1.96 (0.266)
4.(b)	**Tentative and inference**: To what extent are scientists truly sure about the appearance of dinosaurs? How do scientists determine it?	15 21.43%	0 0	55 78.57%	2.21 (0.413)
4.(c)	**Inference and subjectivity:** Why do scientists disagree with their hypotheses even though the data sources are the same?	53 75.71%	4 5.71%	13 18.57%	2.70 (0.574)
4.(d)	**Empirical basis**: How do scientists convince other scientists of their theories on the issue of dinosaur death?	16 22.86%	1 1.43%	53 75.71%	2.21 (0.447)
5.	**Tentative**: Are meteorologists certain of the validity of the weather	35 50.00%	5 7.14%	30 42.86%	2.43 (0.627)

	data from their computer software?				
6.	**Observation and inference**: Is it true that the earth is made up of layers of crust, mantle, and core?	14 20.00%	5 7.14%	51 72.86%	2.13 (0.509)
7.	**Creativity and Imagination:** Do scientists use imagination and creativity in conducting their investigations/experiments?	21 30.00%	7 10%	42 60.00%	2.20 (0.604)
8.	**Theory and law**: Is theory different from the law?	18 25.71%	26 37.14%	26 37.14%	1.89 (0.790)
9.	**Tentative:** Could the theory change in the future?	42 60.00%	15 21.43%	13 18.57%	2.39 (0.822)
10.	**Social and cultural:** Are there societal and traditional value influences in the construction of scientific knowledge?	42 60.00%	11 15.71%	17 24.29%	2.44 (0.754)

To get a clearer picture, a graph is used to show the difference between the percentage of Informed, Transitional and Naïve NOS for each item answered by the pupils (Refer to Figure 2).

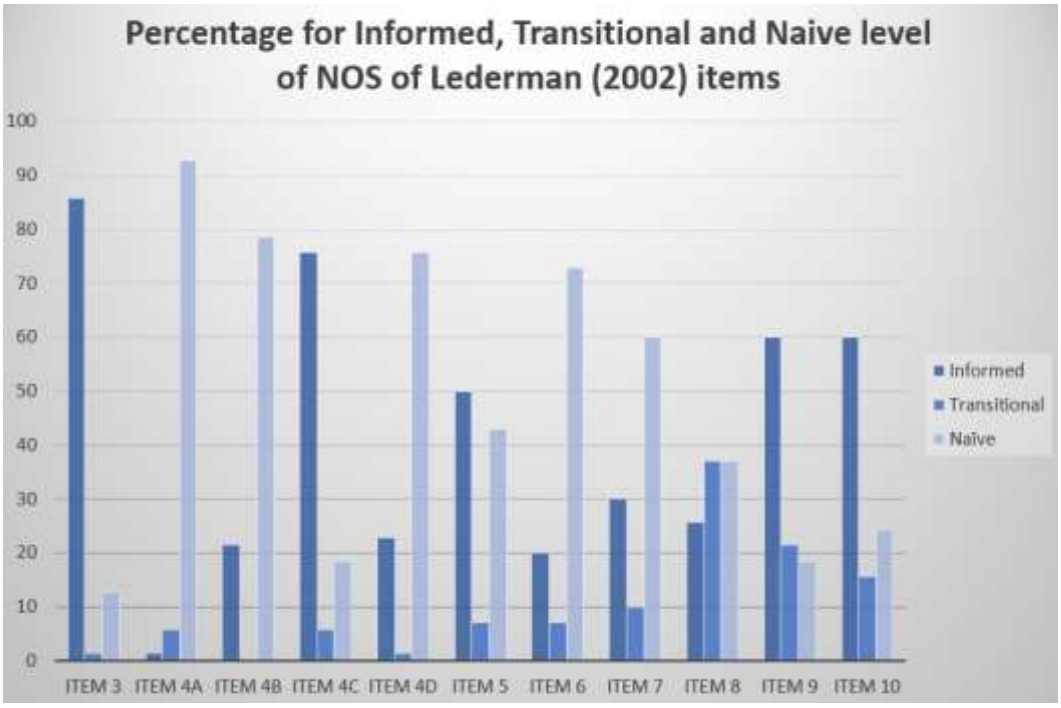

Figure 2. Percentage for Informed, Transitional and Naive NOS based on Lederman (2002) items

In this limited space, the researcher will only discuss findings on item no. 4a,4b, 4c, 4d and 6 in which the questions are directly related to science topics learnt in school. This step is in line with the recommendations of Lederman et al (2016) that suggest researchers to choose and focus on any NOS domain that they want to develop on their pupils. Since item no.3 shows highest mean value (refer to Table 4) therefore it will also be discussed.

Table 4
Mean and standard deviation for each item tested

Item no.	Tested dimensions	Mean	Standard deviation
3	Tentative	2.84	0.404
4(a)	Observation and inference	1.96	0.266
4(b)	Tentative dan inference	2.21	0.413
4(c)	Inference dan subjectivity	2.70	0.574
4(d)	Empirical basis	2.21	0.447
5	Tentative	2.43	0.627
6	Observations and inferences	2.13	0.509
7	Creativity and imagination	2.20	0.604
8	Theory and law	1.89	0.790
9	Tentative	2.39	0.822
10	Social and culture	2.44	0.754

The discussion begins with item no.3 which is, 'Scientists produce scientific knowledge. Could this knowledge change in the future?'. A total of 85.72% of the pupils had demonstrated an Informed NOS for this item that tested the tentative nature domain of science. The tentative nature of science means that the science studied today has no absolute truth. Therefore if there is a discovery of new evidence, facts, and methods of interpretation, the scientists are likely to change their theory. Pupils' understanding of this concept shows that they have the potential to become active seekers of knowledge in exploring new facts of the universe. Without an understanding of the tentative nature of science, the pupils becomes passive and merely memorising facts because they believe that whatever finding presented by scientists are undoubtly true.

A high percentage can also be seen in item no.4 (a) which tests the NOS domains of observation and inference. A total of 92.86% of pupils gave a naive response to the question 'How do scientists know that dinosaurs certainly exist?'. In the responses presented, pupils had failed to distinguish between observations and inferences. The pupils believe that scientists had successfully made complete fossil discoveries. The fact is that scientists only make inferences based on a small amount of evidence instead of having complete evidence. Scientists were merely make an assumptions about the existence of dinosaurs based on incomplete fossils they found. Such hipothesis could change in the future if new fossils and evidence are discovered. School teachers, therefore, need to emphasize the difference between observation and inference. This is important not only in assessing the history of dinosaurs but also in addressing local socioscientific issues such as in assessing testimonials made by customers of health product advertisements nowadays. Sellers claim that their products are great based on customer inferences, not on observations of scientific data.

A large percentage is also shown by item 4 (b) involving the tentative and inferential NOS domain. A total of 78.57% of pupils showed naive NOS to the question, 'To what extent do scientists are certain about the existence of dinosaurs? How do scientists determine that?'. Pupils showed similar response pattern as for item 4 (a). This might due to the lack of information they received regarding dinosaurs issue. In this case, the teacher should play an important role not only in conveying the information in the textbook to the pupils but also in explaining the process of how the scientists conduct their research. Teachers need to explain that scientists were merely made inferences when the evidence and information are not enough. With this exposure, pupils would probably show greater interest in science and therefore and increase their motivation to unveil the mystery of nature. However as mentioned by Rahman & Phang (2016), the teachers were probably lacked the knowledge of NOS and thus failed to develop this concept to their pupils.

Item 4 (c) obtained a percentage of 75.71% of Informed NOS for the domain of Inference and Subjectivity. In answering the question, 'Why do scientists disagree in the presentation of hypotheses even though they refer to the same data information?', pupils have successfully detected the existence of subjectivity domains in NOS. Subjectivity in NOS means that the inferences put forward by scientists are neither neutral nor value-free. Opinions given by scientists might be influenced by the belief systems they hold, the previous knowledge they possess, past experience, or their loyalty to the institutions that funded their research (Lederman et al., 2013).

Furthermore, a high percentage can also be observed in item 4 (d) involving the question, 'How do scientists convince other scientists of their theories on the issue of dinosaurs' death?'. It was found that 75.71% of the pupils fall to Naive NOS category for empirical basis domain. According to Lederman et al (2013), pupils who possess Naive NOS in this empirical basis domain believed that science is empirical, straightforward, and unaffected by individual biases and personal opinions of an individual. In fact, scientists were making inferences on their observational data. Thus, the theories they produce are the result of the perceptions and assumptions of the scientists, which might not be true. Therefore, teachers must play their role to correct their pupils' NOS to ensure pupils gain the ability to make correct decisions regarding socioscientific issues that surround them. Pupils need to aware that even if an argument is supported by empirical data, there is still possibility that the data had been manipulated to deceive the public, for example, to buy certain pharmaceutical products. Thus pupils need to prepare themselves with a high-level understanding of the NOS empirical domain to enable them making accurate justifications in dealing with socioscientific issues in community.

Lastly, item 6 presented a high percentage, 72.86% of the pupils showed Naïve NOS for Observation and Inference domain. Pupils failed to distinguish between observation and inference in responding to the question of 'Is it true that the earth consists of layers of crust, mantle, and core?'. These findings are in line with the findings of item 4 (a), which also tested the domains of observation and inference. The result implies that pupils only passively accept the facts presented in the textbook (these facts are included in the Earth Science chapter, Form One KSSM syllabus) without seeking to know how could scientists assure the contents of earth core which hardly be accessed by man and technology. It is also implied that pupils did not exposed to other source of knowledge like mass media, magazines, fictional books, family, or teachers regarding this issue. This is not surprising given the fact that NOS is not the main focus in this country's science education syllabus, where examination grade achievement were given higher priority (Rahman & Phang, 2016).

Conclusion

This study has succeeded in achieving its objective to explain what NOS is and to identify the level of NOS among Form Four secondary school pupils in a district in Malaysia. On the whole, it showed that pupils' level of NOS is inconsistent, depending on the issues raised. However analysis on items that related to topics being taught in science lesson revealed that pupils were more likely to show naive NOS. Many studies throughout the globe proved that NOS understanding plays an important role to actract pupils' interest towards science. This study therefore implies that stakeholders, especially science teachers, need to work harder to increase pupils' understanding of NOS. This mission is crucial in order to provide the country with ample science-based human capital equipped with brilliant decision-making skill and able to face various challenges in the future.

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